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No. 15

Effects of Urban Land Use on Water Quantity and Quality: An Annotated Bibliography



**NATIONAL WATER AND SOIL
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**EFFECTS OF URBAN LAND USE
ON WATER QUANTITY AND QUALITY:
AN ANNOTATED BIBLIOGRAPHY**

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EFFECTS OF URBAN LAND USE ON WATER QUANTITY AND QUALITY: AN ANNOTATED BIBLIOGRAPHY

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Man's impact on the hydrological regime is nowhere more intensive than in urban areas. The massive increase of urbanisation expected during the next several decades implies that present problems are likely to be compounded.

A brief "state-of-the-art" summary on the hydrological consequences of urban development is presented, and is accompanied by an extensive annotated bibliography and key word index. The material contained will be of value to the planner and other professionals involved in research on urban land use and its effects on water quantity and quality.

Detailed information on peripheral aspects such as sewage disposal, waste water treatment, tip leachates and ground water pollution has not been included, though some suggestions for retrieval are given.

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INTRODUCTION

The runoff response of a drainage basin on precipitation is influenced by the nature of the event, the basin's physical structure, configuration, topography, geological foundation, soil conditions and the amount and kind of vegetation cover. Land development and urbanisation have usually a minor effect upon an area's basic topography or geological base. However, man's impact on land surfaces, top soil, vegetation cover, and hence the hydrological regime, is nowhere more intensive than in

urban areas (Bryan, 1972; IHD Subgroup (UNESCO), 1974). The massive increase in urbanisation expected during the next several decades clearly implies that present problems are likely to be compounded alarmingly.

Research on urban water resources has lagged behind large catchment research in nearly every nation, is complex, time consuming, and requires a considerable financial commitment. Moreover, many more types of hydrological problems will be found in densely populated regions than in rural areas. Most of the urban hydrological problems and effects in developing countries are similar to those in technologically and economically advanced countries. Further, many problems now confronting the developing nations have at one time or another been encountered by the more developed nations (UNESCO, 1976).

A brief "state-of-the-art" summary on the hydrological consequences of urban development is therefore now appropriate, and is accompanied by a extensive annotated bibliography for the period to October 1978.

Of the thousands of references which have been published in the liquid waste and pollution field, the list given here is judged to contain information useful to the planner and other professionals involved in research on urban land use and its effects on water quantity or quality. Several very good but obscure sources have been omitted, as have detailed lists of peripheral aspects such as sewage disposal, waste water treatment, tip leachates and ground water pollution - these have been the theme of extensive bibliographies elsewhere and need not be repeated, though some suggestions for retrieval are given.

Many items on specific topics come from a few sources, but the major sources of information for this study were Journal of the Hydraulics Division ASCE, Environmental Health and Pollution Control, EPA Reports, Journal of the WPCF, Water Research, Water Resources Research, Water Resources Bulletin, Journal of Hydrology, USGS Professional and Water Supply Papers, Water Pollution Control Journal, and the numerous conference proceedings produced by organisations such as the American Society of Civil Engineers, American Public Works Association, US Public Health Service, Water Pollution Control Federation and other educational institutions. More immediate sources of material are published in Pollution Abstracts, Water Pollution Abstracts, Geo Abstracts, Selected Water Resources ~~Water & Soil Technology~~ publication no. 15 (1979)

Research Centre Information, and in the irregular annotated bibliographies produced by the Council of Planning Librarians and by various US Government Agencies.

HYDROLOGICAL EFFECTS OF URBAN DEVELOPMENT

Many reports which deal with the effects of urban development on streamflow have been published in recent years. These effects are summarised by Coughlin and Hammer (1973) as:-

- (a) increases in peak flow magnitude and frequency of flooding due to rendering of land impervious and altering of the drainage systems;
- (b) possible reduction of baseflow of the stream in periods of low rainfall due to decreased infiltration to ground water storage; and
- (c) enlargement and degradation of stream channels due to changes in the streamflow regimen identified in (a) above.

In more detail, Waugh (1978) and Schouten (1979) list the important quantitative effects reported in the literature as:-

1. Sewering a rural basin can increase the mean annual flood by almost two times.
2. With about 15 percent of the catchment as sealed surface, the mean annual flood peak is at least doubled. When the urban basin is 25 percent impervious, the five-year flood may be equal to a 40-year flood for an equivalent rural catchment.
3. A fully impervious basin completely sewered and with channels realigned can lead to an eight-fold increase in flood peak discharge for small floods of around mean annual size.
4. Floods with a return period of 100 years may be doubled in size by complete urbanisation of a catchment, if development results in at least a 30 percent paving of the basin.
5. Floods beyond the 100-year flood show a relatively lesser effect from urbanisation, and a 150-year flood is not materially affected.
6. For a catchment which is 20 percent sewered and 20 percent impervious, the number of bank overflows may double.
7. In a completely sewered basin, or for a 50 percent impervious catchment, lag time to flood peak can reduce to about 10 percent of that in an equivalent rural catchment. The greatest change in lag time occurs as the basin develops from rural to 20 percent impervious. An important effect of this reduction on basin lag time is that it makes short-duration high-intensity rainstorms the critical flood-producing storms.

EFFECT OF URBAN DEVELOPMENT ON STREAM WATER QUALITY

Regional variations in the quality of surface waters arise naturally, determined by the mineral structure of the geological strata and the chemistry of the surface soils (Berry, et al. 1974). However, it is generally accepted that urban development causes a deterioration in this variable natural quality of surface waters. The effect is not a simple one, and methods of predicting it are not well developed. In addition, the manner in which a particular activity or type of development causes a change in water quality may itself be complex (Coughlin and Hammer, 1973).

Among the sources of pollution in urban runoff water are sediments originating from construction sites, debris and contaminants from streets, contaminants from open land areas, publicly used chemicals, air deposited substances, ice control chemicals, and dirt and contaminants washed from vehicles (Sartor, et al. 1974). Previous studies provide valuable information on the total problem of water pollution resulting from urban runoff. They point out the shock pollution loads which storm runoff from urban areas can place on receiving waters. Principal conclusions from many of these studies are listed by Sartor, et al. (1974), Amy, et al. (1974), McElroy, et al. (1976), Wanielista, et al. (1977), and by Waugh (1978) as:-

1. Water temperatures can be increased 5-8 degrees C in summer and lowered up to 3 degrees C in winter.
2. Concentrations of suspended solids can increase dramatically during urban land development and construction.
3. Dissolved load in streams can increase up to ten-fold with urbanisation.
4. With secondary treatment of urban waste water, more than half of the residual pollution in a stream will come from unrecorded and uncontrolled sources, e.g. urban storm water discharges and runoff from farmland.
5. Runoff from street surfaces is generally highly contaminated and is similar in many respects to sanitary sewage. Calculations based on a typical city indicate that the runoff from the first hour of a moderate-to-heavy storm (brief peaks to at least 1.3 cm/hr) contributes considerably more pollutional load than does the same city's raw sanitary waste during the same period of time. These calculations are for a situation in which streets are cleaned (intentionally or by rainfall) about once every five days.
6. The major constituent of street surface contaminants is consistently found to be inorganic, mineral-like matter, similar to common sand and silt. The loading intensities of these contaminants,

expressed as weighted average values for all samples, were found by Sartor, et al. (1974) to be: total solids, 395 kg/curb km; volatile solids, 28.2 kg/curb km; BOD₅, 3.80 kg/curb km; COD, 26.8 kg/curb km; phosphates, 0.310 kg/curb km; nitrates, 0.026 kg/curb km; Kjeldahl nitrogen, 0.620 kg/curb km; total coliforms, 61,000 million/curb km; and faecal coliforms, 3,480 million/curb km.

The extreme variability of water quality in urban storm water is demonstrated by Wanielista, et al. (1977). Ranges of parameter values, expressed as concentrations, are stated to be: total solids, 450 to 14,600 mg/l; total suspended solids, 2 to 11,300 mg/l; volatile suspended solids, 12 to 1,600 mg/l; BOD₅, 1 to 700 mg/l; COD, 5 to 3,100 mg/l; total PO₄, 0.1 to 125 mg/l; soluble PO₄, 0.1 to 10 mg/l; organic N, 0.1 to 16 mg/l; NH₃-N, 0.1 to 2.5 mg/l; chlorides, 2 to 25,000 mg/l (with highway deicing); total coliforms, 200 to 146 million/100ml; faecal coliforms, 55 to 112 million/100ml; and faecal streptococci, 200 to 1.2 million/100ml.

7. Significant amounts of heavy metals were detected in the contaminant materials. Zinc and lead were the most prevalent, and for the cities tested yielded average values of 0.183 and 0.056 kg/curb km respectively.
8. Substantial quantities of organic pesticides and related compounds were also found in the street surface contaminants. Although the data showed considerable variation from site to site, loads in the order of 0.00028 kg/curb km were found for the cities tested. Both chlorinated hydrocarbons and polychlorinated biphenyl compounds (PCB) were found rather consistently.
9. Grease and oil are the major organic constituents of street particulates, and are shown to occur with concentrations up to 110 mg/l.
10. The quantity of contaminant material on street surfaces varies widely. Principal factors which affect the loading intensity at any given site include surrounding land use, elapsed time since streets were last cleaned, local traffic volume and character, street surface type and condition, public works practices, and season of the year. In general, industrial land use areas tend to accumulate contaminants faster than commercial or residential areas.
11. Loading intensities were found by Sartor, et al. (1974) to average 790 kg/curb km for industrial sites, 81.8 kg/curb km for commercial areas, and 338 kg/curb km for residential areas.
12. Total coliforms are higher in industrial than commercial areas, and lowest in residential areas.

13. A great proportion of the overall pollution potential is associated with the very fine silt-like fraction (less than 43 microns) of the street surface contaminants. This fine material may constitute only five percent of the total solids, but may account for 25 percent of the oxygen demand and up to 50 percent of the algal nutrients. It may also comprise half of the heavy metals and three-quarters of the total pesticides.
14. Street surface contaminants are not uniformly distributed across the streets - nearly 80 percent of material may be found within 15 cm of the curb.
15. The rate at which rainfall washes loose particulate matter from street surfaces depends on rainfall intensity, particle size and street surface characteristics. For example, asphalt streets may have loadings which are up to 80 percent heavier than for concrete streets.
16. The chemical oxygen demand (COD) test provides a good basis for estimating the oxygen demand potential of street surface contaminants.
17. Catch basins are reasonably effective in removing coarse inorganic solids from storm runoff but are ineffective in removing fine solids and most organic material.
- of Chicago, Research Paper No.155; 440pp.
- Bryan, E.H. 1972: "Quality of storm water drainage from urban land". Water Resources Bulletin, Vol.8(3); p578-588.
- Coughlin, R.E. and Hammer, T.R. 1973: "Stream quality preservation through planned urban development". Socioeconomic environmental studies series, EPA-R573-019, Washington, D.C.; 238pp. (NTIS PB-222 177).
- IHD Subgroup (UNESCO). 1974: "Hydrological effects of urbanisation". Studies and Reports in Hydrology, No.18, UNESCO, Paris; 280pp.
- McElroy, F.T.R. et al. 1976: "Sampling and analysis of storm water runoff from urban and semi-urban/rural watersheds". Purdue University Water Resources Research Centre, West Lafayette, Indiana, Technical Report No.64; 102pp.
- Sartor, J.D. et al. 1974: "Water pollution aspects of street surface contaminants". J. Water Pollution Control Federation, Vol.46(3); p458-467.
- Schouten, C.J. 1979: "The effects of urban land use and transport network on water". Report, N.Z. Ministry of Works and Development contribution to the Working Party on Land Use and its Effect on Water; 34pp.

ACKNOWLEDGEMENTS

This project was completed as a Research Contract from the New Zealand National Water and Soil Conservation Organisation, Ministry of Works and Development.

Major sources of information were Pollution Abstracts, Water Pollution Abstracts, Geo Abstracts, Selected Water Resources Abstracts, Journal of the Hydraulics Division ASCE, Environmental Health and Pollution Control, EPA Reports, Journal of the WPCF, Water Research, Water Resources Research, Water Resources Bulletin, Journal of Hydrology, USGS Professional and Water Supply Papers, and the Water Pollution Control Journal.

These sources, and the many others used are gratefully acknowledged, as is the supply of bibliographic material by Mr. J.R. Waugh of MWD. Special thanks are also due to staff of the University of Waikato Library and Computer Centre - the entire project was completed on the University PDP 11/70 computer.

INTRODUCTORY REFERENCES

- Amy, G. et al. 1974: "Water quality management planning for urban runoff". EPA 440/9-75-004, prepared by URS, Inc. (NTIS PB-241 689).
- Berry, B.J.L. et al. 1974: "Land use, urban form and environmental quality". Final Report for Office of Research and Development, EPA, by Dept. of Geography, University

- UNESCO. 1976: "IHP International Symposium on the effects of urbanisation and industrialisation on the hydrological regime and on water quality". Information Note No.1, February 1976; 3pp.
- Wanielista, M.P. et al. 1977: "Nonpoint source effects on water quality". J. Water Pollution Control Federation. Vol.49; p441-451.
- Waugh, J.R. 1978: "Magnitude and frequency of floods in the Northland-Auckland region and their application to urban flood design". N.Z. Ministry of Works and Development, Water and Soil Technical Publication No.8; 14pp.

ANNOTATED BIBLIOGRAPHY

ABBOT, J.W. 1977: "Continuous simulation of storm water runoff for use in aquatic systems models". Paper presented at Annual Spring Meeting of the AGU, Washington, D.C. EOS, Vol.58(6); p388.

Key words: mathematical models; storm runoff; hydrographs; low flow; model studies.

The quality and quantity of storm water runoff can be predicted for long term continuous periods of time using STORM, a mathematical model. The primary types of hydrologic analyses where STORM can be used are: (1) prediction of quantities of runoff and pollutants for use in receiving water assessment; and (2) preliminary sizing of temporary detention reservoirs and storm water treatment (or release) rates. Any mathematical model used in hydrological analyses should be considered to be a relatively unchanging set of procedures for simulation of a certain aspect (or aspects) of the hydrologic cycle. However, additions are constantly being made to the newer hydrologic models and, to a lesser extent, improvements are still being made to existing techniques. During the past year, several major additions have been made to the STORM model. These include metric units, use of U.S. Soil Conservation Service (SCS) Curve Number Technique for computing runoff quantity, the SCS triangular unit hydrograph to define runoff from subbasins, quantity and quality of dry weather flow, increase in the maximum number of land uses from six to twenty and ability to specify pollutant accumulation in terms of pounds per acre per day. An example application is discussed where STORM was used to predict quantity and quality of storm runoff. The storm runoff quantities and pollutographs were used in an aquatic system model to assess the impact of landuse alternatives on in-stream water quality.

ACKERMAN, W.C. et al. 1966: "Recommendations for watershed research programs". Office of Water Resources Research, Report of Panel on Watershed Research, June 1966; 21pp.

Key words: model studies; mathematical models; urbanisation.

An advisory report on watershed research is presented, covering the following subject areas: (1) the principal subject matter and geographic areas of watershed research for which previous work has already provided substantially adequate knowledge; (2) watershed research subjects or techniques which past work indicates are not likely now to yield results sufficient to justify additional substantial research effort; (3) watershed research subjects that now appear promising areas for increased emphasis; and (4) recommendations as to measures under the water resources research act that might aid in bringing about needed increases of research. The panel recommendations for consideration of OWRR in adminis-

tering programs under P.L. 88-379 cover watershed research on: experimental watersheds, representative watersheds, physical models, mathematical models, and effects of urbanisation. Mathematical modeling of watershed behaviour is a fruitful field of study. Greater emphasis on the subject of effects of urbanisation is recommended.

AITKEN, A.P. 1968: "The application of storage routing methods to urban hydrology". J. Inst. of Engineers, Australia, Jan. 1968.

Key words: storm runoff; urban drainage.

Methods of runoff routing developed in Great Britain and the United States are examined and extended in application, so that results may be applied as correction to "rational method" of design. Rational method is specifically derived for localities like Victoria and Great Britain, where runoff from pervious area for design is of no significance, but it could be applied in other areas with suitable modifications.

AITKEN, A.P. 1969: "Storm water retarding basins solve urban drainage problems". Australian Civil Engineering and Construction, Vol.10(2); p35-37.

Key words: storm runoff; flood control; peak discharge.

The Board of Works of Melbourne, Australia, has designed and constructed 16 storm water retarding basins varying in capacity from 13 acre-feet to 2,350 acre-feet. The aim of the storm water retarding basin is to reduce the peak flow downstream of the basin by temporarily storing a portion of the inflow from the upstream catchment. The normal outlet is generally designed to pass all storms with recurrence interval less than 20 years. Greater storms cause the spillway to operate. The capacity depends on the catchment size and the rainfall intensity-frequency-duration relationships for the locality. For Melbourne, the most satisfactory basins have capacities about 1/10 acre-foot per acre of catchment. The duration of the critical design storm is many times that of the storm usually used to calculate time of concentration; thus the spillway-design flood may be evaluated by transposing the maximum recorded storms in the region to the catchment under study. Alternatively, the spillway flood may be estimated using probable maximum precipitation.

AITKEN, A.P. 1973: "Hydrologic investigation and design in urban areas - a review". Australian Water Resources Council Tech. Paper No.5.; 79pp.

Key words: urban hydrology; mathematical models; model studies.

This report is the outcome of the Council's effort to discover the research

requirements in urban hydrology. It discusses practice in Australia, the U.S.A., France and the U.K. Mostly the rational method is used - only the U.K. has a more advanced method in that devised by the Road Research Laboratory. Australia has 100 station years of urban records for Brisbane, Sydney, Canberra and Melbourne but only 25 percent are usable so there can be no reliable tests of any theoretical method. The report recommends that a deterministic mathematical model should be developed for Australian urban catchments, six cities should begin schemes of hydrometry to obtain verification data and that an Australian urban hydrology manual should be compiled.

AITKEN, A.P. 1973: "Flood estimation for urban and rural catchments". Australian Road Research, Vol.5(3); p50-71.

Key words: flood forecasting; peak discharge; flood discharge.

This paper discusses methods of flood estimation for urban and rural catchments in Australia. Existing procedures described in Australian Rainfall and Runoff are briefly reviewed and more recent developments are outlined and suggestions are made for their application.

AITKEN, A.P. 1975: "Hydrologic investigation and design of urban storm water drainage systems". Australian Water Resources Council Tech. Paper No.10, Vol.1; 140pp.

Key words: urban hydrology; urban drainage; rainfall-runoff relationships; mathematical models; urban runoff; hydrographs; hydrologic data.

A comprehensive report dealt with urban hydrology in Australia. Existing sources of urban rainfall-runoff data in Australia were examined in considerable detail. Specific basins were examined and the kinds of available data were discussed. The Rational Method, the Road Research Laboratory Method, the Modified Road Research Laboratory Method, and Laurenson's Runoff Routing Model were described and evaluated. An earlier evaluation of 8 other mathematical simulation models was summarised and these models compared. Consideration was given to water quality aspects of urban drainage and the types of quality data available.

AITKEN, A.P. 1975: "Catchment models for urban areas". In, Prediction in catchment hydrology, AAS, Canberra; p257-275.

Key words: model studies; urban hydrology; urban runoff; rainfall-runoff relationships.

A general review of problems associated with catchment modeling in urban areas is presented. The particular characteristics of Australian urban catchments are discussed, and the appropri-

ate existing models suggested for use in relation to the various types of problems encountered. Attention is drawn to the deficiency in available data in Australia, and in research efforts directed towards determining accuracy requirements for the models.

AITKEN, A.P. 1976: "Urban hydrological modeling and catchment research in Australia". ASCE, New York, Urban Water Resources Research Council, TM-IHP-2; 30pp.

Key words: ground water resources; urban runoff; computer models; mathematical models.

Modeling and catchment research for Australian urban underground conduit drainage is emphasised. Only those models that have been tested against actual field data are discussed and applications are emphasised.

AKERLINDH, G. 1950: "The quality of storm water flow". Nordisk Hygienisk Tidskrift (Stockholm), Vol.31(1).

Key words: bacteria; chemical oxygen demand; suspended solids; water pollution sources; biochemical oxygen demand.

Summer rainwater drainage samples mainly from streets and parks in Stockholm, Sweden, from 1945 to 1948, indicated median values for coliforms at 4,000 per 100 ml; COD, 188 mg/l; total solids, 300 mg/l; fixed residue, 210 mg/l; and BOD, 17 mg/l. The levels for individual samples ranged as high as 200,000 per 100 ml for coliforms; 3,100 mg/l COD; 3,000 mg/l total solids; 2,420 mg/l fixed residue; and 80 mg/l BOD.

ALBERTSON, M.L. et al. (eds). 1971: "Treatise on urban water systems". Colorado State University, Fort Collins; 836pp.

Key words: watershed management; storm runoff; mathematical models; urbanisation; data collection; urban hydrology; hydrologic systems.

This assemblage of lectures, supplemented with case studies, discusses the concepts of systems analysis and optimisation of the urban water cycle. Sections I and II are designed to develop an understanding of how the many parts of the urban water system interact and fit together. The systems approach and the role of models is discussed in Section III. A discussion of deterministic and stochastic models is included in Section IV. Newly developed computer programs for forecasting urban water demands are presented in Section V. A water resources management game that demonstrates how and where water resources are allocated is described in Section VI. Two widely used tools in systems analysis, linear and dynamic programming, are discussed in Section VII. In Section VIII, the needs for various types of urban water

data are presented. Suggestions are given as to how these needs can be met. Nonlinear programming and sensitivity analysis are introduced in Section X. Sensitivity analysis is used in studying the effects of changes in system parameters and inputs as measured by changes in results. The environmental and humanistic factors that affect the decision making processes are considered in Section XI. The future trends of city water demands, possibilities for optimising the urban water resource, and a recent innovation of pressure sewer systems are included in Section XII.

ALBRECHT, J.C. 1974: "Alterations in the hydrologic cycle induced by urbanisation in northern New Castle County, Delaware: magnitudes and projections". Completion report, Delaware University, Newark; 22pp. (NTIS PB-232 153).

Key words: surface runoff; urban runoff; urban hydrology; computer models; model studies; data collection; landuse change; aquifers.

A model of surface runoff as a function of land surface characteristics in an urban residential area was developed from measured land surface characteristics, precipitation, and runoff data. Surface runoff from impervious surfaces feeding directly into drainage ways began after an initial extraction for wetting the surface of .03 inches (.08 inches after hot, sunny weather). Surface runoff from impervious surfaces draining onto lawns and gardens was counted as additional precipitation spread evenly over the vegetated surfaces. Surface runoff from vegetated surfaces was then estimated by the Soil Conservation Service's method for estimating storm runoff. The combined estimates for the different surface types corresponded closely with measured runoff ($r=.996$, $s=.06$ in., $a=.01$, $b=1.04$). The model was used to evaluate the effects of urbanisation on other components of the hydrologic cycle by incorporation into a standard daily water budget run for Shellpot Creek watershed, Wilmington, Delaware for 1954 to 1968. The application revealed a tripling of surface runoff, a one-half increase in total runoff, and a halving of both percolate to ground water and actual evapotranspiration as urbanised surface (residential use, 54 percent impervious surface) increased from 20 to 100 percent of the watershed area.

AMERICAN PUBLIC WORKS ASSOC'N. 1969: "Water pollution aspects of urban runoff". U.S. Dept. of the Interior, Federal Water Pollution Control Administration. American Public Works Assoc., Report No. WP-20-15; 272pp. (NTIS PB-215 532/3; EPA-11034DNS01/69).

Key words: water pollution; surface runoff; storm runoff; pollution abatement; solid wastes; urban drainage; biochemical oxygen demand; air pollution effects; combined sewers; pesticides.

Analysis and evaluation of environmental pollution factors and their potential pollutional effects resulting from the water-wastes interfacial contacts during precipitation and runoff. Factors studied included: street refuse and litter, catch basins, environmentally used chemicals, contributions from air pollution and its control, and sewer solids deposition. Street refuse is found to be significant to pollution load. Pollution load measured in terms of BOD is estimated in terms of average daily load, and in terms of the shock pollution load on the receiving body of water. Findings and recommendations are presented in summary form. A comprehensive set of typical ordinances regarding possible sources of pollution is included.

AMERICAN PUBLIC WORKS ASSOC'N. 1969: "Water pollution aspects of urban runoff". American Public Works Assoc., Chicago, Illinois, Research Foundation, Final Report No. WP-20-15; 272pp. (NTIS PB-216 127).

Key words: water pollution; storm runoff; urban hydrology; water pollution control; environmental effects; urban drainage; solid wastes; air pollution effects; combined sewers; pesticides.

A study was conducted to determine the factors in the urban environment which contribute to the pollution of urban storm water runoff and to determine methods to limit this source of water pollution. It was found that tree refuse litter could be a significant factor when the nature of the shock discharge of the pollution is considered. An evaluation was made of the efficiency of street cleaning methods and limitations of commonly used equipment explored. Catch basins in conjunction with street inlets to the storm water disposal system were also determined to be a potential major source of pollution. Other potential sources of pollution considered included air pollution, roof discharges, and chemicals used in the urban environment.

AMERICAN SOCIETY AGRICULTURAL ENGINEERS. 1972: "Erosion and sediment control on urban and construction sites: annotated bibliography". W. and S. Divn., Sediment Committee, St Joseph, Michigan; 13pp.

Key words: bibliographies; abstracts; sediment control; erosion; erosion control.

The bibliography is published to serve as a reference to the latest field applications and research papers on control of sediment in urban areas. References have been assembled in the one bibliography and will be useful for people engaged in design, construction and research. The bibliography lists technical papers as well as manuals and handbooks that are not routinely referenced in libraries. Source for obtaining copies is included with each reference.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1968: "Urban water resources re-
search". First year report to Office
of Water Resources Research, U.S.
Dept. of Interior, ASCE, New York,
N.Y. (NTIS PB-184 318).

Key words: rainfall-runoff relation-
ships; urbanisation; data collection;
storm runoff; urban hydrology; urban
drainage.

The first year emphasis was on subjects
requiring earliest consideration, such
as urban storm drainage. An assessment
is given of the potentials, liabilities,
and available knowledge of the
rainfall-runoff-water quality process,
and model requirements for process sim-
ulation are detailed. Immediate re-
search needs with regard to damage eval-
uation are given, and the utilisation
of storage to ameliorate flooding is
outlined. The principal non-hydrologic
aspects of urban water are listed, and
include administration of works, eco-
nomics of planning and operation, fi-
nancing of systems, recreational facil-
ities, planning and operation, and so-
ciological problems. The report con-
tains 11 appendices, each with techni-
cal papers dealing with the appendix
subject.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1969: "Progress report and bibliogra-
phy, ASCE task force on effect of urban
development on flood discharges". J.
Hydraul. Divn., Proc. ASCE,
Vol.95(HYI); p287-309.

Key words: flood discharge; storm run-
off; rainfall-runoff relationships;
bibliographies; urbanisation.

This progress report includes brief
discussions of the future impact of ur-
banisation on hydrology in the United
States, the factors directly contribut-
ing to flooding in urban areas and the
critical research work required in this
field. The main part of the report is
an annotated bibliography of urban hy-
drology, and an appendix of current re-
search projects in urban areas of the
United States.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1969: "Basic information needs in
urban hydrology". A study for the
Geol. Survey, U.S. Dept. of Interi-
or, New York, N.Y.; 133pp. (NTIS
PB-185 442).

Key words: urban drainage; water pol-
lution; data collection;
instrumentation.

Under the U.S.G.S. - sponsored portion
of the program, an intensive study is
being made: of the types of data need-
ed for improved design of storm drain-
age facilities, including both quantity
and quality of drainage flow; of needs
for data collecting instrumentation;
and of types of networks necessary to
collect adequate data. The ultimate
objective is to facilitate transfer of
data findings between metropolitan re-
gions.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1970: "Sediment sources and sediment
yields". J. Hydraul. Divn., Proc.
ASCE, Vol.96(HY6); p1283-1329.

Key words: channel erosion; erosion;
erosion rates; sediment yield.

Methods and procedures are analysed for
determining erosion rates, sediment
yield, or deposition rates at locations
downstream from the erosion source.
Emphasis is given to the erosion types
and processes which cause the most en-
gineering problems, either by the large
sediment quantities involved or by the
locally severe damages. Accelerated
erosion and deposition rates caused by
man's activities are of special
concern; these derive from sheet er-
osion processes on tilled lands and from
such specialised activities as strip
mining, urban development, construction
of highways and utilities, and sheet
erosion on any portion of the land sur-
face that is denuded or inadequately
protected. Present bases for estimat-
ing these rates on both a storm and an
average annual basis are given.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1974: "Agricultural and urban consi-
derations in irrigation and drainage".
Selected papers from the ASCE Irriga-
tion and Drainage Divn., speciality
conference, Fort Collins, Colorado;
800pp.

Key words: urban drainage; weather
modification; ground water resources.

The conference objective was to explore
many of the questions of the interde-
pendencies between urban and irrigation
water use. The twelve broad subjects
discussed were ground water, changing
water use, weather modification, drain-
age by pumping, operation and mainte-
nance, efficient irrigation, automatic
controls, agricultural and urban consi-
derations, suburban drainage, water
utilisation, irrigation water require-
ments, and water quality.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1974: "International workshop on the
hydrological effects of urbanisation,
Warsaw, 1973". ASCE Report to National
Science Foundation on International
Workshop. NSF Grant G.K. 35974;
61pp.

Key words: urbanisation; urban hy-
drology; rainfall-runoff
relationships; water pollution;
environmental effects; waste water
disposal.

An International Workshop was held by
IHD-UNESCO on the Hydrological Effects
of Urbanisation. The developed coun-
tries have already experienced the ef-
fects of urbanisation on the hydrologi-
cal cycle, and urbanisation of areas is
increasing with likelihood that further
damage will be done. There is also ev-
idence that urbanisation will increase
in the developing countries and that
problems will arise there similar to
those that have been encountered else-
where. The effects of water pollution

from large-scale mining operations are comparable to those from industries. Urban areas affect, and are affected by, distant human activities. Among the obvious effects are increased population densities and increased concentrations of residential, industrial and commercial buildings and facilities, with resultant increases in areas that are impervious. Hydrological impacts then include the effects of these changes on the natural drainage, runoff, ground water, sediment, water quality, water demands, and on measures utilised for the disposal of wastes and surplus water and for the supply of water. Among the hydrological problems associated with urbanisation are the continually increasing demands for water for various uses, changes in the physical environment that alter the natural water balance and the disposal of wastes that may contaminate streams and ground water. The most important topics for research are changes in surface runoff caused by urbanisation; quantity and quality of runoff; soil moisture and ground water; water demand forecasting; water quality effects related to ground water; and effects of waste water and sludge on the natural purification capacity of receiving waters and on aquatic life.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1975: "Urban sediment problems: a statement of scope, research, legislation and education". ASCE Task Committee on urban sedimentation problems, J. Hydraul. Divn., Proc. ASCE, Vol. 101(HY4); p329-340.

Key words: sediment control; urban runoff; urbanisation; erosion control.

Present (1974) erosion control guidelines and technology indicate that: there are sufficient and varied erosion control guidelines available for use as models for local governments. Past implementation experience can provide valuable information to new programs and help avoid many initial problems. Evaluation of social and physical damages still remains a weak point in economic analyses of control systems; however, design criteria developed for agricultural areas should be reviewed for adequacy in each case until sufficient experience in urban areas is documented and evaluated. Guideline handbooks are meant to provide general local information and should not be used arbitrarily as final design manuals. Erosion control systems do not have to be 100 percent effective in reducing soil loss to be acceptable. Needed research for more useful erosion and sediment control should be focused in two general areas: on improving the application of rurally developed technology to the urban situation and on developing methods and criteria for evaluating social and physical costs of various control systems relative to alternative costs of allowing specific amounts of sediment into specific water bodies.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Water & soil technical publication no. 15 (1979)

1975: "Committee report, aspects of hydrological effects of urbanisation". J. Hydraul. Divn., Proc. ASCE, Vol. 101 (HY5); p449-468.

Key words: ground water resources; urbanisation; low flow; streamflow; bibliographies.

Urbanisation both alters and complicates the natural hydrologic cycle. However, the effects are often not consistent, but depend on the nature and magnitude of the urban influence. The effects of urbanisation on four aspects of the hydrologic cycle are examined: (1) low flow; (2) total runoff; (3) infiltration; and (4) ground water recharge. Both supporting data and a selected bibliography are provided. Inherent in the alteration of the hydrologic cycle by urbanisation is the contamination by urban wastes, and the consequent pollution of the water resource.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1975: "Conclusions, work group on user needs for problem solving". In, Urban runoff, quantity and quality, ASCE, New York; p34-35.

Key words: urban runoff; urbanisation; water pollution.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
1976: "Utility of urban runoff modeling". Proceedings of a special session, Spring Annual Meeting, AGU, Washington, D.C. ASCE, Urban Water Resources Research Program Technical Memorandum No.31; 126pp. (NTIS PB-261460).

Key words: urbanisation; urban runoff; computer models; water pollution sources; data collection; rainfall-runoff relationships; combined sewers; urban drainage; model studies; mathematical models.

The proceedings of a Special Session, Spring Annual Meeting, American Geophysical Union, Washington, D.C., on 14 April 1976 include three invited papers by a Panel on Local Government Model Use and Need, seven related invited papers, two written discussions, and the full text of all Session floor discussion. A third of the about 60 participants contributed to the floor discussion, which occupied two-fifths of the total Session duration. The thrust of the Session was an attempt to define reasons why mathematical models of urban runoff should be used more extensively and more effectively in local government projects: that is, why the use of more sophisticated models would be more cost-effective than simpler, traditional procedures. Rationales were identified for planning, design and automatic control applications. The Session provided an outstanding opportunity for communication between users of the findings of research products and the science-oriented researchers.

AMERICAN WATER RESOURCES ASSOC'N.
1975: "Urbanisation and water quality control". American Water Resources Assoc., Proc. No.20; 294pp.

Key words: water pollution sources; nonpoint pollution sources; urban hydrology; urban runoff; urbanisation.

This publication contains nearly 40 papers on the quantitative and qualitative contribution of urban areas to surface water and, to a lesser extent, ground water, with most of the examples coming from the U.S.A. Various types of nonpoint source pollution are discussed, and the necessity for a proper appreciation of the effects of planning decisions on hydrological conditions at an early stage of future land development is stressed. The conference posed the question of the extent to which urban runoff clean-up is a political rather than a technical problem.

AMY, G. et al. 1974: "Water quality management planning for urban runoff". EPA 440/9-75-004, prepared by URS, Inc. (NTIS PB-241 689).

Key words: waste water treatment; analytical techniques; water pollution; urban runoff; storm runoff; pollution abatement.

This manual provides technical assistance to state and local water quality management planners to enable them to quantify within reasonable limits the urban nonpoint water pollution problem in a local planning area without extensive data generation, and to make a preliminary evaluation of cost effective abatement and control practices. The manual prescribes procedures for several levels of input, each requiring more self generated data, with increasingly sophisticated results. A 'state-of-the-art' and an extensive bibliography on urban storm water runoff is presented in the appendix. A glossary is also included. The manual is not intended to be used for abatement design but does provide a guide to data generation for this purpose.

ANDERSEN, D.R. 1975: "Water quality models for urban and suburban areas". Office of Water Research Technology, Dept. of the Interior; 114pp. (NTIS PB-238 622).

Key words: surface runoff; mathematical models; biochemical oxygen demand; chemical oxygen demand; nitrates; phosphorus compounds; bacteria; pesticides; suspended solids.

Urban storm runoff was sampled and analysed for various pollutional parameters. Data obtained were used in the development of modeling techniques for simulating the quality and quantity of runoff. A hydrograph simulation model developed by the Department of Computer Science at the University of Nebraska was used to generate flow hydrographs comparable to observed runoff data. Modeling techniques similar to those used in the EPA Storm Water Management

Model were used for modeling COD, BOD, and solids. Data were also obtained relative to concentrations of nitrogen, phosphorus, pesticides and bacteria in the runoff. Data generally confirmed the 'flush effect' of pollutants at the start of the runoff period. These data also showed that urban storm water may contain significant amounts of pollutants. Portions of this document are not fully legible.

ANDERSON, B.T. 1977: "Provisional procedure for hydrological design of urban storm water systems". Presented at NZIE Conference 1977, by working party on hydrological design of urban storm water systems; 45pp.

Key words: computer models; mathematical models; urban runoff; storm runoff; rainfall-runoff relationships.

The paper discusses the results of a 1970 questionnaire on Urban Hydrologic Design practice obtained by a Working Party of the Auckland Branch N.Z.I.E. The rational formula and its components are explained and the paper leads to a development of the procedure for using the rational formula including a computer application. Further background papers are included on the statistical model of the rational formula, variation of rainfall intensities, calculation of time of concentration and a philosophy on the choice of return periods.

ANDERSON, D.G. 1963: "Effect of urbanisation on floods in Northern Virginia". U.S. Geol. Survey prof. paper No.475-A; p69.

Key words: urbanisation; peak discharge; flood discharge.

The paper lists primary effects of urbanisation on flood flow as: (1) reduced infiltration increases flood volume; (2) complete sewerage of basins reduces lag time by as much as 85 percent; and (3) urbanisation changes the flood frequency distribution. The degree of effect decreases with increasing flood magnitude.

ANDERSON, D.G. 1970: "Effects of urban development on floods in Northern Virginia". U.S. Geol. Survey water supply paper No.2001-C; p1-21.

Key words: peak discharge; urban runoff; mathematical models; model studies; landuse change; rainfall-runoff relationships.

Graphical and mathematical relations are presented to estimate the flood peak magnitudes having recurrence intervals ranging up to 100 years for drainage basins with various degrees of urban or suburban development. Five independent variables are required for use of the relations. They are the size, length, and slope of the basin, which may be measured from maps, and the percentage of impervious surface

and type of drainage system, which may be evaluated by a basin inspection but in actual practice will usually be estimated for future developed conditions. Based on analysis of flood information for 81 sites, 59 of which are in the Washington, D.C., metropolitan area, the relations should be useful for design of drainage systems and for definition of flood limits. The relations presented are applicable only to the Washington, D.C., area, but the method of analysis is general and may be used for any area where the major floods result from rainfall. Urban and suburban development are shown to affect flood flows to a significant degree. Improvements of the drainage system may reduce the lag time to one-eighth that of the natural channels. This lag time reduction, combined with an increased storm runoff resulting from impervious surfaces, increases the flood peaks by a factor that ranges from two to nearly eight. The flood peak increase depends upon the drainage basin characteristics and the flood recurrence interval.

ANDERSON, H.W. 1957: "Relating sediment yield to watershed variables". Trans. AGU, Vol.38; p921-924.

Key words: sediment yield; landuse change; surface runoff; streamflow; sediment transport; suspended solids; mathematical models.

The yield of sediment from watersheds depends upon three sets of variables: (1) inherent watershed characteristics such as geology and topography; (2) land use, condition of vegetation, and management and protective measures; and (3) nature of storms and streamflow which produce and transport sediment. Measured quantities of yield also depend on the sediment measuring device and on which fraction of total sediment is measured. The sources of variation in sediment yield between and within watersheds can be evaluated by study of the yield from many watersheds which have wide differences in variables affecting sediment yields. Such studies are useful to determine and evaluate the principal sources of sediment, to evaluate the probable effects of conservation programs on yield, and to provide criteria for design of reservoirs and channels. This paper summarizes some recent studies in which multiple regression analysis was used in relating sediment yield to watershed variables. The studies are discussed in the light of methods of selecting watersheds, data, variables, and functions; and the effects of neglected variables, errors in variables, and exclusion of nonsignificant variables.

ANDERSON, J.J. 1970: "Real-time computer control of urban runoff". J. Hydraul. Divn., Proc. ASCE, Vol.96(HY1); p153-164.

Key words: mathematical models; urbanisation; combined sewers; urban runoff; water pollution control.

A real-time process computer control is

being built in the Minneapolis - St. Paul Sanitary District to drastically reduce combined sewer overflows without incurring the huge cost and lengthy construction time involved in installing a separate sewage system in place of combined sewers. The use of the mathematical model of this interceptor sewer system will aid remote operation of gate settings and runoff diversion devices via a computerised supervisory system. Through gate processing techniques a river quality monitoring program, the amount, nature, and effects of overflow wastes of the Mississippi River will be evaluated. Diagrams of the format for the new system are included in addition to data predicting its future effectiveness.

ANDERSON, J.J. 1971: "Case study on design of urban water data acquisition system". In, Treatise on urban water systems, (eds. M.L. Albertson, et al.), Colorado State University, Fort Collins; p557-596.

Key words: data collection; flood control; water pollution control; hydrologic data; instrumentation; model studies; watershed management; storm runoff; urban hydrology.

This case study provides an introduction to the design of urban water data acquisition systems. A great deal of judgement is required concerning all aspects of urban water resources management, and a certain amount of trial and error is necessary. Fortunately, a computer-based data acquisition system is extremely flexible and can be revised easily. A trial design is outlined for acquiring data for major revisions to the waste water and surface water collection systems. The revisions might include lumped or distributed storage, relief or express sewers, transfer of flow between basins, and multiple facilities. The kinds of data needed concern surface water, rainfall, runoff, and waste water. Surface water information should include flow as well as quality measurements. Measurements should show the conditions before and after the addition of pollutants. Runoff data include flow and quality in both combined and separate storm sewer systems. Measurements should be taken at key junctions, major outlets, and treatment facilities. An attempt should be made to provide correlations with parameters measured on-line.

ANDERSON, M.W. and ROSS, B.E. 1975: "A hydrologic study of a small suburban watershed." Florida Univ., Gainesville, Water Resources Research Centre, Publication 31; 96pp.

Key words: instrumentation; data collection; hydrologic data; storm runoff; suspended solids; nutrients; phosphorus compounds.

A 126 acre tract of land in a natural undisturbed state, and adjacent 239.3 acres that made up the watershed, were instrumented in November 1971 in order to determine the effect of development

on the hydrology of the 126 acre tract. Data were obtained pertaining to: (1) the changes in runoff quality during a storm; (2) yearly variation of runoff quality from a partially developed watershed; (3) the lack of change in quality of ground water in the surface aquifer; (4) the purification of urban runoff by routing it over a natural vegetative system. The study confirmed that disturbing marshes or lakes causes a significant increase in suspended solids and nutrient content in runoff, especially phosphates.

ANDERSON, P.W. and McCALL, J.E. 1968: "Urbanisation's effect on sediment yield in New Jersey". J. of Soil and Water Conservation, Vol.23(4); p142-144.

Key words: sediment yield; urbanisation; storm runoff; water pollution; bacteria; organic compounds; suspended solids.

Data on sediment content of New Jersey streams are summarised; they suggest that yields are proportional to the degree of urbanisation. The sparsely populated pine barrens yield 10-40 tons per sq ml per year. The moderately heavily urbanised Delaware River area yields 25-100 tons generally, and up to 500 tons near Philadelphia. The northwestern area of New Jersey is hilly with steep slopes and rapid runoff, but has a low degree of urbanisation; its sediment yields are 25-100 tons per sq ml per year, while yields in the Trenton - New York City area, which is very heavily urbanised and probably has about the same topography and natural sediment yield as the northwestern area, are several thousand tons. Bacteria and organic content of water are also much higher in urban streams. In the Delaware River near Trenton, 5-25 percent of the suspended load is oxidisable. The U.S. Geological Survey is studying the effects of urbanisation on sediment in the Stony Brook basin, about 48 sq mls in area, 10 ml north of Trenton. The amount of sediment for a given rate of runoff has increased significantly with urbanisation of the area from 1956 to 1958.

ANDREWS, W.H. et al. 1973: "Modeling the total hydrologic-sociologic flow system of urban areas". Report PRWG109-1, Utah Water Research Lab., Logan; 108pp. (NTIS PB-234 318).

Key words: computer models; flood control; mathematical models.

The first phase is described of a larger study directed toward the development of a general technique for analysing and solving urban metropolitan hydrologic problems through considerations of both the physical and social dimensions. This report is limited to the preliminary work of identification of social variables, the first steps in assigning mathematical values to them, and developing a mathematical format for these variables. In addition, the physical-hydrologic system is identified for purposes of clarifying the

elements in that system. The ultimate objective of the entire study is directed toward discovering a theoretical and generally applicable mathematical model of both the physical and social dimension involved in metropolitan flooding problems.

ANGINO, E.E. et al. 1972: "Effects of urbanisation on storm water runoff quality: a limited experiment, Naismith Ditch, Lawrence, Kansas". Water Resources Research, Vol.8(1); p135-140.

Key words: storm runoff; urbanisation; low flow; snowmelt; chemical oxygen demand; biochemical oxygen demand; nitrates; chlorides; water pollution; miscellaneous chemicals.

The extensive use of storm water runoff as an auxiliary source of water will probably be justified economically in the near future, providing the water is of proper quality. Water samples were collected for dry weather periods, rainstorms, and snowmelts and evaluated for pH, residue (total, volatile, filterable), chemical oxygen demand (COD), biochemical oxygen demand (BOD), NO₃, Cl and total alkalinity. Most changes in water quality are not so great as to be apparent by inspecting the data. Statistical analysis is necessary for testing the more subtle chemical relationships. Suspended solids concentrations during snowmelt and rainstorms do not differ; NO₃ is relatively high, COD averages 34 ppm (parts per million). Occasional pollutants include Cr+6, 27 ppm, Br, 5 ppm, and Cl, 2150 ppm; Pb concentrations in suspended solids as high as 0.55 percent were found. The general extent to which urban storm runoff contributes to pollution of the streams is yet to be completely determined.

ANON. 1968: "Basic data for urban hydrology study in Dallas, Texas, 1966". U.S. Geol. Survey open-file report; 203pp.

Key words: rainfall-runoff relationships; data collection; hydrologic data; hydrographs.

Basic hydrologic data compiled for the study of urban hydrology in Dallas, Texas, include data from raingauges, stream gauges, and flood profile partial record stations. Hydrographs and mass curves are given for major storms at each station.

ANON. 1969: "Compilation of hydrologic data, Green Creek, Brazos River basin, Texas, 1967". U.S. Geol. Survey open-file report; 34pp.

Key words: data collection; rainfall-runoff relationships; hydrologic data; storm runoff; flood control; low flow; peak discharge; hydrographs.

Rainfall and runoff data were collected during the 1967 water year for the 46.1 square mile area above the stream gauge-

ing station Green Creek near Alexander, Texas. The locations of floodwater retarding structures and hydrologic instruments in the area are shown on a map. Data are to be used to determine the net effect of floodwater-retarding structures on the regimen of steamflow at downstream points, to develop computation techniques that will provide more accurate estimates of runoff resulting from a given amount of rainfall on small watersheds, and to develop relationships between maximum rates of runoff and rainfall in small watersheds that will enable more accurate design of small storm drainage structures.

ANON. 1969: "Basic data for urban hydrologic study, Austin, Texas, 1967". U.S. Geol. Survey basic-data report; 59pp.

Key words: storm runoff; rainfall-runoff relationships; data collection; hydrologic data; peak discharge; hydrographs.

Basic data of the urban Waller Creek and the rural Wilbarger Creek, Austin, Texas, are compiled to compare the watersheds as the Waller Creek becomes more urban. Each gauging station record includes location, drainage area, gauge type and history, average discharge, extremes, remarks, daily discharge, total discharge, mean discharge, annual maximum and mean discharges, and peak discharges. Rainfall and runoff are computed for each drainage basin, and hydrographs and mass curves are drawn. The objectives are to determine the effects of progressive urbanisation on infiltration, rates of peak discharge, and rainfall-runoff relations in the Waller Creek watershed; to provide rainfall and runoff data from the rural Wilbarger Creek watershed to be used for comparative purposes in determining the effects of urbanisation in the Waller Creek watershed; and to provide applied research facilities for studies at the University of Texas at Austin. The Waller Creek drainage area lies entirely within the city of Austin, with the headwaters in the northern part of the city. The Wilbarger Creek drainage area is 15 miles north of Austin. The principal land use of this rural watershed is farming and ranching.

ANON. 1969: "Basic data for urban hydrology study, Dallas, Texas, 1967". U.S. Geol. Survey open-file report; 80pp.

Key words: hydrologic data; data collection; urbanisation; storm runoff; rainfall-runoff relationships; hydrographs.

This report presents the basic hydrologic data collected during the 1967 water year (October 1, 1966, to September 30, 1967). Basic data were collected for urban hydrology studies to: determine the magnitude, frequency, and areal extent of flooding; document and define floods of greater than ordinary magnitude; and, determine the effect of urban development on small streams in Dallas, Texas.

ANON. 1969: "Urban runoff adds to water pollution". Environ. Science and Technol., No.3(6); p527.

Key words: data collection; overflows; biochemical oxygen demand; urban runoff; combined sewers; dissolved solids.

An APWA survey indicated that: (1) urban runoff constitutes approximately 1 percent of the raw sewage load which amounts to 5 percent of the BOD discharged from the area's secondary waste treatment facilities; (2) water pollution from this urban source occurs creating a shock pollution load on receiving waters; (3) the most determinable measure of pollution potential of street litter is the BOD load of the soluble dust and dirt fraction; (4) an estimated expenditure of \$48 billion would be needed to separate sanitary and storm waters; and, (5) \$15 billion would be needed for alternate control methods for abatement of combined sewer overflows.

ANON. 1970: "Compilation of hydrologic data, Austin, Texas, 1968". U.S. Geol. Survey open-file report; 68pp.

Key words: data collection; hydrologic data; rainfall-runoff relationships; urbanisation; peak discharge.

Rainfall and runoff data compiled in this report for the 1968 water year (October 1967 to September 1968) from the Waller Creek watershed in Austin, Texas, and the rural Wilbarger Creek watershed in Travis County are primarily for comparative purposes in determining the effects of progressive urbanisation in the Waller Creek watershed. Also included are average stream discharge values, extreme values, and weighted mean rainfall data for several years of record in both watersheds.

ANON. 1970: "Basic data for urban hydrology study, Dallas, Texas, 1968". U.S. Geol. Survey basic-data report; 103pp.

Key words: storm runoff; data collection; hydrologic data; peak discharge; urbanisation; streamflow; rainfall-runoff relationships.

Basic data of the urban hydrology of Dallas, Texas, are compiled. Surface water records are from gauging stations, crest stage partial record stations, rain gauges, and miscellaneous sites. Each gauging station record includes location, drainage area, gauge type and history, average discharge, extremes, remarks, daily discharge, total discharge, mean discharge, annual maximum and mean discharges, and peak discharges. Runoff and rainfall are computed for each drainage basin, and the hydrographs and mass curves are drawn. The objectives are to provide basic runoff data for small urban drainage areas which differ in topography, soil, vegetation, tributaries, basin shape, and degree of urbanisation; to

provide related rainfall data with consideration of variation in intensity and location; and to provide data showing the effects of progressive urbanisation on flood peaks and volume. Six storm periods were selected for detailed analysis. The analyses for these storms include a tabulation of incremental rainfall and discharge data, as well as hydrographs and mass curves.

ANON. 1971: "Urban runoff in Lake County, Illinois". In, Report to the Governor and the 77th General Assembly, Vol.II - supporting studies. State of Illinois, Lake Michigan and Adjoining Land Study Commission; p73-101.

Key words: urbanisation; biochemical oxygen demand; suspended solids; phosphorus compounds; urban runoff; sewage treatment.

An attempt is made to quantify the amount of various pollutants which may reach Lake Michigan as a result of runoff from urban areas in Lake County, Illinois and to compare these quantities with those which reach the lake in effluents from sewage treatment plants in the same area. Various complex interrelationships between runoff and sewage treatment plants with regard to storm water are outlined. Physical factors - geography, precipitation, and land use - are described together with a summary of existing sewage treatment practices. Sufficient data was available to compose two parameters, BOD and suspended solids. It was estimated that runoff usually accounted for approximately 80 percent of the total suspended solids and 12 percent of the total BOD released to Lake Michigan, the remainder coming from sewage treatment plant discharges. However, during periods of rainfall, the percentage of BOD resulting from runoff is greatly reduced. It is also concluded that accepted figures for the quantity of phosphate contributed by urban runoff to Lake Michigan appears to be significantly low.

ANON. 1971: "Storm water quality". Public Works, Vol.102(1); p99.

Key words: storm runoff; urbanisation; water pollution sources; dissolved solids; suspended solids; phosphorus compounds; pesticides; chlorides; biochemical oxygen demand; chemical oxygen demand; lead; faecal coliforms.

This is a synopsis of a report by E. H. Bryan at the Water Resources Research Institute of the University of North Carolina which investigated the "Quality of Storm Water Drainage from Urban Areas in North Carolina". This project was undertaken to evaluate the quality characteristics of storm water runoff from a 1.67 square mile drainage basin within the city of Durham, North Carolina. Parameters selected for routine examination included total solids, volatile total solids, BOD, COD, chloride, soluble phosphate, faecal coliform counts, and lead. Flows were sam-

pled from approximately 30 storms among 70 which occurred over a period of fourteen months. Results obtained indicated that: discharged BOD is estimated at 0.23 pound/acre/day; COD measures at 2.85 pounds/acre/day; total solids contribution is substantially larger than expected from raw domestic sewage; pollutants are discharged in slugs during and immediately following storms; pesticide analyses indicate a total concentration of 1.16 ppb; and, lead concentration of the runoff averaged 1190 lbs/sq mile for an annual yield.

ANON. 1975: "Lead in urban dust and on clothing". Environmental Health, Vol.83(7); p267-269.

Key words: water pollution sources; lead; metals; heavy metals.

The former Health Committee of the City of Birmingham, now the Environmental Services Committee, set up a specialised unit within the Environmental Department to pay special attention to pollution. One of the particular activities of this unit was the development of a metal survey, part of which involved the sampling of dust from roads, gutters, school playgrounds, houses both inside and outside and from some commercial premises. Nearly 5000 samples have been taken to date (thought to be more than in any other city in Europe) and have been analysed for lead and a proportion of the samples for other metals. The data are at present being assessed to find out if there is any relationship between samples obtained from different areas in the City. A preliminary extract of the data is appended.

ANON. 1976: "Storm water management looks to natural drainage". The American City and County, Vol.91(10); p51-53.

Key words: storm runoff; urban runoff; flood control; lakes; watershed management; urban drainage.

New trends in storm water are discussed, with particular emphasis on detention, long-term equalisation, and natural drainage. The objective of these solutions is to attenuate both peak and local short-term runoff and to reduce major facilities investments required for protecting against flood hazards in the lower portion of a drainage basin. The initial planning for a residential subdivision should begin with a study of the total drainage areas, with the major components of the system (streams, large depressions, lakes, and ponds) being located for an assessment of their storm water management potential. During this phase, existing plans for storm water management should be assessed both in terms of the effect of the subdivision drainage on basin-wide drainage and vice versa. Temporary storage can be achieved using rooftop and parking lot ponding; while ponds, reservoirs, and stream channels provide permanent storage. Street design in residential areas should take into account the functions of streets

as part of the storm water management system. Maximum use should be made of natural drainage. The installation of storm water inlets should be delayed as long as possible because as soon as the runoff enters the pipe system it is carried rapidly downstream and may pose flood hazards in the lower part of the drainage basin.

ANON. 1977: "Effects of urbanisation and industrialisation on the hydrological regime and on water quality". Proceedings of the Amsterdam Symposium, October 1977, IAHS Publication No.123; 572pp.

Key words: urbanisation; urban hydrology; water pollution; landuse change.

The volume contains 63 papers, submitted for the plenary sessions of the symposium, referring to the following themes: (1) the effects of urbanisation and industrialisation on the hydrological regime; (2) the effects of urbanisation and industrialisation on water quality; and (3) water policy as a factor in urbanisation and industrialisation. Papers are abstracted separately.

APMANN, R.P. 1974: "The influence of urbanisation on stream channel behaviour". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky; p183-188.

Key words: urbanisation; streamflow; erosion; channel erosion; alluvial channels; bank erosion; erosion rates.

A method was proposed for evaluating the impact of urban development on stream channel behavior. The method was based on equations relating the hydraulic geometry to mean flow discharges. Urban development can result in stream channel enlargement in affected watersheds with consequent production of sediments from the channel. If development proceeds for a long time, channel instability may be a continuing problem. In the first approximation, the rate of channel sediment production and the ultimate channel size can be evaluated from equations derived from the hydraulic geometry relations for a stream. As an example, a channel in a watershed changing from natural conditions to an urbanised area having 30 percent impervious area would enlarge by a factor of about 2.8 times in the process. Another example indicated that the steady development of the Cy Cuyahoga River Basin, Ohio, is responsible for a sediment production of about 40,000 tons/year from the channel between Old Portage and Independence, a distance of 31 miles.

ARAI, A. et al. 1977: "Urban flood water management systems in semi-arid regions: model extension, design and applications". Arizona Water Resources Research Centre, Tucson. Completion

Report, OWRT A-049-ARIZ(1); 63pp. (NTIS PB-277 485).

Key words: model studies; urban runoff; rainfall-runoff relationships; urban drainage; watershed management.

A non-linear reservoir model is used to present the rainfall-runoff relationships for thunderstorms on the urban watersheds of Tucson, Arizona. Two types of computer programs are developed: a calibration program to obtain a best-fit calculated hydrograph; and a verification program to generate storm hydrographs given the watershed characteristics and a hyetograph. Calibration reveals the relationship of the model parameters, namely, (f) the inflow coefficient, (a) the constant coefficient, and (TL) the time lag, to the total rainfall, drainage area, channel length, and infiltration capacity of the watershed. The average discrepancy between the predicted hydrograph and the actual hydrograph for Tucson urban watersheds is 20-25 percent.

ARGUE, J.R. 1976: "An 'environmental' approach to storm water management in the Adelaide Hills (Australia)". In, Hydrology Symposium, Sydney, NZIE Australia Preprints of papers; p108-112.

Key words: urban drainage; storm runoff; urbanisation; landuse change; channel erosion; erosion; flood control.

The establishment of urban subdivisions creates increased flooding and erosion of natural channels downstream: this problem is solved, conventionally, by straightening, widening or lining such channels. A less costly and more environmentally acceptable solution is to control runoff within subdivisions so that peak outflowing discharges differ little from those prior to development. This approach, using retention basins for temporary storage of storm water, is examined for the case of urban subdivisions in the Adelaide Hills. The study presents technical information which simplifies the joint tasks of site selection and preliminary design of the retention basins.

ARNETT, R. et.al. 1973: "Diurnal flow and quality patterns in a combined sewerage system". Pacific Northwest Lab., Battelle Memorial Inst., Richland, Wash. Paper presented at 46th Annual Conference., Water Pollution Control Federation, (Oct. 1973).

Key words: combined sewers; urban runoff; water pollution.

ARON, G. et al. 1976: "Quantitative and qualitative implications of urban storm runoff abatement measures". Pennsylvania State University, University Park, Pa. Institute for Research on Land and Water Resources, Research Publication No.97; 101pp.

Key words: computer models; storm ru-

noff; surface runoff; urbanisation; urban drainage; urban runoff; urban hydrology; model studies.

Storm water detention devices can be effective in reducing downstream problems as a result of urban development and they can be compatible with their surroundings. Problems can arise with storm water detention devices especially if they are not constructed or maintained properly. Some devices are environmentally more acceptable than others in certain areas, but there should be no problems which cannot be handled with adequate planning. Urban runoff models are becoming more refined and reliable with use, but they still have a long way to go. They will, however, continue to be an important tool to the engineer and planner in the future. The decision-making process in regard to urban storm water management and nonpoint source pollution control is severely hampered by the lack of good real-time data on both urban runoff quantity and quality. The present market demand for storm water monitoring equipment has resulted in a desirable research effort into the development of more reliable equipment at lower cost.

ARON, G. and LAKATOS, D.F. 1976: "Penn State urban runoff model - user's manual". Pennsylvania State University, University Park, Pa. Dept. of Civil Engineering Research Publication No.96; 60pp. (NTIS PB-267 312).

Key words: computer models; storm runoff; surface runoff; urbanisation; urban hydrology; urban drainage.

Successful urban water resources management depends on the ability of urban planners to predict accurately, in advance, the effects that increased urban development will have on storm water runoff. The present inability to predict watershed response is a major factor leading to increased urban flooding, and a lowering of runoff quality due to the lack of proper control. The situations for which the Penn State Urban Runoff Model is intended are less general than those of many urban runoff models. The Penn State Runoff Model was developed as an alternative to the traditional Rational Method and other semi-empirical procedures for urban drainage design. It deals entirely with the quantity of storm water runoff, and does not directly consider urban runoff quality. The objectives adopted for the Penn State Urban Model were: (1) to produce an urban runoff simulation model which would provide acceptable hydraulic accuracy while remaining at a level of sophistication compatible with minimum practice and data collection time, (2) to keep the model as simple and concise as possible to insure its convenient use, (3) to allow for the analysis of the timing of subarea flow contributions to peak rates at various points in a watershed.

ATHYDE, D.N. (ed). 1976: "Urban storm water management". Proceedings seminars held at Atlanta, Georgia, on Nov.

4-6 1975, and Denver, Colorado, on Dec. 2-4 1975. Divn. of Water Planning, U.S. EPA, Washington, D.C., EPA-68-01-3565; 513pp.

Key words: storm runoff; urban runoff; water pollution control; water pollution sources; pollution abatement; bibliographies.

Three areas are discussed: problem assessment for pollution from urban storm water runoff; means to control pollution, and the legal, institutional, and financial aspects of controlling urban storm water runoff for pollution abatement. Included is a bibliography on institutional arrangements.

ATKINSON, B.W. 1970: "The reality of the urban effect on precipitation, a case study approach". W.M.O. Technical Note 108, W.M.O. No.254 T.P.141, Urban climates, Vol.1; p342-360.

Key words: weather modification.

Thunderstorms which occurred over London, England, on August 21, 1959, were analysed for the urban effect. Data from 608 rain gauges revealed a marked localisation of precipitation over the city with maximum amounts of 68 mm, and radar records showed that clouds developed over the urban area by 1200 G.M.T. and again at 1300 G.M.T. A synoptic trough lay north-west/south-east over the area, and convergence was strong over the London area. Weak divergence prevented cloud growth over neighbouring high ground. Both wet and dry bulb temperatures at the surface defined a strong urban heat island over London by 1200 G.M.T. The storms were triggered by the high urban temperatures. Turbulence, potential condensation, and ice nuclei in the urban area played a negligible role in the initiation of the storms.

ATKINSON, B.W. 1971: "The effect of an urban area on the precipitation from a moving thunderstorm". J. Applied Meteorology, Vol.10(1); p47-55.

Key words: weather modification; urban runoff.

A case study of a thunderstorm cloud on 9 September 1955 was made to investigate the effect of London's urban area on its growth and precipitation amounts. Radar evidence was used to follow the development of the cloud, and dense observation networks provided data on synoptic meteorological elements and rainfall amounts. The cloud originated to the west of London and moved eastward with the mid-tropospheric wind. As it crossed the city, rapid growth occurred and precipitation amounts were heavy. The cloud growth was due to the high values of potential and wet-bulb potential temperatures in the urban area. It is concluded, in this case, that the urban effect was real, but it is stressed that generalisation from this conclusion may not be valid.

AUGUSTINE, M.T. 1966: "Using vegetation to stabilise critical areas in building sites". USDA Soil Conservation, Vol.32(4); p78-80.

Key words: erosion; landuse change; watershed management; erosion control.

Links agriculture erosion, land use, and siltation problems to similar problems in urbanising areas. Several major differences between agricultural conservation work and work in areas of rapidly changing land use are given. Much of the paper deals with the troublesome non-farm erosion problems on cuts and fills. Recommendations are provided on the type of vegetative growth needed, seed-bed preparation, mineral additives, mulching and mulch anchoring.

AUSTIN, G.L. and AUSTIN, L.B. 1974: "The use of radar in urban hydrology". J. of Hydrology, Vol.22(1/2); p131-142.

Key words: urban hydrology; remote sensing.

The radar and raingauge records of summer storms occurring over the city of Ottawa between 1969 and 1972 were used to study events which lead to the flooding of house basements. It was found that these tended to occur as a result of slow moving storms and on one occasion due to a storm elongated in its direction of travel. These features of storm dynamics appeared to be more important than either the intensity of the storm (maximum instantaneous rainfall rate) or the total accumulation. A brief discussion of the match between the scale of resolution of the radar and the watershed scale size in urban areas is included.

AUSTRALIAN ACADEMY OF SCIENCE. 1975: "Prediction in catchment hydrology". A National Symposium in Hydrology, AAS, Canberra, (eds. T.G. Chapman; F.X. Dunnin); 482pp.

Key words: model studies; flood forecasting; hydrologic data; urban hydrology; rainfall-runoff relationships; watershed management.

The twenty-one invited papers are presented. The theme of the symposium was an examination of the extent to which useful predictions can be made in a range of situations, with emphasis on the complexities of the real world. Topics covered include physical processes in surface hydrology, catchment models (including application to urban areas), water quality models, input and output series, data needs, and trends in catchment modeling.

AVAKYAN, A.B. et al. 1977: "Integrated use of reservoirs in urban areas". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p226-230.

Key words: water pollution control;

streamflow.

Developing society imposes heavy demands on the amount and quality of water used in urban areas. The important aspects of the problem are water supply for domestic and industrial purposes, replenishment of water resources, irrigation, recreation, pollution control of water bodies and environmental protection in water-land complexes. These are discussed as applied to the built-up area of Moscow.

AVCO ECONOMIC SYSTEMS CORP. 1970: "A multi-phase component study to predict storm water pollution from urban areas". U.S. Dept. Interior, Office of Water Resources Research, Contract No. 14-31-0001-3164; 262pp.

Key words: storm runoff; model studies; water pollution sources; water pollution control; mathematical models.

Attempts were made to develop storm water pollution prediction models applicable in different regions of the country and criteria for urban storm water pollution control strategies. Existing prediction models were evaluated and additional ones developed. Appropriate urban runoff pollutional models were validated by application to four demonstration cities. Refinements that could broaden the scope of use of the storm water prediction models are indicated, and an evaluation is made of various structural and non-structural control methods for both undeveloped and developed drainage basins. Costs and general effectiveness of these procedures are presented. Guidelines for use of the procedures, as well as guidelines for the selection of an optimal control plan, are discussed. Two salient conclusions of the study are: (1) storm water pollution prediction models applicable in a wide variety of areas cannot be developed until additional data on the hydrological, precipitation, and runoff quality characteristics of representative metropolitan areas become available; and, (2) control strategies can be chosen only after the specifics of the area are defined in terms of the sewer hydraulics, topography, geology, land use patterns, availability of construction sites, land costs, rainfall and runoff characteristics, location of drainage outlets, and water quality standards for the receiving waters.

AVCO ECONOMIC SYSTEMS CORP. 1970: "Storm water pollution from urban land activity". AVCO Economic Systems Corp., Washington, FWQA, U.S. Dept. of the Interior; 352pp. (I67.13/4: EPA-11034 FKLO7/70; NTIS PB-195 281).

Key words: water pollution sources; storm runoff; surface runoff; nutrients; industrial wastes; bacteria; chlorides; biochemical oxygen demand; nitrogen compounds; phosphorus compounds; water pollution control; chemical oxygen demand; total organic carbon; Kjeldahl nitrogen; faecal coliforms.

An investigation of the pollution concentrations and loads from storm water runoff in an urban area was conducted in Tulsa, Oklahoma. The scope of the project included: a field assessment of the storm water pollution by obtaining samples of the water resulting from precipitation and surface runoff from selected test areas within the metropolitan area; development of an analytical procedure for correlation of storm water pollution with selectively defined variables of land uses, environmental conditions, drainage characteristics, and precipitation; and development of a plan for implementing remedial measures necessary to abate or control sources of pollution in an urban area. Storm water runoff samples were collected from 15 'discrete' test areas in the Tulsa metropolitan area for laboratory analysis in terms of quality standards for BOD, COD, TOC, organic Kjeldahl nitrogen, soluble orthophosphate, chloride, pH, solids, total coliform, faecal coliform, and faecal streptococcus pollutants. Selected land use parameters, environmental conditions, drainage and precipitation data, along with storm water pollution factors, provided input data for functional relationships to enable assessment of pollution from storm water runoff. Recommendations were made for a plan of action for preventing and controlling storm water pollution from urban areas.

BACON, M.R. 1976: "Storm water pollution and flooding effects of urban use". Unpublished report to the Auckland Regional Authority, paper No.2; 21pp.

Key words: urban runoff; urbanisation; channel erosion; low flow; salinity; flood discharge; ground water resources; water pollution sources; watershed management; sewage disposal.

The conversion of land from rural to urban use results in a decrease in surface permeability and a marked increase in freshwater runoff to receiving waters. This increased runoff has the following effects: (1) Stream channels become eroded, widened and unstable and stream ecology changes. (2) Flooding occurs more frequently as the land is unable to store peak rainfall and release it gradually after the peak of the storm. (3) Ground water becomes depleted as water runs off impermeable surfaces instead of soaking into the ground. (4) Possible reduction of base flow of the stream in periods of low rainfall due to decreased infiltration to ground water storage. (5) Marine waters into which fresh waters discharge change in character and ecology as a result of a decrease in salinity and inflow of urban storm water pollutants. The intention of this paper is to present some evidence of these urban use effects and to suggest ways in which these problems might be reduced both through better urban management and the siting of urban use away from the most vulnerable locations. The actual process of urban development is not discussed here and neither is the question of sewage disposal.

BAILEY, B.H. et al. 1975: "Variation of urban runoff quality and quantity with duration and intensity of storms". Phase III, Vol.3, analysis of flow models, final report. Texas University, Lubbock, Water Resources Centre; 32pp. (See also Phase III, Vols. 1,2,4).

Key words: peak discharge; data collection; mathematical models; surface runoff; urban runoff.

Runoff from a 1499 acre urban watershed in Lubbock, Texas, was monitored over a 9 month period from September 1974 to May 1975. The observed peak flows and runoff volumes were compared to the outputs generated from 4 runoff models which used the precipitation records and watershed characteristics as input.

BARFIELD, B.J. and HAAN, C.T. 1972: "Erosion sediment production". In, Proceedings of symposium on urban rainfall management problems, University of Kentucky, Lexington, Ky. Technical Report UKY 51-72-CE16; p73-95.

Key words: urban hydrology; erosion; sediment yield; urban runoff; urbanisation.

Sediment is the largest single pollutant of our waterways today in terms of total solids. Of the total solids

which enter streams and reservoirs, approximately 50 percent comes from agricultural areas and 50 percent comes from urban and construction areas, with the major portion coming from construction areas. The kinetic energy of falling raindrops is the agent primarily responsible for erosion. Kinetic energy of raindrops for a given storm is more than 200 times that of the runoff. Rainfall provides the energy necessary for detachment while the runoff provides the carrier necessary to carry the detached particles away. The amount of gross erosion occurring depends on the eroding power of the rainfall and the erodibility of the soil. The Universal Loss Equation gives erosion as a function of rainfall energy and quantity, soil erodibility, slope and length, cover, and management practice.

BARKDOLL, M.P. et al. 1977: "Some effects of dustfall on urban storm water quality". J. Water Pollution Control Federation, Vol.49(9); p1976-1984.

Key words: water pollution; urban runoff; air pollution effects; water pollution sources; storm runoff; heavy metals; nutrients; chemical oxygen demand; miscellaneous chemicals; erosion.

Runoff from 47 storms in a small urban watershed was analysed for 16 water contaminants. Dustfall was also collected and analysed. There were two distinct but overlapping groups of contaminants found in the storm water quality analysis. Minerals and solids have relatively constant concentrations from storm to storm, whereas, heavy metals, nutrients and COD had decreasing concentrations with increasing storm water discharge. Further COD, Hg, Cl, Pb, SiO₂, PO₄ are primarily due to dustfall. The relative influence of dustfall for other constituents will have to be verified by further study. Pervious area in urban watersheds should not be disregarded in determining pollutant yields. Models using only street surface contaminants will yield conservative results. Removal was found to be a function of storm runoff volume and only mildly affected by runoff rates. Certain pollutants such as S.S., Ca, Mg, SO₄, and CaCO₃ are available in extremely large quantities. These constituents probably arise from the erosion of disturbed land areas.

BARNARD, J.R. and CROLEY, T.E. 1974: "Physical and economic aspects associated with runoff from urban growth: a methodological approach". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p219-228.

Key words: model studies; mathematical models; urban runoff; streamflow; storm runoff; analytical techniques; flood routing; flood discharge.

Urban growth often impinges upon local watersheds resulting in alteration of

the frequency and magnitude of flooding along small creeks and low areas. Urban development generally takes place within the context of governmental intervention through land use zoning and planning with the explicit purpose being to protect property rights. In spite of land use regulation, urban growth frequently produces negative externalities in the form of increased frequency and magnitude of flood hazard. This paper presented the methodology for examining the physical and economic aspects of urban growth in a local watershed. Specifically, the Stanford Watershed Hydrologic Model was further developed for statistically determining the impact of urbanisation upon flooding frequency and magnitude. The results from the hydrologic model were linked to an economic model to determine the extent that negative externalities impinge upon property as a result of urbanisation and change in frequency and magnitude of flooding. An analysis of the property market is central to the issue of determining the effect of the changes in flooding hazard on property values and the extent of negative externalities upon property owners and possible income distribution effects.

BARNES, R.C. 1969: "Erosion control practices adapted for urban use and pollution abatement". ASAE Paper No.69; p233.

Key words: erosion control; pollution abatement; erosion; flood control.

Changes in land use brought about by rapidly expanding urban centres are causing serious erosion and sediment pollution problems. This is focusing attention on the need for overall planning for best land use for all segments of our society; for adequate zoning to implement orderly development; for trained staff to administer, guide, and supervise developments, and for guidelines, standards and specifications for use by those who require them. The basic principles for erosion control, orderly removal of excess runoff, control of flooding, and reduction of sediment damage are known and have been used for other land uses for years, and can be modified for urban use. Any practice which uses these principles will also reduce pollution below the development.

BARRE, N.LA. et al. 1973: "Lead contamination of snow". Water Research, Vol.7(8); p1215-1218.

Key words: lead; oil wastes; snowmelt.

Snow from disposal sites and along roads contained considerable Pb due to the combustion of leaded gasolines by automobiles. In spite of Pb concentrations up to 4,330 ppm in the sample sediment, the highest concentration in the filtrates was 0.21 ppm with an average of 0.04 ppm. Dumping snow away from watercourses instead of directly into them significantly reduces Pb contamination in the waters from this

source.

BATTAGLIA, G.M. 1976: "Pollutional characteristics of urban snowmelt runoff". M.S. Thesis, Dept. of Civil and Environmental Engineering, University of Colorado, Boulder; 120pp. (NTIS PB-264 715).

Key words: storm runoff; urban drainage; urban runoff; water pollution sources; urbanisation; snowmelt; miscellaneous chemicals; lead; solid wastes.

This research was the second of a two part study on urban storm water runoff in Boulder, Colorado. The objectives were to give a representation of the concentrations and loadings of selected pollutants from snowmelt runoff, and their impact upon a receiving stream, Boulder Creek. A 183 acre residential area served by a separate storm and sanitary sewer system was selected. The storm sewer system discharges into Boulder Creek. The recorded snowfalls and subsequent runoff have been investigated for the fall and winter of 1975-76. Concentrations of urban storm water runoff, pollutant variations in Boulder Creek, and loadings from the storm sewer were also evaluated during this period. Concentrations of the various chemical parameters in snowmelt runoff were highly variable, similar to rain runoff. These concentrations peaked during the middle of the day, corresponding with peaks of maximum runoff. Pollutant concentrations in the storm sewer were usually below those found for rain runoff, but due to lower flows in the creek during the winter months, the detrimental effects from the sewer were as significant as those found in the previous rain study. The impact of urban runoff upon receiving waters is brought into perspective when comparing the storm sewer discharge loadings with those of the municipal sewage treatment plant effluent. While adding only 13.5 percent of the total flow to the creek, the storm sewer contributes almost 50 percent of the total solids and lead, and over 75 percent of the suspended solids.

BAUER, K.W. 1965: "Determination of runoff for urban storm water drainage system design". Southeastern Wis. Regional Planning Committee Tech. Rec., Vol.2(4); 19pp.

Key words: storm runoff; urban drainage.

Storm water runoff determinations are made to determine design criteria for the planning and design of urban drainage systems. The storm water runoff determination criteria is the rational method whose variables are the coefficient of runoff, rainfall intensity for the area, time of concentration, and soil information. The application of these criteria should promote common storm sewer design methods and the adoption of common design methods for storm water drainage system design.

BAUER, W.J. 1969: "Urban hydrology". In, The progress of hydrology, Vol.2 - specialised hydrologic subjects. Proc. 1st International Seminar for hydrology professors, Illinois University, Urbana, (University of Illinois); p605-637.

Key words: urban hydrology; storm runoff; flood routing; model studies; rainfall-runoff relationships; urbanisation; mathematical models; flood control; instrumentation; analytical techniques.

This paper presents viewpoints of a practicing consulting engineer concerning the following aspects of urban hydrology: the controlling economic factors; the need for improved analytical and design techniques; and the use of simplified methods pending the gathering of data required for the use of improved techniques. The Northeastern Illinois Metropolitan area is used as an example in illustrating each of these aspects. Storm runoff in urban areas takes up valuable space, and only the location of this space is subject to engineering control. Therefore it is the volume of runoff more than the rate of runoff which is important to evaluate for design purposes. Runoff from urban areas presents a quality control problem. Therefore it behoves the planner to move in the direction of large storage and small rates of flow, because of the high cost of treatment at high rates of flow for short periods of time. All methods of analysis of storm runoff and the associated flow in open channels involve the use of mathematical models. Every decision regarding storm drainage, even one to do nothing, involves an allocation of space, the temporary storage of storm water, and therefore involves an acceptance of the cost associated with that decision.

BAXTER, S.S. 1968: "Effects of urbanisation". Water Resources Bulletin, Vol.4(1); p51-56.

Key words: urbanisation; watershed management; water pollution sources.

Existing urban water problems and the types of remedial research needed are reviewed. Particular stress is placed on economic, social, and political factors involved. Shortages and failure in water supply, needed water pollution control, flooding caused by undersized storm sewers, and fire losses resulting from low water pressures are the major water problems complicated by growing urbanisation. Increased federal funding, particularly under various water quality acts, has lessened local and State control problems. Although basic research may provide a breakthrough in water knowledge, there is need to apply more fully what is already known to meet the growing problems as they occur.

BEABLE, M.E. 1977: "Urban flood estimation - a look to the future". In, proceedings N.Z. Institution Engineers, Annual Conference 1977, Technical Group on

Water session; 15pp.

Key words: flood forecasting; peak discharge; urban runoff; storm runoff; mathematical models.

A description is given of three methods which are used overseas and which could be employed in the future to estimate design flood peaks for urban New Zealand catchments. The three methods are: the statistical Rational Formula; regional flood frequency analysis; and catchment modeling (specifically the Laurenson model). However, the development of such methods is restricted at present by the limited amount of data on urban New Zealand catchments.

BEACH, C.H. 1964: "Runoff and stream control in urban areas". NZIE Symposium, The use and control of water in New Zealand; p107-115. (Discussion p124-127).

Key words: erosion; flood control; peak discharge; storm runoff.

Flooding and erosion should always be considered together; they are one involved problem. Flooding rarely occurs without erosion and both are equally damaging. One may control flooding only to find that the methods adopted have created an erosion problem. This paper is concerned with urban areas only and is written to promote discussion. It maintains that: (1) for reasons of economy it is necessary to avoid over-design as much as under-design in the planning of storm water systems. Both lead to extra expenditure; (2) the popular "rational" formula for estimating peak flows has its limitations and is often applied to problems for which it is quite unsuited; and (3) there is a need to investigate the reliability of formulae and methods used for estimating runoffs from urban catchments that discharge through larger pipes and channels.

BECKER, B.C. and MILLS, T.R. 1972: "Guidelines for erosion and sediment control planning and implementation". Hittman Associates, Inc., Columbia, Md. W73-01773, EPA-15030-FNZ/2; 243pp. (NTIS PB-213 119/1).

Key words: erosion control; urbanisation; sediment transport.

The principal purpose of the guidelines is to help those engaged in urban construction to prevent the uncontrolled movement of soil and the subsequent damage it causes. A comprehensive approach to the problem of erosion and sediment control provides: a description of how a preliminary site evaluation determines what potential sediment and erosion control problems exist at a site being considered for development; guidance for the planning of an effective sediment and erosion control plan; and procedures for the implementation of that plan during operations. Technical information on 42 sediment and erosion control products, practices, and techniques is contained in

four appendices.

BEERS, G.D. 1973: "Management of storm water runoff in suburban environments". Engineering Science Inc., Cincinnati, Ohio, completion report; 121pp.

Key words: surface runoff; flood control; watershed management; storm runoff.

The overall objective was to assess the feasibility of managing surface runoff from various suburban watersheds to meet suburban water demands. Definitive results were not anticipated from this study. Rather a first cut definition of an essentially uncharted area in suburban hydrology would be constituted. Although it appears technically possible to incorporate storm water runoff into the suburban water resources arsenal, a number of key areas require additional information before the overall feasibility can be ascertained. First, information is needed on the current status of suburban social attitudes towards the reuse of storm water and all that it implies. Second, certain modifications could be made to suburban watershed surfaces, and in man's use of them, with resultant higher quality runoff flows from these watersheds.

BELL, D.E. et al. 1975: "Variation of urban runoff quality and quantity with duration and intensity of storms". Phase III, Vol.2, impacts of dual storms. Texas University, Lubbock, Water Resources Centre; 59pp. (See also Phase III, Vols. 1,3,4).

Key words: model studies; mathematical models; water pollution; urban runoff.

The urban runoff model proposed by Austin to describe both quantity and quality of runoff was applied to a 1499 acre area. The model was then modified to include parameters related to sand/dust storm events.

BELL, W. and WINN, C.B. 1972: "Minimisation of pollution from combined storm sewer systems". In, International symposium on systems engineering and analysis, Vol.II, contributed papers, Purdue University; p41-48.

Key words: combined sewers; water pollution control; water pollution; sewage treatment; overflows.

A national survey has disclosed the fact that there are 1,329 jurisdictions utilising combined sewers serving approximately 36 million people. These systems were built prior to the establishment of new water quality requirements and consequently they do not meet present and proposed standards on water pollution. This results from the fact that they were designed to overflow during storms in order to relieve severe overloading of collection lines, interceptors, and sewage pumping and

treatment works. The discharge of these overflows into natural receiving waters creates pollution and is of growing concern to water pollution control authorities. This paper presents the optimal control strategy to be followed in minimising the total overflow from given storage reservoirs within the system. The individual overflows are weighted unequally to account for the real situation in which overflows from some regions within a system may contain more pollutants than those from other regions.

BENSON, M.A. 1962: "Factors influencing the occurrence of floods in a humid region of diverse terrain". U.S. Geol. Survey water supply paper No.1580-B; 64pp.

Key words: flood forecasting; peak discharge; mathematical models; model studies; rainfall-runoff relationships; snowmelt.

This report describes relations between flood peaks and hydrologic factors in a humid region with limited climatic variation but a diversity of terrain. Statistical multiple-regression techniques have been applied to hydrologic data in New England. Many topographic and climatic factors have been evaluated, and their relations to flood peaks have been examined. Many of the factors that influence flood peaks are interrelated, and part of the investigation consisted of determining the most efficient factor in each of several groups of highly interrelated variables. Drainage area size was found to be the most important factor. Main-channel slope was found to be next in importance, and a simple yet efficient index of main-channel slope was developed. The surface area of lakes and ponds was found to be a factor significantly influencing peak discharges. Of several indices tested, the intensity of rainfall for a given duration and frequency was found to be most highly related to the magnitude of peaks. The increase in peaks caused by snowmelt and frozen ground was found to be related to an index of winter temperature - the average number of degrees below freezing in January. After the above-mentioned topographic and climatic characteristics had been taken into account, there remained deviations in peak discharges that showed an evident relation to orographic patterns. An orographic factor was mapped as defined by the peak discharges of record. Multiple-regression equations were developed that related, with acceptable accuracy, peak discharges of 1.2- to 300-year recurrence intervals to 6 hydrologic variables; 3 of the variables were topographic, 2 climatic, and 1 orographic. The remaining unexplained variations in flood-peak occurrence are believed attributable to the chance variation in storms.

BENZIE, W.J. and COURCHAINE, R.J. 1966: "Discharges from separate storm sewers and combined sewers". J. Water Pollution Control Federation, Vol.38; p410.

Key words: faecal coliforms; chemical analysis; bacteria; combined sewers; nitrates; phosphorus compounds.

Discharges from a separate storm sewer system showed mean median bacterial counts per 100ml of $12 \times 100,000$, $0.62 \times 100,000$, and $1.4 \times 100,000$ for total coliform, faecal coliform, and faecal streptococci, respectively. Corresponding figures for discharge from a combined system were $94 \times 100,000$, $3.7 \times 100,000$, and $5.8 \times 100,000$. The ratios of faecal coliforms to faecal streptococci in the combined and separate systems were 4.7 and 0.6, respectively, indicating that the bacteria in the combined system are primarily of human origin, whereas those in the separate system are derived from other warm-blooded animals. Phosphates and nitrates in combined system discharges were about 3 to 4 times greater than contents in discharges from separate systems.

BERG, J.A.VAN DEN. 1974: "Some aspects of the runoff hydrology of urban areas". Water, Vol.7(23); p508-516 (In Dutch, English summary p507).

Key words: bibliographies; urban runoff; hydrologic data; urban drainage.

Giving a bibliography of 41 references and some diagrammatical data, the author discusses the runoff process within an urban area, particularly in relation to the measurements made at the new town of Lelystad, Netherlands, emphasising the need for data on the intensity of rainfall as well as the total precipitation, and showing the effects of subsurface drainage of roads. Based on analyses at Lelystad, the effects of storm sewage from the separate sewage system on the quality of canal waters in the town are also discussed.

BERG, J.A.VAN DEN. 1976: "Data analysis and system modeling in urban catchment areas (in the new town of Lelystad, The Netherlands)". Hydrological Sciences Bulletin, Vol.21(1); p187-194.

Key words: model studies; analytical techniques; computer models; mathematical models.

The objective is to determine the probability distribution of the outputs from the distribution of the input and from the deterministic operations which can be represented by a matrix. Screened data are rearranged in time series and represented in combinations of two or three connected variables. From these data rainfall and discharge intensities can be calculated for periods up to 30s.

BERG, J.A.VAN DEN. et al. 1977: "Some qualitative and quantitative aspects of surface water in an urban area with separate storm water and waste water sewer systems". In, Symposium on effects of urbanisation and industrial-

sation on the hydrological regime and on water quality. IAHS Publication No.123; p109-123.

Key words: surface runoff; urban drainage; mathematical models; model studies; water pollution; overflows.

A part of the flat urban area (116 ha) of the new town of Lelystad, situated in a recently reclaimed polder in the former Zuiderzee, was the subject of a study on the flow of surface and sub-surface water into and through open drains. Precipitation, discharge of storm drains and of subsurface drainage were measured in three catchment areas. From these data the runoff coefficients and the transformation of the rainfall outflow from the storm water drains are calculated. These outputs are used for modeling the nonsteady flow through the open drains. This model is applied in the design of the urban system of open drains, culverts and weirs. The water quality of the system was also investigated. From the measurements it can be concluded that the system of separate storm and waste water sewers produces less water pollution than a combined system with zero overflows.

BERKSHIRE COUNTY REGIONAL PLANNING COMMISSION. 1976: "The upper Housatonic '208' water quality management plan". Phase I report, Berkshire County Regional Planning Commission, Pittsfield, Mass.

Key words: watershed management; urban hydrology; eutrophication; lakes; combined sewers; industrial wastes; ground water resources; nonpoint pollution sources; urban runoff.

This plan is prepared under Section 208 of the Federal Water Pollution Control Act Amendments, by the Berkshire County Regional Planning Commission, in accordance with a designation by the Governor of Massachusetts, with funds provided by the U.S. Environmental Protection Agency. The goal is to have, wherever attainable by 1983, a water quality which is safe for swimming and which will protect fish and wildlife. This is the Phase I report. It is issued part way through the process to inform the public and obtain their reactions before the final plan is prepared. The report addresses growth and land use; lake eutrophication; ground water protection; municipal facilities; industrial sources; combined sewers; urban runoff; nonpoint sources; and legal, institutional, and financial arrangements. The report suggests a \$55 million, six point water quality management program, with 43 percent of the costs borne at the community level.

BERRY, B.J.L. et al. 1974: "Land use, urban form and environmental quality". Final Report for Office of Research and Development, EPA, by Dept. of Geography, University of Chicago (Research Paper No.155); 440pp.

Key words: environmental effects; Water & soil technical publication no. 15 (1979)

watershed management; landuse change; water pollution.

This study deals with the ways in which urban form and land use affect the nature and intensity of environmental pollution. The inquiry proceeds at two scales: (a) from one urban region to another, and (b) on a more detailed basis within urban regions. At the first level of analysis, attention is directed to the effects of different urban forms and land use mixes on the levels of environmental pollution reported by U.S. government monitoring stations to be characteristic of the urban regions. At the second scale, spatial patterns of pollution are related to spatial patterns of land use within a sample of metropolitan areas that have different urban forms and that exemplify the range of pollution types characterising American urban regions today. The report is structured cumulatively, to provide an understanding of those urban forms that naturally generate the lowest pollution levels, the environmental consequences of contemporary urban dynamics, and the role that urban planning may potentially play in the achievement and maintenance of the nation's environmental quality standards.

BERRY, B.J.L. and HORTON, F.E. 1974: "Urban environmental management". Englewood Cliffs, New Jersey, Prentice Hall Inc.

Key words: urbanisation; urban runoff; streamflow; sediment yield.

A general discussion of the effect of urbanisation on hydrology (especially runoff) listing numerous studies previously performed. Describes the method of plotting the effect of urbanisation on drainage. A discussion of urbanisation effects on sedimentation is also included.

BETSON, R.P. 1977: "Bulk precipitation and streamflow quality relationships in an urban area". Paper presented at Annual Spring Meeting of the AGU, Washington, D.C. EOS, Vol.58(6); p389.

Key words: streamflow; water pollution; rainfall-runoff relationships; weather modification; urban runoff; metals; nutrients; chemical oxygen demand.

A systems study of urban hydrology was undertaken in Knoxville, Tn. Measurements of bulk precipitation quality were related to streamflow quality in several small watersheds. The yields of streamflow in these catchments are affected to varying degrees because they are located in carbonate terrain. Compared with bulk precipitation concentrations measured in other urban areas and in rural areas the quality of bulk precipitation measured in Knoxville was found to be similar to that measured elsewhere for some 20 constituents. Input-output studies for the various constituents revealed that for one suburban-type watershed in which most of the potential streamflow

was lost to the carbonate rock drainage system, the atmospheric loading for every constituent exceeded the streamflow loading. At a residential/industrial watershed where most of the potential runoff did occur as surface flow, bulk precipitation accounted for important amounts of the minerals, nutrients, metals, and COD. And finally, at a watershed with an extensive commercial strip development where about half the potential runoff was lost to carbonate rock drainage, bulk precipitation loadings were also found to be able to account for a high percentage of the streamflow loadings of many constituents. The streamflow quality for the watersheds was next compared with expected rural area or background values predicted using models. For most constituents the urban streamflow quality was not found to be much different from that in rural area streams. These findings lead to the conclusion that bulk precipitation can be an important source for many of the constituents found in streamflow from both urban and rural areas.

BHUTANI, J. et al. 1975: "Impact of hydrologic modifications on water quality". Mitre Corp., McLean, Va.; 543pp. (MTR-6887, EPA/600/2-75/007; NTIS PB-248 523/3WP).

Key words: water pollution sources; sediment yield; water pollution control; sediment control.

The report describes the scope and magnitude of water pollution problems caused by hydrologic modifications (dams, impoundments, channelisation, in-water construction, out-of-water construction, and dredging). Types of pollutants released by each class of hydrologic modification are identified, and quantitative estimates are made of the amount of the major pollutant-sediment that enters the Nation's surface waters as a result of highway and urban construction. Methods for controlling the release of pollutants from hydrologic modification activities are described, and the effectiveness of sediment control measures is estimated. Two 'loading functions' are developed for predicting the quantities of sediment released from construction operations of given magnitude and location. These functions are based on measurements of sediment yields and other parameters at 10 construction sites. The accuracy and limitations of the functions are analysed. Measurement data from all classes of hydrologic modifications are reported in the 42 case studies of field projects summarised in the appendices of the report.

BISHOP, H.F. 1974: "Master planning methodology for urban drainage". J. Hydraul. Divn., Proc. ASCE, Vol.100(HY1); p189-199.

Key words: urban hydrology; urban runoff; data collection; flood control; watershed management.

Effective operation and maintenance of
Water & soil technical publication no. 15 (1979)

the urban environment requires the co-ordinated management of the various elements of the urban area. One of the principal elements of the urban system is that of water resource management which includes urban drainage and flood control. A systems engineering methodology was developed for master planning of the major drainage system in the Denver area under Project REUSE (Renewing the Environment through Urban Systems Engineering). The methodology incorporates a functional description of the urban drainage system and a systematic process of data acquisition, runoff analysis, concept identification and selection, and master plan development and implementation.

BITTON, G. 1975: "Adsorption of viruses on to surfaces in soil and water". Water Research, Vol.9(5/6); p473-484.

Key words: viral factors; water pollution control.

The present review considers the physico-chemical mechanisms involved in the adsorption of viruses to biological and non-biological surfaces and to stress the influence of these sorptive interactions on the behaviour of viruses in their environment. The author also discusses the importance of the adsorption process in water pollution control and the concentration and purification of viruses.

BLACK, CROW and EIDSNESS INC. 1971: "Storm and combined sewer pollution sources and abatement, Atlanta, Ga.". Black, Crow and Eidsness Inc., Atlanta, Ga.; 184pp. (NTIS PB-201 725; EPA 11024EIB01/71).

Key words: water pollution; combined sewers; pollution abatement; overflows; surface runoff; waste water treatment; water pollution control; biochemical oxygen demand.

Six urban drainage basins in Atlanta, Georgia, served by combined and separate sewers, were studied to determine the major pollution sources during storm events. Rainfall frequency analysis and simulation techniques were used to obtain design criteria for alternative pollution abatement schemes. High frequency storms cause the worst impact and most of the pollution from combined sewer areas. Annual BOD from these areas is 2,078,000 pounds, or 460 lbs/acre, of which 57 percent is due to storms of two week or higher frequency. Bypassing of waste water treatment plant flows during storms adds 690,000 pounds BOD/year. Runoff from storm sewered areas, at 253 lbs/acre, adds 5,577,000 pounds/year. Overflows and bypassed flows have severe impact upon the South River, due to their high deoxygenation rates and coliform concentrations. Annual BOD reduction from combined sewer areas of 57 percent may be achieved for a total annual cost of \$165,000, by modifying the three regulators and treating 80 percent of the overflows, in conjunction with storage sufficient to contain a two week storm.

BLACK, CROW and EIDSNES INC. 1975: "Water pollution abatement technology: capabilities and costs, urban runoff". National Commission on Water Quality, Washington. Report NCWQ-75/14; 380pp. (NTIS PB-247 391).

Key words: urban runoff; pollution abatement; erosion; mathematical models; urban hydrology; waste water treatment; water pollution control; suspended solids.

This study shows that urban storm water runoff contributes significantly to the annual pollutant loads of the nation's waters in urban areas. Suspended solids and oxygen demand characteristics of urban runoff appear to be the most significant contributions to pollution when compared with other publicly owned sources. The composition of urban storm water runoff was found to vary widely in pollutant constituents for many poorly defined reasons. The treatment technology best suited to the abatement of urban storm water pollution remains to be developed. Abatement of urban storm water pollution to a level equivalent to secondary treatment would represent a commitment of approximately 150 to 170 billion dollars.

BLACKWOOD, K.R. 1974: "Runoff water quality of three Tucson watersheds". Arizona University, Tucson, Department of Civil Engineering, Research Report, OWRT B-023-ARIZ(4); 39pp. (NTIS PB-240 287).

Key words: urbanisation; watershed management; storm runoff; urban runoff; data collection.

An interdisciplinary study of three watersheds was conducted during the years of 1969 through 1973 by the Water Resources Research Centre, University of Arizona, to monitor the quantity and quality of urban runoff in Tucson, Arizona. Three watersheds are drained by nearly natural drainage channels. Flow was measured by concrete critical flow measuring flumes. Quality was determined through tests run on manually collected samples taken at various intervals throughout runoff events. Because of a rapidly burgeoning population and a growing recognition of the limited water resources available to the Tucson Metropolitan area, many suggestions for the use of storm water runoff have been made. The water quality of the runoff water is presented in order to enable a better evaluation of these proposals to be made. The study was divided into three sections. The first compared the land use and geological characteristics of the three watersheds in an attempt to determine their effect on water quality. The second section examined the variation in average water quality between storms for each watershed. Characteristics of the storms were examined to determine the possibility of predicting the water quality. Finally, water quality variations during a storm were investigated to determine if they followed a predictable pattern, and whether significant improvements in average quality of the captured water could be obtained if

some of the runoff water was bypassed.

BLASZCZYK, P. 1977: "Urban runoff research in Poland. Report 11, 1975-77". ASCE, New York, Urban Water Resources Research Council, Technical Memo., TM-IHP-11; 12pp.

Key words: urban runoff; computer models; mathematical models.

Modeling and catchment research for underground conduit drainage systems in Poland is emphasised.

BLEEK, J. 1975: "Synthetic unit hydrograph procedures in urban hydrology". Paper in proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Ky.

Key words: storm runoff; hydrographs; urbanisation; mathematical models.

Synthetic unit hydrograph procedures provide a convenient means of estimating the increasing storm water runoff from a catchment that is undergoing urban development. There are two basic approaches to the synthetic unit hydrograph technique: the 'analysis' approach, relating unit hydrograph characteristics directly to catchment parameters and the 'synthesis' approach, correlating the coefficients of a linear conceptual model with catchment and storm parameters. The application of both these procedures to urban catchments in southeast England has shown that both methods have their advantages but the analysis approach most consistently reproduces the unit hydrographs of these particular catchments.

BOCH, P. 1958: "A study of urban rainfall - runoff relationships". Ph.D Thesis, John Hopkins, University, Baltimore, Md.

Key words: rainfall-runoff relationships; urban runoff; data collection; model studies.

Reports on a study of flows into storm drains and inlets in the city of Baltimore. The data were collected using inlet weirs and tipping bucket rain-gauges with as many as nine inlet areas recorded simultaneously on one chart. The "Inlet Method" proposed herein reportedly gives much more accurate results than the "Rational Method" by attenuating estimated inlet flows to calculate discharge at any point in the system. The primary functions are the degree of imperviousness and magnitude of the rainfall during the most intense part of thunderstorms.

BOESCH, B.E. and EAKER, C.A. 1972: "Urban erosion - practical alternatives". In, Proceedings symposium on urban rainfall management problems, University of Kentucky, Lexington, Ky; Technical Report UKY 51-72-CE16; p96-107.

Key words: urban hydrology; erosion control; urbanisation; erosion; sediment control; watershed management.

In urbanisation, critical sediment problems occur between the appearance of earth-moving machines on the site and the completion of the development. The first step is often to strip the natural vegetation from the land and level the site. Then the sub-soil is left exposed to rainfall and running water. In the Detroit metropolitan area, in the summer of 1968, 2.1 percent of the urban zone was under development. This part produced nearly the same amount of eroded soil materials as the undisturbed 97.9 percent of the area. Erosion from the developing areas averaged 69 tons per acre per year, compared with an overall rate for the metropolitan area of about 3.0 tons, and an overall average rate from southeast Michigan of 2.6 tons. To control erosion, natural vegetation should be retained and protected. Where inadequate vegetation exists, temporary or permanent vegetation should be established. The exposed area should be limited to the smallest practical size for the shortest practical time. Permanent vegetation and improvements such as streets or storm sewers should be installed as early as possible. Sediment basins should be constructed. Diversions, grassed waterways, grade stabilisation structures, and similar measures should be installed as early as possible.

BOHNERT, J.E. 1971: "The effect of urban land use on total runoff: a case study for Salt Creek Basin, Cook and Dupage Counties, Illinois". Thesis, Sth. Illinois University; 152pp. (Diss. Abstr. 32B; p5290).

Key words: urban runoff; analytical techniques; landuse change.

A synthetic hydrology method, the Thornthwaite water-budget procedure, was used to test the hypothesis that urban land use, with its impervious surfaces should increase annual runoff. Studies in Salt Creek basin, Ill., where the impervious area increased from about 7 percent in 1946 to an estimated 22 percent in 1967, showed that runoff has increased throughout this period and suggested that in suburban districts, where impervious surfaces are discontinuous, some of the surplus water generated by the impervious surfaces may be trapped by the surrounding pervious areas; increasing urban development increases the conversion of surplus water to runoff.

BOUWKNEGT, J. 1977: "Flood waves from impervious areas". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p93-100.

Key words: urbanisation; storm runoff; surface runoff; mathematical models.

Precipitation falling on an impervious surface runs off, in general, very rapidly. This results in discharges to the drainage system of considerable intensity and short duration. These essentially nonstationary flows can be described by the St. Venant equations. There are several techniques available to solve these equations, and in this study the author has chosen the method of characteristics. This method has been successfully applied to many problems and two examples are given.

BOYSEN, S.M. 1974: "Predicting sediment yield in urban areas". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p199-203.

Key words: urbanisation; sediment yield; erosion; erosion control; sediment control.

Predicting sediment loss from urban construction sites is an important aspect in the planning and enforcement phases of a sediment control program. The Universal Soil Loss Equation (USLE) is an excellent means of relating soil management, cover, and other erosion control practices to erosion in agricultural areas. The USLE, however, cannot individually be used to estimate sediment yield. This paper describes a procedure to predict sediment yield from urban construction areas. A sediment basin design procedure based on trap efficiency has been used for several years in Maryland. The USLE concept for relating degree of erosion control to sediment basin trap efficiency is as yet untried in the field, but it appears to be one of the best procedures available. The Universal Soil Loss Equation is complex. Urban construction sites are not only complex but also changing daily. The complexities prevent accurate estimates of sediment yields from urban sites.

BRADFORD, W.L. 1977: "Urban storm water pollutant loadings: a statistical summary through 1972". J. Water Pollution Control Federation, Vol.49(4); p613-622.

Key words: water pollution; suspended solids; data collection; water pollution sources; storm runoff; urban runoff; mathematical models; surface runoff; bacteria.

The data on urban storm water pollutant loading rates and composition available from the literature published through 1972 were used to find differences related to different regions of the nation, gross land use types, average daily traffic, type of landscaping, and type of street surface. From 153 records, the mean and standard deviation of dust and dirt loading rates and composition were calculated for each of the independent variables listed and compared to those of the entire data set. Although apparent differences exist between subsets and the whole set of data, with some important exceptions, the null hypothesis was accepted

at the 95 percent confidence level in most cases. To improve future analyses, study methods need to be more standardised than at present.

BRANDSTETTER, A. 1974: "Comparative analysis of urban storm water models". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p333-420.

Key words: analytical techniques; combined sewers; mathematical models.

Eighteen mathematical models for the nonsteady simulation of runoff in urban storm and combined sewerage systems were reviewed in a study sponsored by the U.S. Environmental Protection Agency. The models were evaluated on the basis of information published by the model builders and model users. Seven models were also tested by computer runs using both hypothetical and real catchment data. Most of the models evaluated include the nonsteady simulation of the rainfall-runoff process and flow routing in sewers; a few also include the simulation of waste water quality, options for dimensioning sewerage system components, and features for realtime control of overflows during rainstorms.

BRANDSTETTER, A. 1976: "Assessment of mathematical models for storm and combined sewer management". EPA, Cincinnati, Ohio, Final Report, Contract No. 68-03-0251; 387pp.

Key words: watershed management; urban runoff; mathematical models; computer models; combined sewers; water pollution control; overflows.

Input data and selected output are presented as part of a general evaluation of storm water management models. Hypothetical catchments and pipe systems were used in simulations. Storm water management models which are considered include: Battelle Urban Waste Water Management Model, Chicago Flow Simulation Program, Dorsch Consult Hydrograph-Volume Model, Environmental Protection Agency Storm Water Management Model (SWMM), Massachusetts Institute of Technology Urban Watershed Model, and Water Resources Engineers Storm Water Management Model.

BRANDSTETTER, A. 1976: "Evaluation of (25) mathematical models for the simulation of varying runoff and water quality in storm and combined sewerage systems". In, EPA Conference on Environmental Modeling and Simulation; p78.

Key words: combined sewers; urban runoff; mathematical models; computer models.

The EPA sponsored an assessment of 25 simulation models to provide a readily available reference guide for selecting models best suited for specific purposes. Most models reviewed include the computation of the time-varying ru-

noff from rainfall and flow routing in sewage networks. Some models simulate the time-varying waste water quality, and a few models include mathematical optimisation techniques for the least-cost design of new storm sewer system components or for optimal real-time operations of combined sewer overflow structures. An evaluation of the principal features, assumptions, and limitations of each model is given; a comparison of flow and water quality routing results and computer running costs for 8 models which were tested with the same data is presented. Additional model features are recommended which would enhance or extend simulation capabilities and use.

BRANNAN, R.W. 1962: "Drainage problems in an area changing from rural to urban". Public Works, Vol.93(10); p193-196.

Key words: storm runoff; rainfall-runoff relationships; landuse change; peak discharge.

In Lucas County, Ohio, as long as watercourses served only to drain agricultural and forested areas, no more than 5 percent of the rainfall found its way immediately to creeks. As urbanisation took place, residential subdivisions, parking lots, commercial buildings, schools, churches, driveways, highways, sidewalks, and other impervious improvements were made. Runoff increased rapidly, and the capacity of the natural watercourse was soon exceeded. As the choicer lands at higher elevations were improved, the lower-lying lands became more desirable for improvements. They in turn were developed, and they added to the storm water. Peak discharges rose to new highs and inundated lands that had never before been subject to flooding. High-water damage occurred at more frequent intervals. Accompanying this was physical deterioration of the stream. This further reduced the ability of the stream to transport sediment, and as a result deposits formed. At an increasing rate, the shape and frictional characteristics of the stream changed so that it had less capacity for the simultaneously increased runoff demand.

BRAS, R.L. and PERKINS, F.E. 1975: "Effects of urbanisation on catchment response". J. Hydraul. Divn., Proc. ASCE, Vol.101(HY3); p451-466.

Key words: rainfall-runoff relationships; urbanisation; mathematical models.

A mathematical model was utilised as an experimental tool to perform a series of controlled experiments on small hypothetical catchments characteristic of areas in Puerto Rico. The purpose of the experiments was to quantify the likely effects of typical urban developments on the hydrologic response characteristics of the hypothetical catchments, and to relate these effects to the separate physical changes introduced by urbanisation. An important modeling issue was also investigated.

Initially a very detailed model of the catchments was employed thus providing a fine spatial resolution but at relatively high cost. A simple scheme was developed in which the detailed model may be replaced by a much coarser and less expensive mathematical model with no significant loss of accuracy.

BRATER, E.F. 1968: "Steps towards a better understanding of urban runoff processes". Water Resources Research, Vol.4(2); p335-47.

Key words: urbanisation; rainfall-runoff relationships; urban drainage.

Rainfall and runoff from drainage basins in various stages of urbanisation were analysed to determine the initial retention, the hydrologically significant impermeable area, and the infiltration capacities of the permeable portions of the basins. The drainage basins, varying in size from 9.5 to 185 square miles, are located in the Detroit metropolitan area. Techniques were developed that largely eliminated personal judgement in separating surface runoff from ground water discharge. Infiltration capacities in this region are from 3 to 5 times higher in late summer than in early spring. The average initial retention for the basins studied is approximately 0.2 inch. The hydrologically significant impermeable area appears to be closely related to the population density, but the effect of other factors is being studied. An investigation of the cause of seasonal and short period variations of infiltration capacity may provide a better understanding of the infiltration process.

BRATER, E.F. et al. 1974: "Seasonal effects in flood synthesis". Water Resources Research, Vol.10(3); p441-445.

Key words: flood forecasting; peak discharge; storm runoff; model studies; mathematical models; snowmelt.

The effect of urbanisation on flood flows is being investigated by analysing inputs and corresponding flood hydrographs from many watersheds along with corresponding inputs and responses from watershed models. The inputs consist of precipitation plus snowmelt minus infiltration and retention. Because of the large seasonal variation in infiltration rates, accuracy was improved by treating rainfall frequencies seasonally in predicting flood runoff from precipitation and snowmelt. As procedures were developed and improved in accuracy, it became necessary to examine the effect of snowmelt on winter frequencies and the seasonal variation in time-intensity rainfall patterns more closely. A procedure was developed for including snowmelt with winter rains, and the resulting frequency curves of rain plus snowmelt are presented and compared with conventional rainfall frequency curves. A method of deriving time-intensity patterns from daily rainfall was developed, and it was shown that a large difference ex-

ists between typical winter and summer patterns in southeastern Michigan.

BRATER, E.F. and SURESH SANGAI, 1969: "Effects of urbanisation on peak flows". In, Effects of watershed changes on streamflow, Section 3, urban watersheds (eds. W.L. Moore; C.W. Morgan), University of Texas, Austin; p201-214.

Key words: peak discharge; storm runoff; urbanisation; surface runoff; hydrographs.

The authors point out that the effects of building structures may be to aggravate the flood problem. This is compounded by the evidence of increased rainfall in urban areas. Changes due to urbanisation will be dependent on the original state of the basin. The need for quantitative means of study of the effects of urbanisation on surface runoff is stressed. One approach is to establish relations between parameters defining the shape of the unit hydrograph and some measures of basin characteristics. Preliminary results from 15 basins in the Detroit area reinforce the view that hydrograph peaks are enhanced and the period to rise shortened with increased urbanisation.

BRATER, E.F. and SHERRILL, J.D. 1975: "Rainfall-runoff relations on urban and rural areas". Final Report, Michigan University, Ann Arbor, Dept. of Civil Engineering; 108pp. (EPA/670/2-75-846).

Key words: mathematical models; hydrographs; peak discharge; analytical techniques; rainfall-runoff relationships.

A procedure was developed for estimating the frequency of storm runoff of various magnitudes from rainfall and/or snowmelt on small drainage basins in various stages of urbanisation. The study was based primarily on the analysis of storm runoff events on real basins varying in size from 0.02 to 734 square miles. The method is based on applying unit hydrographs to precipitations of various frequencies after deducting infiltration and retention. A concurrent study with an analytical drainage basin model provided additional understanding of the effects of some parameters. The unit hydrograph-infiltration capacity concept was selected as the most accurate practical method for predicting storm runoff. It was found that the form of the unit hydrograph could be related to drainage basin size and degree of urbanisation as measured by population density. Other characteristics of the drainage basin are much less important.

BREHMER, M.L. 1972: "Agricultural and urban pollution". In, Remote sensing of the Chesapeake Bay, U.S. NASA, 73-76. U.S. Govt. Printing Office, Washington, D.C. Contributions of the Virginia Institute of Marine Science, 1971-72, No.468.

Key words: agricultural pollution; water pollution sources; erosion; organic compounds; nitrogen compounds; phosphorus compounds.

The adverse effects of pollution caused by agricultural and urban development around Chesapeake Bay are discussed, particularly silting of tributary rivers by eroded material and their enrichment by organic substances, nitrogen, and phosphorus.

BREHMER, M.L. et al. 1968: "The biology and chemistry of a warm water stream". Institute of Water Research, Michigan State University, East Lansing, Technical Report No. MSU-IWR-TR-68-003, Red Cedar River Series; 50pp.

Key words: water pollution sources; urban drainage; sewage disposal; urbanisation; erosion; ammonia; benthic fauna; dissolved oxygen; nutrients; industrial wastes.

The Red Cedar River, once a productive small-mouth bass stream, is located within the recreation area of metropolitan Lansing. The aesthetic and recreational value of this stream has been reduced as the result of urbanisation and increased agricultural use, with the resulting fast runoff, erosion, and siltation, and by the introduction of domestic and industrial pollution. This study is concerned with the effects of nutrient inputs on the ecology of the stream and presents data vital to the reclamation processes. Specific emphasis is given to the ammonia nitrogen content and the dissolved oxygen content of the water, and the families of benthic forms present in the stream. Early observations seem to indicate that stream fertilisation resulting from nutrient input released by the decomposition and mineralisation of the organic material in the domestic sewage increased the complexity of the standing crop of the area.

BRIGHAM, C. 1972: "The qualitative and quantitative analysis of urban runoff for the area of the Memorial School Red Maple swamp in Springfield, Massachusetts". Massachusetts Water Resources Research Centre Research Report; 92pp.

Key words: phosphorus compounds; urban hydrology; urban runoff; water pollution sources; chemical analysis; nitrates; data collection; bacteria; dissolved oxygen; turbidity; miscellaneous chemicals; nitrogen compounds; chlorides.

A qualitative analysis of storm water for a thickly populated residential area within Springfield, Massachusetts is presented, along with other related data. After determining all the storm drains entering into the Red Maple Swamp a series of chemical, biological, and physical tests were performed on the incoming storm sewer flow. The chemical and physical tests performed were for temperature, pH, dissolved oxygen, carbon dioxide, specific conductance, turbidity, colour, silver, copper, tannin and lignin, iron, ammo-

nia, nitrogen, nitrite nitrogen, nitrate nitrogen, orthophosphate, metaphosphate, total hardness, chloride, sulphate, and discharge. The biological tests performed were the standard plate count and the coliform test. Chloride in storm water is mainly derived from the salting of roads. Chloride concentrations well after salting were recorded as high as 1500 ppm. Approximately 30,072 pounds per year of chloride are supplied to the Red Maple Swamp by its drainage basin. The total inorganic nitrogen content of the Red Maple Swamp influent was 3.64 ppm. Water with the concentration of phosphorus characteristic of that entering the Red Maple Swamp (1.02 ppm) is capable of initiating eutrophication.

BROECKER, W.S.B. et al. 1971: "Road salt as an urban tracer". In, Proceedings of the street salting - urban water quality workshop, (ed. R.H. Hawkins), Syracuse University, Syracuse, N.Y.; p24-38.

Key words: water pollution sources; chlorides.

Road salting affects the quality of waters in the suburban area northwest of New York City. The area studied is the drainage basin of the Hackensack River. The total amount of salt added to the roads of Bergen County, N.J., in the winter of 1969-70 was 150,000 tons. If the road salt from the 1969-70 winter were uniformly dissolved in the runoff water for one year, the average chloride ion concentration would be 40 ppm. Adding the background level of about 10 ppm gives 50 ppm for the expected mean annual chloride concentration. The chloride ion content of Oradell Reservoir, through which much of the drainage from Rockland and northern Bergen County passes, was 40 ppm.

BROEZE, H.G. and COUWENHOVEN, T. 1977: "Ground water withdrawal and water control in the Netherlands. How to increase the possibilities of exploiting ground water by adequate water management". In, Symposium on urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p179-187.

Key words: ground water resources; watershed management; surface runoff.

In the Netherlands, the growth in the population in combination with an increasing degree of industrialisation over the past few decades have led to a rapid increase in the extraction of ground water for domestic and industrial supplies. As a result of the hydrogeological conditions, most of the ground water extractions cause a draw-down of the ground water table. This can influence agricultural production and the natural environment, because in most of the Netherlands the ground water table is found within 1 or 2 m of the soil surface, so that the capillary fringe reaches the root zone. Also, the discharge of brooks and rivers can be reduced by ground water extraction.

These effects can only be partly compensated by the supply and conservation of surface water. As a consequence the issue of licenses for ground water extraction is at present limited. The use of surface water for the production of drinking water is still a very expensive alternative, compared with the use of ground water. Therefore the relationship between ground water and surface water has been studied in order to find ways for the optimal management of the hydrological system. In agricultural and municipal areas measures are taken to prevent damage caused by excess water in rainy periods. It is a plausible theory that these measures can partly remain in obedience when the ground water level is lowered by ground water extraction. Further, the existing system of ditches in agricultural areas can be used for agricultural water supply as well as to replenish the ground water. In both cases a synthesis between the objectives of the interested parties is pursued on behalf of optimal water management.

BROMSSEN, U.VON. 1977: "Urban hydrology: examples of the reduction and replenishment of ground water formations in urban areas". *Striae*, Vol.4; p101-103.

Key words: ground water resources; storm runoff.

Deals with examples of ground water flow due to drainage in soils and rock and the possibilities of restoring ground water recharge in urban areas by storing storm water in underground voids.

BROWN, J.W. et al. 1974: "Models and methods applicable to Corps of Engineers urban studies". U.S. Army Engineer Waterways Experiment Station Misc. Paper H-74-8, Vicksburg, Mississippi; 420pp. (NTIS AD-786 516).

Key words: model studies; mathematical models; computer models; watershed management; urban drainage; water pollution control; flood routing; solid wastes; air pollution effects.

This report is basically a source book for individuals who are actually concerned with the problem of constructing alternative plans for developing urban areas. It reviews the methods and computer models that are currently available to the planner or engineer for developing water and related land resources. These reviews discuss the availability and usefulness of several models; give a brief technical description of each model, including the input data required; and indicate the amount and type of computer hardware needed to use each model. The report is directed mainly toward water related problems. Thus, most of the methods discussed deal with urban drainage, waste water management, flood routing, reservoir operation, water supply, flood zoning, and the social and economic aspects associated with these areas. Recreation, air pollution, and

solid waste disposal are discussed only briefly. Other important urban problems such as transportation, energy, cultural improvement, and noise abatement were not considered in this study.

BROWN, R.J. and LEHMANN, E.J. 1975: "Urban storm sewer and water runoff. Vol.1, 1964-1973 (a bibliography with abstracts). Report for 1964-1973". U.S. NTIS, Springfield, Va.; 182pp.

Key words: urban runoff; bibliographies; abstracts; combined sewers; model studies; storm runoff; flood control; urban hydrology.

Urban storm runoff problems and abatement, combined and storm sewers, and urban hydrology and its modeling are covered in the bibliography.

BROWNING, J.A. 1972: "Man's effect on the quality of our water". In depth report, West Palm Beach, Vol.1(2); 01-8.

Key words: water pollution; urban runoff; rainfall-runoff relationships; storm runoff; water pollution control; bacteria; waste water disposal; agricultural pollution.

Background material is presented on pollution as it occurs through agricultural, urban, and storm runoff. South Florida's forecast is encouraging in that the Florida Department of Pollution Control has successfully required non-polluting waste disposal. One remaining problem is that urban runoff bacteria levels in street gutters are extremely high. The optimum solution will be to eliminate much of the trash and debris which finds their way into the waterbodies during rainstorms. Agricultural pollution runoff can be controlled through the use of private, small reservoirs. Tables are given which show characteristics of storm water and pollutant levels according to land use type.

BROWNLEE, R.C. et al. 1970: "Variations of urban runoff with duration and intensity of storms". Texas Technical University, Lubbock, Water Resources Centre, Interim Report, WRC-70-3 W71-01546, OWRR-B-064-TEX(1); 77pp.

Key words: urban runoff; sewage treatment; storm runoff; combined sewers; dissolved solids; nitrates; biochemical oxygen demand.

A great many cities transport raw domestic sewage to treatment facilities in the same sewer system used to carry storm runoff from their streets. The storm runoff carried by these combined sewers, during even moderate rainstorms, can greatly exceed the capacity of municipal sewage treatment plants. This study was undertaken to determine the concentrations of pollutants carried by the storm runoff from a small residential watershed, and to consider the variations of pollutant concentrations with the duration of runoff.

Surface runoff from rainstorms on the small residential watershed contains pollutant concentrations which vary in average and extreme values from storm to storm. Average total dissolved solids and nitrates as well as the average pH value of storm runoff are within the USPHS standards for drinking water, while solids concentrations and total alkalinity concentrations are in the range of those found in raw sewage influent. Average BOD concentration of the samples tested is approximately the same as that of secondary sewage treatment effluent.

BRUNNER, P.G. 1973: "Pollution of the runoff in separate sewer systems, and measures for the reduction of rainwater and runoff-generated pollution of water bodies". Gas-Wasser-Abw, Vol.53(4); p102-113 (In German).

Key words: storm runoff; pollution abatement; biochemical oxygen demand; chemical oxygen demand; nitrogen compounds; dissolved solids; bacteria; air pollution effects; phosphorus compounds.

Storm runoff pollution measurement in sewer systems conducted in Cincinnati, Ohio; Tulsa, Oklahoma; Ann Arbor, Michigan; and in Oxley, England as well as measures for pollution abatement of water bodies have been investigated. The filtrable matter content and dissolved solids content of the rainfall runoff in Tulsa ranged from 84 to 2052 mg/litre and from 89 to 400 mg/litre, respectively. The BOD5 and COD values of the runoff in the four cities were in the ranges of 8-28 mg/litre and 42-138 mg/litre. The soluble orthophosphate content and the organic nitrogen content average 0.54-3.49 mg/litre and 0.36-2.10 mg/litre. This runoff pollutant load can be effectively reduced by intensified street clean-up, especially in March and April, and by global air pollution abatement. A Cincinnati experiment with storm water retention for 10 to 20 minutes in a retention basin gave results concerning (mediocre) pollutional load abatement, (no) effect on bacteria count, and (fairly high) investment and operating costs. The rates of reduction in the BOD5 value, the organic nitrogen and total phosphate contents achieved after retention of 20 minutes in the four systems were 15, 33, 25 and 8 percent.

BRYAN, E.H. 1969: "Urban hydrology, waste water treatment and stream pollution". Proc. 18th Southern Water Resources and Pollution Control Conference, North Carolina State University, Durham.

Key words: water pollution control; urban hydrology; water pollution; waste water treatment.

BRYAN, E.H. 1970: "Quality of storm water drainage from urban land areas in North Carolina". Water Resources Res. Inst., Rep. No.37, Dept. of Civil Engineering, Duke University, Durham,

N.C; 68pp.

Key words: urban drainage; landuse change; data collection; mathematical models.

The objective of this project was to determine the quality characteristics of storm water draining from an urban land drainage basin in North Carolina as influenced by the nature of land use on the basin. A number of areas in North Carolina and elsewhere are confronted with the need to require high degrees of water quality management. Urbanisation of a region has an effect on the quality of its storm water. The purpose of this study was to determine quantitative relationships between different land use patterns and consequent differences in the water quality. The drainage basin selected has an area of 1.67 square miles and is in the upper portion of the Cape River basin of North Carolina. Residential, commercial and industrial activities on the selected basin are representative of the urban land use pattern in North Carolina cities and towns. During the first year a gauging and sampling station was installed on the outlet of the major basin. Sampling and analyses were initiated to characterise the quality of water draining from the basin and its two major constituent basins. In the second year, the major basin was divided into a number of subsidiary basins to characterise the quality of water draining from each sub-basin and attempt correlation of its qualities with land use.

BRYAN, E.H. 1971: "Urban storm water quality and its impact on the receiving system". Proc. 20th Southern Water Resources and Pollution Control Conference, University of North Carolina, Durham; 19pp.

Key words: storm runoff; pollution abatement; analytical techniques; biochemical oxygen demand; chemical oxygen demand; solid wastes; erosion; lead.

A study undertaken to characterise storm water from a typical urban drainage basin in Durham, N.C., indicated that BOD discharged to the receiving stream by urban storm water was about equal to the effluent from the secondary sewage treatment plant, which, in this case, was 50 percent above the BOD normally attributable to domestic sewage. The major long-term pollution impact was a large fixed solids residue and long-term COD. Efforts to improve excessive erosion of construction sites should improve the problem of solids which projected to an annual loss of volume displacement capability of 100 cu ft of impoundment capacity per tributary acre. Contribution of pollutants by urban storm water is intermittent, made in slugs during and immediately following storms. Large amounts of lead in surface wash were attributed to leaded gasoline in internal combustion engines. Correlation coefficient between rainfall and runoff was 0.89. The drainage basin, an area of 1.67 sq mls, represented a good cross section of land use in the state; typical of

North Carolina, the storm water drainage system was largely made up of exposed open channels. Findings are compared with similar studies made in Tulsa, Oklahoma.

BRYAN, E.H. 1972: "Quality of storm water drainage from urban land". Water Resources Bulletin, Vol.8(3); p578-588.

Key words: storm runoff; urban runoff; biochemical oxygen demand; organic compounds; chemical oxygen demand; solid wastes; chlorides; phosphorus compounds; lead; pesticides.

Urban storm water from a 1,067 acre drainage basin in Durham, N.C. was characterized to determine yield of pollutants. Population density averaged 9 persons per acre (ranging from less than 3 to 16). Annual BOD contribution attributable to surface wash during storms was determined to be approximately equal to the contribution by its secondary waste water treatment plant effluent. Total organic matter (COD) was estimated to exceed the amount in raw sanitary sewage from a residentially developed area of the same size. Mean basin yields (lb/acre/day) were: BOD-0.23, COD-2.85, total solids-43.6, volatile total solids-4.8, total phosphate-0.01 and chloride-0.20 (as NaCl). The yield of lead presumed to originate from internal combustion engines operating on and near the basin was determined to be 0.0006 lb/acre/day. The concentration of total pesticides (Dieldrin; o,p'DDE; o,p-DDT; p,p'DDD and p,p'DDT) weighted for flow significance was estimated to be 1.2 parts per billion. The major long term pollutional impact on a projected downstream reservoir was considered to be the fixed solids residue and long term oxygen demand (COD). Intermittent release of other pollutants in slugs during runoff periods may be a significant factor in causing undesirable effects in streams draining urban areas.

BRYAN, E.H. 1974: "Concentration of lead in urban storm water". J. Water Pollution Control Federation, Vol.46(10); p2419-2421.

Key words: lead; heavy metals; biochemical oxygen demand; chemical oxygen demand; solid wastes; phosphorus compounds; chlorides; pesticides.

Results of the Durham research provided insights into the quality of storm water drainage from urban land and confirmed prior work, which, in turn, has also been supported by recent observations. Urban storm water from the 1,067 acre (432 ha) drainage basin in Durham, N.C., which has population densities ranging from less than 3 to 16 persons/acre (averaging 9), contributed pollutants in the following amounts: BOD = 0.23 lb/day/acre (2.5 kg/day/ha), COD = 2.85 lb/day/acre (32 kg/day/ha). Total solids = 43.6 lb/day/acre (488 kg/day/ha), volatile total solids = 4.8 lb/day/acre (53.7 kg/day/ha), total

phosphate = 0.01 lb/day/acre (0.11 kg/day/ha), and chloride (as NaCl) = 0.20 lb/day/acre (2.24 kg/day/ha). The yield of lead presumed to originate from internal combustion engines operating on and near the basin was determined to be 0.0006 lb/day/acre (0.00672 kg/day/ha). The concentration of total pesticides (Dieldrin; p,p'DDE; o,p-DDT; p,p'DDD; and p,p'DDT) weighted for flow significance was estimated to be 1.2 ppb.

BUBECK, R.C. et al. 1971: "Runoff of deicing salt: effect on Irondequoit Bay, Rochester, New York". Science, Vol.172; p1128-1132.

Key words: water pollution; chlorides; surface runoff.

Salt used for deicing the streets near Rochester, New York, has increased the chloride concentration in Irondequoit Bay at least fivefold during the past two decades. During the winter of 1969-70 the quantity and salinity of the dense runoff that accumulated on the bottom of the bay was sufficient to prevent complete vertical mixing of the bay during the spring. Comparison with 1939 conditions indicates that the period of summer stratification has been prolonged a month by the density gradient imposed by the salt runoff.

BUCKINGHAM, P.L. et al. 1970: "Combined sewer overflow abatement alternatives, Washington, D.C.". Water Pollution Control Series, Roy F. Weston, Inc., West Chester, Pa; 240pp.

Key words: combined sewers; surface runoff; water pollution; storm runoff; water pollution control; overflows.

Objectives of the project were: define the characteristics of combined sewer overflow, investigate the feasibility of high rate filtration for treatment of combined sewer overflow, and develop and evaluate alternative methods of solution. Investigative activities included: review of pertinent reports and technical literature; field monitoring of combined sewer overflows and separated storm water discharges at three sites; laboratory studies of ultrahigh-rate filtration of combined sewer overflow; hydrological analysis; and evaluation of feasible alternatives (based on conceptual design, preliminary cost estimates, and other factors). Reservoir storage, treatment at overflow points, conveyance tunnels, and mined storage and sewer separation were the approaches considered sufficiently promising for detailed evaluation. Tunnels and mined storage with treatment at the Blue Plains plant and at Kingman Lake after subsidence of the storm is recommended. Estimated capital costs (based on the 15 year storm) are \$318,000,000 with annual operation and maintenance costs of \$3,500,000. This approach also was preferable to the others on the basis of systematic evaluation of reliability, flexibility, public convenience and other non-quantifiable factors.

BUCKINGHAM, R.A. and BETSON, R.P. 1970: "Faecal coliform concentrations in storm water". Paper presented at the American Geophysical Union, 51st Annual Meeting.

Key words: storm runoff; faecal coliforms; water pollution sources; bacteria.

Recent limited storm water bacteriological water quality sampling in the Tennessee Valley indicates that high faecal coliform loads are common in storm water runoff. In clean residential areas sustained high faecal coliform loads were observed during storm water runoff. The source of these loads was associated with overland flow, and it appears that staggered contributing times account for the sustained high loads. High faecal coliform counts were also measured in storm waters originating from agricultural areas and forested watersheds. The consistency with which faecal coliform counts in excess of accepted standards are commonly found further substantiates the need for an appraisal of this test as an indicator of pathogenic organisms. The data also point to the importance of recognising the streamflow regime in the analysis of water quality sampling data since observations taken during storm periods are usually high in bacteriological loads.

BULLARD, W.E. 1966: "Effects of land use on water resources". J. Water Pollution Control Federation, Vol.38(4); p645-659.

Key words: erosion; pesticides; toxicity; nutrients; solid wastes; urban runoff.

Land areas included in drainage basins or watersheds constitute a source of water supplies. Land condition among other factors determines the quality of water produced. Erosion and sedimentation, toxins and nutrients, and wastes resulting from land use are factors involved in water quality and pollution. Erosion causes turbidity and sedimentation, lowers water quality, and damages aquatic life habitats. Fertilisers, pesticides, and other toxins and nutrients contribute to pollution. Agriculture, timber, mining, urban runoff, and recreation also are pollution contributors resulting from land use. All of these sources can be controlled to beneficial degrees by more effective landuse practices.

BURGESS and NIPLE LTD. 1969: "Stream pollution and abatement from combined sewer overflows, Bucyrus, Ohio". Burgess and Niple Limited, Columbus, Ohio; 201pp. (NTIS PB-195 162; EPA-11024FKN 11/69.)

Key words: water pollution sources; water pollution control; storm runoff; combined sewers; overflows; pollution abatement; bacteria; sewage treatment; biochemical oxygen demand.

The report contains the results of a detailed engineering investigation and

comprehensive technical study to evaluate the pollutional effects from combined sewer overflows on the Sandusky River at Bucyrus, Ohio, and to evaluate the benefits, economics and feasibility of alternate plans for pollution abatement from the combined sewer overflows. The city of Bucyrus is located near the upper end of the Sandusky River basin which is tributary to Lake Erie. Bucyrus has an incorporated area of about 2,340 acres, a population of 13,000, and a combined sewer system with an average dry weather waste water flow of 2.2 million gallons per day. A year long detailed sampling and laboratory analysis program was conducted on the combined sewer overflows in which the overflows were measured and sampled at three locations comprising 64 percent of the city's sewered area and the river flow was measured and sampled above and below Bucyrus.

BURM, R.J. 1967: "The bacteriological effect of combined sewer overflows on the Detroit River". J. Water Pollution Control Federation, Vol.39(3); p410-424.

Key words: faecal coliforms; combined sewers; storm runoff; water pollution sources; bacteria; overflows.

A study was made of water quality at various points in the Detroit River before and after rainfalls causing overflows of combined sewers. Effects of these overflows on water quality persist for several days after discharge has ceased. The duration of effects increases with increase in the intensity of the storm. Bacterial densities increased as much as a thousandfold after moderate rains, at sampling points miles downstream from combined sewer outfalls. Further downstream, increases in bacterial densities were less but affect more of the stream width. Faecal coliforms and faecal streptococci follow patterns similar to those of total coliforms.

BURM, R.J. et al. 1968: "Chemical and physical comparison of combined and separate sewer discharge". J. Water Pollution Control Federation, Vol.40; p112.

Key words: biochemical oxygen demand; suspended solids; combined sewers; nitrates; phosphorus compounds; nitrogen compounds; phenols.

A comparative study of separate storm-sewer discharges at Ann Arbor, Mich., with combined discharges in Detroit showed that the BOD in the separate discharges was about 20 percent of that in the combined discharges. Concentrations lessened as discharges progressed. Values for total and volatile suspended solids and for total and volatile settleable solids were higher in the separate system because of greater erosion in hillier terrain. Phosphates were higher in combined flows, but nitrates were lower. Higher concentrations also were found in the combined system for phenols, NH₃-N, and organic N. In the separate system, BOD

was fairly constant throughout the year, but in the combined system summer BOD's were higher. Both systems showed lower phosphate concentrations in autumn.

BURM, R.J. and VAUGHAN, R.D. 1966: "Bacteriological comparisons between combined and separate sewer discharges in Southeastern Michigan". J. Water Pollution Control Federation, Vol.38; p400.

Key words: bacteria; faecal coliforms; combined sewers.

Comparison of discharges from combined and separate sewer systems in two Michigan cities showed that total coliform concentrations in runoff carried by separate storm systems are about one tenth of those in combined sewers. Faecal coliform densities in combined systems are about 29 percent of total coliform densities, but are usually a lesser percentage in separate systems. Faecal streptococcus densities in combined systems are only about twice those in separate systems. Ratios of faecal coliform to faecal streptococci for the systems indicate that faecal coliform in separate sewer discharges are primarily of non-human origin, and those in combined sewer discharges are of human origin.

BURTON, T.M. and TURNER, R.R. 1975: "The effects of land use on storm water quality and nutrient and suspended solids exports from three North Florida watersheds". Proc. Storm Water Management Workshop, Orlando, Florida, Florida Technological University; p143.

Key words: suspended solids; nutrients; landuse change; watershed management; water pollution; storm runoff.

CAHILL, T.H. et al. 1974: "Evaluation of phosphorus dynamics in a watershed". J. of the Environmental Engineering Divn., Proc. ASCE, Vol.100(EE2); p439-458.

Key words: phosphorus compounds; point sources (pollution); nonpoint pollution sources.

Phosphorus dynamics in a small river system have been measured to determine phosphorus transport mechanisms and correlation with hydrodynamic phenomena. Variation of chemical forms with flow conditions are related to point and diffuse sources and general equations derived. Mass balances are developed and diurnal changes are described.

CAREY, G.H. et al. 1972: "Urbanisation, water pollution and public policy". Centre for Urban Policy Research, Rutgers University, The State University of New Jersey, New Brunswick, New Jersey; 214pp.

Key words: analytical techniques; water pollution; ground water resources; model studies; waste water treatment; hydrologic data; dissolved oxygen; mathematical models.

This monograph concludes a two-part study of the water resources of the New York-New Jersey Metropolitan Region, the first of which was published under the title, 'Benefits from integrated water management in urban areas - the case of the New York Metropolitan Region' by the Clearinghouse, U.S. Department of Commerce, Document PB-184 019, April, 1969. In the present study the authors present a picture of the state of the river, estuarial and ground waters in the New York-New Jersey Metropolitan Region, gleaned from an exhaustive analysis of existing data, and devise a model by which the impact of certain policy alternatives upon river systems with respect to waste treatment strategy may be gauged. Chapter I describes the regional data bank which has been amassed in great detail. Chapters II, III, and IV present detailed technical analyses of riverine, estuarial and ground water data relating to water quality and the impact of pollutants. Chapter V reviews the substance of the three technical chapters. Chapter VI addresses the problem of formulating the effect of urban development upon the pollution load introduced into rivers. It is concerned with devising methods suitable for computer application to make such estimates. Chapter VII describes the mathematical model by which the impact of the effluents simulated as a result of the processes devised in Chapter VI are translated into variations in the dissolved oxygen quality of the stream. Chapter VIII presents the findings arising from the application of the model.

CARBERRY, M.E. 1976: "Remote sensing applications to water quality assessment. An annotated bibliography of selected literature, 1970 to 1975". Council of

Planning Librarians, Exchange Bibliography, No.1121, 36pp.

Key words: bibliographies; abstracts; remote sensing; water pollution.

During the late 1960s and continuing to the present, there has been a substantial increase in remote sensing technology. LANDSAT, Skylab, numerous high flight missions, and refinement of both active and passive sensor systems are illustrated. Water quality assessment has been enhanced through many remote sensing technology advancements; this bibliography is an overview of selected applications as found in the literature of the 1970-1975 period.

CARISSON, L. and FALK, J. 1977: "Urban hydrology in Sweden - an inventory of the problems and their costs". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p478-487.

Key words: urban hydrology; urbanisation; model studies; overflows.

A model of the water budget for urban areas has been constructed as a basis for dividing the urban hydrological cycle into three storage and three transport parts. Within each part problems and costs of water management are described. The total cost for management of water supply and sewerage in Sweden is estimated to be about 5.5 million Swedish crowns per day. The largest problems from the environmental point of view are considered to be the management of storm water and overflows. From the economic point of view, land subsidence due to lowering of the piezometric head is a great problem. Management of the storm water must be performed on the assumption that it is partly a resource which can be handled and used within the urban area. This has given rise to extensive research regarding quantity and quality of storm water together with field experiments on artificial infiltration of storm water. In order to prevent damage to buildings, roads, conduit system, etc, due to land subsidence, instructions for underground planning and building are in preparation.

CARRANZA, C. and BEMBEN, S.M. 1973: "The origin, effects and control of turbidity in an urban recreational lake". Massachusetts University, Amherst, Water Resources Research Centre Report No. Completion-PY-73-5; 118pp.

Key words: lakes; turbidity; water pollution; suspended solids; storm runoff; water pollution control.

'State-of-the-art' is described of the water quality parameter known as turbidity, particularly with regard to the effects of urbanisation on a recreational water body. Field and laboratory data are presented which support a new broader definition for the parameter. For the general case, it is shown that turbidity is a composite parameter

which is well related to apparent colour, suspended solids concentrations, dissolved ion concentrations and the optical properties of suspended solids. The traditional relationships to BOD, DO, CO₂, total hardness, alkalinity, and pH are not challenged but rather are augmented. For the specific field case considered, it is shown that the degree of turbidity is related to the character and degree of urbanisation, the natural geologic setting and the weather conditions.

CARRE, Y. 1975: "Pollution of recipients by storm runoff in mixed sewer systems: storm retention basins as a remedy". Techniques et sciences Municipales - L'Eau, Vol.70(7); p313-317.

Key words: storm runoff; waste water treatment; water pollution sources; biochemical oxygen demand; water pollution control; combined sewers.

A method for the control of the pollution of recipients by storm runoff in combined sewer systems in Baden-Wuerttemberg, Germany, is discussed. The BOD content and the pollutant load were measured. It was determined that the storm runoff, especially that discharged during the initial phase of rain, is often as polluted as the effluents that occur during dry weather. Therefore, retention of the initial runoff in retention basins for subsequent biological in-plant treatment is necessary. Storm runoff retention basins have been designed to retain 90 percent of the annual BOD₅ content in the Baden-Wuerttemberg area.

CARTER, R.W. 1961: "Magnitude and frequency of floods in suburban areas". U.S. Geol. Survey research prof. paper No.424-B; p9-11.

Key words: flood discharge; flood forecasting; storm runoff; analytical techniques.

The effect of suburban development on the magnitude of floods may be evaluated by examining the relations between floods of a given recurrence interval and the drainage area, lag time, and a length-slope parameter. They permit fairly accurate prediction, using existing records, of the effect of suburban development upon flood peaks.

CARTER, R.W. 1971: "Urban water data needs". In, Treatise on urban water systems, Colorado State University, Fort Collins; p480-498.

Key words: hydrologic data; hydrologic systems; urban drainage; waste dilution; data collection.

Urbanisation creates a special demand for hydrologic data. There is a need to redefine the water regime, both quality and quantity, in the new environment. Data are needed for the design of water supply facilities and the protection of raw water supplies; for planning and disposal of waste; for

determining the optimum pattern of land use; and for the design of storm drainage facilities. Data may also be needed for the real time management of water for use in homes and industries; to reduce flood flows; and to insure the maximum possible dilution of wastes. This paper reviews the hydrologic problems of urban areas and identifies deficiencies in present data programs. Data are classified according to the two primary uses - planning and design, and management.

CARTER, R.W. and THOMAS, D.M. 1968: "Flood frequency in metropolitan areas". In, Proc. 4th American Water Resources Association Conference, New York; p56-67.

Key words: flood forecasting; peak discharge; urbanisation; computer models; data collection.

When one considers that the estimated expenditures for needed urban drainage improvement exceeds 2 billion dollars per year through 1975, the need for data upon which to base adequate design is apparent. However, very little data is presently available on flood flow in urban areas. This area of hydrology is not yet receiving the attention it deserves. Several approaches that have been used by the Geological Survey in studies of the frequency of floods in urban areas are described and compared in this paper. These studies indicate that a large increase in peak flow occurs due to urbanisation and that this increase is primarily due to changes in the concentration time of precipitation excess. The design of future Survey projects will feature the use of a digital computer model of the rainfall-runoff process and an automated system for the collection of rainfall and runoff data.

CASTER, A.D. and STEIN, W.J. 1970: "Pollution from combined sewers: Cincinnati, Ohio". ASCE Meeting, Preprint No.1090; 39pp.

Key words: sewage treatment; combined sewers; hydrologic data; analytical techniques.

The sampling and gauging program was designed to provide basic data to estimate the magnitude of combined sewage pollution in and from the Mill Creek basin, and by extrapolation, the Cincinnati Service Area. The description of the Service Area, the background hydrological and water quality data, the field investigation program, the analysis of the data, and the conclusions are presented herein.

CECH, I. and ASSAF, K. 1976: "Quantitative assessment of changes in urban runoff". J. Irrigation and Drainage Divn., Proc. ASCE, Vol.102(IR1); p119-125.

Key words: urban runoff; urbanisation; storm runoff; computer models.

The detection and quantitative assessment of the magnitude of man-induced changes in flood regimes in part of the Texas Gulf Coast were made using the method of trend surface analysis of distribution of storm runoff. The procedure incorporated the elements of frequency analysis and two- and three-dimensional synographic computer mapping. The natural geographic tendency in runoff distribution typical for the study area was compared with the runoff pattern induced by urbanisation. The range of differences between urban and non-urban runoff found in this study was proposed as a guide for development planning in the coastal territories that are now primarily rural.

CHAN, M.L. 1974: "Optimal real-time control of urban storm water drainage". Tech. Report No.87, studies in the analysis of metropolitan water resource systems, Vol.X. Cornell University, Water Resources and Marine Sciences Centre, Ithaca, N.Y.; 170pp. (NTIS PB-236 858).

Key words: urban runoff; mathematical models; urban drainage; flood routing.

An operational model using optimal control theory is developed for routing urban storm water drainage comprehensively in a combined sewer network. The storm water flow dynamics are modeled as a system of linear stochastic difference equations. Together with a quadratic criterion function, the optimisation model is posed as a stochastic output regulator problem. The resulting control logic is divided into two parts: the estimator and the controller. The incorporation of this control logic into a central computer, coupled with a monitoring and communication network, forms the core of a real-time computer-based automatic routing control system. This control system can be used to improve the effectiveness of storm water runoff routing.

CHANDLER, T.J. 1970: "Urban climate". Selected bibliography. WMO-No.276, T.P.155; 383pp.

Key words: bibliographies; weather modification.

A final version of a selected bibliography on urban climate, covering more than 2000 references.

CHANGNON, S.A. 1963: "A climatological evaluation of precipitation patterns over an urban area". Robert A. Taft Sanitary Engineering Centre, Tech. Report A62-5; p37-67.

Key words: weather modification; network design; instrumentation.

Urban rainfall distribution was studied in Champaign-Urbana, Ill., for a period of 13 years. The annual precipitation pattern was compared with that of a

nearby rural network to help evaluate the apparent urban affected precipitation pattern obtained over the urban area. The precipitation increase in Urbana could result either from urban effects or from natural variations of precipitation. Raingauge exposures were a problem in the evaluation of the effects. To instrument an urban area for this purpose is difficult and expensive.

CHANGNON, S.A. 1969: "Increased precipitation from urban industrial effects". ASCE Annual and Environmental Engineering Meeting, Chicago. ASCE Conference Preprint 1015, New York, NY.

Key words: weather modification.

Urban-produced precipitation increases of four midwest cities and two large eastern cities range from 5 to 16 percent in annual precipitation and rain days, with 7 to 22 percent increases in summer thunderstorm days. Within the past 25 years, in an area downwind from Chicago, increases in precipitation were 31 to 246 percent. In Chicago, St. Louis, and Champaign-Urbana, district maxima were centred in or east of the cities. This supports the theory of urban-produced increases in the prevailing eastward moving precipitation systems. Similar increases in precipitation were noted in Tulsa, Washington, D.C., New York City, and much greater increases in La Porte, Ind.

CHANGNON, S.A. 1969: "Recent studies of urban effect on precipitation in the United States". American Met. Soc. Bulletin, Vol.50(6); p411-421.

Key words: weather modification; environmental effects; air pollution effects.

Urban produced increases in precipitation range from 5 to 16 percent, and increases in number of thunderstorm days range from 7 to 20 percent. Even greater increases in precipitation have been observed downwind from major steel mill complexes. These changes have been credited to urban-induced nuclei concentrations and urban thermal effects. The results of these studies may indicate the effectiveness of ground-based seeding, the possibility of successful increases in all seasons, the likelihood of thunderstorm and hailstone increases with rainfall increases, and the need for dense raingauge networks to adequately determine the area and amount of increase.

CHANGNON, S.A. 1973: "Urban-industrial effects on clouds and precipitation". In, Proceedings from a workshop on inadvertent weather modification, Utah State University, Logan; p111-139.

Key words: urbanisation; weather modification; air pollution effects; turbidity; urban runoff; streamflow.

Man through modifications of the biosphere has been affecting the atmosphere

on local and regional scales for many years. These alterations have been produced by urban-industrial centres, non-urban industrial centres, landuse changes in rural areas (deforestation, crop changes, drainage etc.) and marine areas. A major means whereby man has affected weather has been through his urban environment. The increase in urbanisation that began 200 years ago with the industrial revolution has led to relatively significant local and mesoscale changes in the weather in and near urban locales. Since urban areas first proliferated in Europe, considerable scientific attention has been directed to this problem in the European area during the last 100 years. Now that major urban-industrial complexes are prevalent in many countries, worldwide attention to this problem has grown rapidly in the last 20 years, and the development of megalopolises in the United States during the past 30 years has brought with it increasing public and scientific awareness of the degree and the seriousness of urban effects on mesoscale weather and climate.

CHANGNON, S.A. 1973: "Study of urban effects on precipitation and severe weather at St. Louis. Annual report March 1970 - February 1973". Illinois State Water Survey, Urbana; 54pp.

Key words: weather modification.

The general goal of the Water Survey program involving METROMEX (Metropolitan Meteorological Experiment) consists of the delineation of any anomalies in the precipitation and severe weather patterns and frequencies in St. Louis and environs, the quantification of the causes for any such anomalies, investigations of the relevance of these findings to the local area and to other urban-agriculture areas of Illinois, and the transmission of these findings to potential users in the scientific community and to the public of Illinois.

CHANGNON, S.A. 1973: "Inadvertent weather and precipitation modification by urbanisation". J. Irrigation and Drainage Division, Proc. ASCE, Vol.99(IR1); p21-41.

Key words: urbanisation; weather modification; urban hydrology; air pollution effects.

Urban-industrial complexes produce measurable modification of all weather conditions. Particularly significant are increases in the precipitation conditions of interest to hydrologists and urban planners. In and immediately downwind of major urban areas, the annual precipitation may be increased from 5-30 percent, the annual thunderstorm frequency is increased 15-30 percent, the heavy daily rainstorm frequencies are increased by 20-40 percent. Increases in local runoff may be from 15-20 percent. Local crop yields may be increased 2-10 percent by this rain modification.

CHEMERY, J.C. 1967: "Effect of urban development on quality of ground water". U.S. Geol. Survey prof. paper No.575-B; p212-216.

Key words: water pollution sources; detergents; ground water resources; aquifers; chemical analysis.

In the Raleigh area samples taken from wells 25 to 200 feet deep have not yielded appreciable amounts of ABS detergent (alkylbenzenesulphonate) - a major component of hard synthetic detergents. The potential movement of ABS detergents in water with time was checked by analyses of water from selected wells in 1962 and again in 1965. Determinations were also made on related constituents that might be useful precursors of pollution. The area is underlain chiefly by granites, schists, and gneisses, which are blanketed in most places by residual soils and a cover of vegetation. Soil in which septic tanks lie is effective in removing or retarding the movement of most contaminants in the ground. Shallow wells draw water from the soil mantle, but deep wells draw water directly from fractures in the rock.

CHEN, C.L. 1976: "Urban storm inlet runoff hydrograph study. Volume 1. Computer analysis of runoff from urban highway watersheds under time - and - space varying rainstorms". Utah Water Research Lab., Logan, Final Report, PRWG-106-1; 273pp.

Key words: urban runoff; model studies; mathematical models; computer models; storm runoff; analytical techniques; hydrographs.

The objective is to develop an accurate design method for computing inlet hydrographs of surface runoff, with average recurrence intervals of 10, 25, and 50 years, from typical urban highway by flood routing technique. The most comprehensive mathematical model based on the method of characteristics was developed for computing the inlet hydrograph. All flood routing methods were extensively reviewed and the most efficient and accurate technique was adopted for the formulation of a numerical (computer) model including all the rainfall-runoff processes on a highway watershed. Accuracy of the computer model was then examined by comparing the computed inlet hydrographs with field data obtained from both the Corps of Engineers airfield experiments and from typical highway cross-sections in the Salt Lake City area.

CHEN, C.L. 1976: "Urban storm inlet runoff hydrograph study. Volume 2. Laboratory studies of the resistance coefficient for sheet flows over natural turf surfaces". Utah Water Research Lab., Logan, Final Report, PRWG-106-2; 107pp.

Key words: surface runoff; mathematical models.

Resistance to sheet flows over natural turf surfaces is experimentally inves-

tigated. The formulation of a functional relationship between the resistance coefficient and controlling parameters for shallow flows over various turf surfaces is essential to the mathematical modeling of the surface runoff from urban highway sideslopes covered with different species of turf. An analysis of results obtained from laboratory experiments for laminar flow on Kentucky Blue grass and Bermuda grass reveals that a relationship exists between the Darcy-weisbach friction coefficient, Reynolds number, and bed slope.

CHEN, C.L. 1976: "Urban storm runoff inlet hydrograph study. Volume 4. Synthetic storms for design of urban highway drainage facilities". Utah Water Research Lab., Logan, Final Report, PRWG-106-4; 173pp.

Key words: model studies; mathematical models; urban drainage.

Knowledge of the time distribution of rainfall in heavy storms constitutes a basis for the design of an urban storm sewer system. A unified time-coordinate system and the rainfall intensity-duration-frequency relationships are used to develop the generalised synthetic (design) hyetograph equations for all types of storms. The hyetograph equations are further normalised for identifying the dimensionless parameters that play predominant roles in the formulation of a design storm pattern. The method of least squares and an optimisation technique are applied to the evaluation of the storm parameters through the use of the rainfall intensity-duration-frequency maps in the Weather Bureau Technical Paper No.40.

CHEN, C.L. 1976: "Urban storm runoff inlet hydrograph study. Volume 5. Soil - cover - moisture complex: analysis of parametric infiltration models for highway sideslopes". Utah Water Research Lab., Logan, Final Report, PRWG-106-5; 185pp.

Key words: model studies; mathematical models; storm runoff.

The boundary-value problem of one-dimensional infiltration resulting from rainfall is formulated and solved numerically on a digital computer. The numerical solutions of this idealised mathematical model are used as a basic testing tool in the subsequent analysis of various parametric infiltration models including the Green-Ampt, Kostiaikov, Philip, Horton, and Holtan equations. The time of ponding is shown to be the most important parameter in a parametric infiltration model and can be expressed in terms of other parameters in the model as well as the rainfall intensity. Validity of typical standard curves so developed were experimentally examined in the Utah Water Research Laboratory stormflow experiment facility.

CHEN, C.N. 1974: "Evaluation and control of soil erosion in urbanising watersheds". In, Proceedings national symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p161-173.

Key words: erosion; erosion control; suspended solids; erosion rates; data collection.

The natural processes of waterborne sedimentation generally consist of three basic elements - erosion, transportation and deposition of soil by the action of rainfall, runoff and gravity. The natural equilibrium of the sedimentation processes can be severely upset through man's uncontrolled land development activities. During urbanisation or suburbanisation involving construction activities, acceleration of the erosion process occurs as land surfaces are denuded and exposed to rainfall and runoff. As a result, transport and deposition of sediments in excessive quantities cause damages to downstream environments. In this paper, results of our current study for the County of Fairfax, Virginia, on setting erosion control criteria and on establishing the methodology for on-site erosion control were presented. The quantitative information on overland soil erosion and stream sediment concentration was established on the basis of field data collected from neighbouring watersheds in the metropolitan area of Washington, D.C., and Baltimore, Maryland. Although the study was performed with the aim of achieving overall erosion control in the Fairfax County area, the concept and the methodology developed in this study are believed to be universally applicable to other urbanising watersheds. The soil erosion rates from construction sites were determined to range from 50 to 200 t/a/yr while those from non-construction areas ranged between 1 and 3 t/a/yr.

CHEN, C.N. 1974: "Effect of land development on soil erosion and sediment concentration in an urbanising basin". In, Effects of man on the interface of the hydrological cycle with the physical environment, Paris. IAHS Publication, No.113; p150-157.

Key words: urbanisation; sediment yield; erosion; erosion rates; erosion control.

Based upon data collected from drainage basins in the metropolitan regions of Washington, D.C. and Baltimore, the soil erosion rates from construction sites and non-construction lands were determined. The gross soil erosion from an urbanising basin, with various percentages of area undergoing construction, was then evaluated on the basis of erosion rates from: (1) non-construction lands; (2) construction sites without erosion control; and (3) construction sites under different levels of on-site control practices.

With regard to sediment runoff in the stream, a functional relationship was established to correlate the sediment

concentrations with: (1) the soil erosion rates from construction sites; (2) the percentage of basin area undergoing construction; (3) the sediment delivery ratio of the basin; and (4) the direct runoff in the stream. The quantitative information established in this study provides a tool to assess the potential impact of both controlled and uncontrolled land development on soil erosion and sediment concentration in an urbanising basin. Furthermore, the information can be used as a guide in setting criteria for erosion control practices in terms of soil-loss from construction sites and/or sediment concentration in streams.

CHEN, C.W. and SHUBINSKI, R.P. 1971: "Computer simulation of urban storm water runoff". J. Hydraul. Divn., Proc. ASCE, Vol.97(HY2); p289-301.

Key words: computer models; storm runoff.

As part of an overall storm water management program, a model was developed to simulate the runoff phenomena of a drainage basin for any given rainfall pattern. The model represents the basin by an aggregate of idealised sub-catchments and gutters. The computer is instructed to make a step-by-step accounting of rainfall, infiltration, detention, overland flow and gutter flow in the calculation of the hydrograph. Three preliminary simulations are made to demonstrate the validity of the method.

CHERKAUER, D.S. 1975: "The hydrological response of small watersheds to suburban development: observations and modeling". In, Urbanisation and water quality control, Proc. American Water Resources Assoc., No.20; p110-119.

Key words: urbanisation; surface runoff; storm runoff; landuse change; rainfall-runoff relationships.

Urban land development practices create a land surface which has a profound effect on the hydrologic system. Innumerable reports have verified that both the quantity and quality of waters which runoff or infiltrate into urban lands are modified. This paper reports on a study to quantify the impact of urban fringe development by directly comparing the response of small watersheds in different stages of development to the same meteorological events. Small perennial streams which drain watersheds on Milwaukee, Wisconsin's urban fringe and which receive no significant input from point sources have been monitored since June, 1974. Three contiguous watersheds, which have similar topography and soils and are underlain by thick glacial drift atop dolomitic bedrock, cover a small enough area that they are subjected to similar meteorological conditions. All drain to the Milwaukee River and then to Lake Michigan. The major difference among them is land cover.

CHERKAUER, D.S. 1975: "Urbanisation impact on water quality during a flood in small watersheds". Water Resources Bulletin, Vol.11(5); p987-998.

Key words: urban runoff; urbanisation; waste dilution; water pollution sources; dissolved solids; suspended solids; chlorides.

The effect of urban land use on stream flow and water quality during a moderate rainfall was determined by monitoring two small watersheds of similar topography, one rural and one urbanised, and both draining into the Milwaukee River, Wis. Samples collected from both streams before, during and after an autumn rainfall of 2.2 cm were analysed, and the results are shown in tables and graphs. Peak flow in the urban stream was 250 times that in the rural stream, resulting in much greater urban dilution. Despite the lower ion concentrations, outflow from the urban basin carried much greater quantities of dissolved material, and suspended sediment was also greater. Sodium chloride, from road salting 7 months previously, was the dominant dissolved material in the urban water. A bibliography of 19 references is appended.

CHERKAUER, D.S. 1977: "Effects of urban lakes on surface runoff and water quality". Water Resources Bulletin, Vol.13(5); p1057-1067.

Key words: lakes; surface runoff; chlorides; salinity; peak discharge; hydrographs.

The effects of an artificial lake system upon the runoff hydrology of a small watershed have been determined by comparing the quantity and quality of runoff with that of an adjacent and similar watershed containing no lakes. Lake storage reduced peak discharge and slowed flood recession rate downstream. Water stored within the lakes is generally of different quality than downstream surface runoff. Salt stored in the lakes from winter deicing is released during periods of surface runoff throughout the rest of the year. During summer or fall runoff events, lake outflow dominates the salt load of the outlet stream, generating the double-peaked load hydrographs in which the second, or lake-induced, crest is many times larger than the peak which corresponds to maximum flow. On the other hand, the lakes cause a reduction of salt loads and concentration in winter runoff. The concentration and loads of ions which are not related to road salt are generally less affected by the lakes, although they are increased substantially in the fall.

CHIEN, J.S. 1974: "Testing of methods for determination of urban runoff". J. Hydraul. Divn., Proc. ASCE, Vol.100(HY7); p1081-1082.

Key words: urban hydrology; analytical techniques; mathematical models.

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Water & soil technical publication no. 15 (1979)

is challenged with regards to the estimation of infiltration parameters and sewer routing procedures. The following factors should be considered in addition to the efforts endorsed by Papadakis and Preul: the adoption of individual hyetographs for each event with its associated catchment as input instead of using the average Thiessen hyetograph; field verification of Manning's 'n' in the sensitivity study; consideration of possible backwater conditions from the downstream interceptor under high flow situations; ground water infiltration and other inflows as part of the flow monitored.

CHIEN, J.S. and SAIGAL, K.K. 1974: "Urban runoff by linearised sub-hydrographic method". J. Hydraul. Divn., Proc. ASCE, Vol.100(HY8); p1141-1157.

Key words: hydrographs; mathematical models.

The development of a simple, accurate hydrograph method is presented. The linearised subhydrograph method utilises functional relationships between rainfall and runoff. The parameters used in this method include time of concentration and runoff coefficient. Along with functional development, test applications are also examined. In two typical storms applied, time synchronisation and rate of runoff predicted are in good agreement with the recorded hydrographs.

CHIEN, J.S. and SARIKELLE, S. 1976: "Synthetic design hyetograph and rational runoff coefficient". J. Irrigation and Drainage Divn., Proc. ASCE, Vol.102(IR3); p307-315.

Key words: urban hydrology; hydrographs; urban runoff.

A simple method of establishing the synthetic design hyetograph was presented. The method was based on rainfall intensity-duration-frequency curves with simple computation. The method incorporated the rainfall duration, rainfall depth, and the advancing storm patterns. In addition, a method of computing the average runoff coefficient for the Rational Method was developed. This method was predicated on the principle of mass conservation using Horner's field data. Examples were given for the establishment of a synthetic design hyetograph and its application to the determination of average runoff coefficient. The methods presented were useful tools for drainage analysis.

CHILDS, E.F. 1970: "Effect of urban expansion on hydrological investigations". In, seminar on urban hydrology, Davis, California, U.S. Army Corps of Engineers, Hydrologic Engineering Centre, Paper No.1; 22pp.

Key words: urban hydrology; urban runoff; flood control; storm runoff; urban drainage; rainfall-runoff relationships.

A simple, straightforward procedure was used recently for studying the hydrology of a brook undergoing rapid changes in urban expansion. The method is acceptable for reconnaissance reports. In an example for Town Brook, Quincy, Mass., the hydrologic relationships were empirical, as there are no stream gauging stations in the watershed. The rational formula was used to compute discharges for different dates of analysis. Urban conditions are projected to the year 2000.

CHIU, S.Y. et al. 1975: "Nonpoint pollutant loading functions as water quality management and planning tools". In, Second annual National Conference on Environmental Engineering Research, Development and Design; 3pp.

Key words: nonpoint pollution sources; erosion; sediment transport; sediment yield.

Pollutants from nonpoint sources may adhere to soil particles and be eroded from the land; the movement of some pollutants is therefore strongly correlated with sediment generation and transport. A loading function is described which relates sediment yield from surface erosion to various source characteristics. The function is based on the mechanisms of on-site sheet and rill erosion, and on concepts of mechanisms of sediment delivery to surface streams. The gross equation is predicted by the Universal Soil Loss Equation. The function is relevant to planning for rural areas and for developing urban areas.

CHOW, V.T. 1952: "Hydrological studies of urban watersheds, rainfall and runoff of Boneyard Creek, Champaign - Urbana, Illinois". University of Illinois, Civil Engineering Studies, Hydraulic Engineering Series No.2; 66pp.

Key words: hydrographs; storm runoff; rainfall-runoff relationships; network design.

The report studies a creek with a 4.5 sq mile urban watershed. It describes the watershed and stations for collecting data, and presents a rainfall frequency analysis, a study of areal distribution of storms, derivation of a unit hydrograph, and determination of consumptive water use.

CHOW, V.T. and YEN, B.C. 1976: "Urban storm water runoff: determination of volumes and flowrates. Report for June 1973- September 1975." Illinois University at Urbana - Champaign, Dept. of Civil Engineering; 253pp. (EPA-600/2-76-116).

Key words: urban runoff; storm runoff; mathematical models.

An investigation is made to: a) develop a method of depth-duration-frequency analysis for precipitation events having short return periods for urban storm water runoff management and con-

trol purposes; b) develop a new high accuracy urban storm water runoff determination method which when verified, can also be used as the calibration scale for the less accurate urban runoff prediction methods; and c) compare and evaluate selected urban storm water runoff prediction methods.

CHUN, M.J. et al. 1972: "Waste water effluents and surface runoff quality". Hawaii University Water Resources Research Centre Tech. Report No.63.

Key words: surface runoff; water pollution.

CINCINNATI WATER RESEARCH LABORATORY, 1966: "Storm water runoff from urban areas, selected abstracts of related topics." Cincinnati Water Research Laboratory, Federal Water Pollution Control Administration, Mimeographed Report. (April).

Key words: bibliographies; abstracts; storm runoff; urban runoff.

CLARK, J.B. 1970: "Urban hydrology considerations, State of Hawaii". In, Seminar on urban hydrology, Davis, California. U.S. Army Corps of Engineers, Hydrologic Engineering Centre, Paper No.11; 9pp.

Key words: urban hydrology; hydrographs; rainfall-runoff relationships; storm runoff; urban runoff; peak discharge; flood forecasting.

Kiliouou Valley is on the southeastern corner of the island of Oahu, about 10 miles southeast of Honolulu, on the leeward side of the Koolau Mountains. The population of Kiliouou Valley has increased from 800 in 1950 to 1,700 in 1963. The flood plain is presently fully developed. On islands such as Oahu, where mountain peaks do not exceed 5,000 feet, maximum annual rainfall accumulations and intensities occur along the ridge lines and decrease with elevation on both the leeward and windward sides. The increased runoff and shorter concentration times caused by urbanisation areas are offset by the lesser rainfall depth-duration relationship at the lower elevations where the cities are located. Unit hydrographs for the project area were developed synthetically, utilising mountain-lag curves transferred to the Hawaiian Islands on the basis of rainfall and runoff studies. Runoff volumes from the 50-year and 100-year floods are 1.8 and 2.5 inches, respectively.

CLARK, R.A. 1971: "Hydrometeorology for urban runoff systems". In, Proceedings of the 16th Annual Conference on water for Texas, Urban water resources planning and management, San Antonio, Texas. Texas Water Resources Institute; p59-72.

Key words: urban runoff;

urbanisation; urban hydrology; air pollution effects; flood control; weather modification.

Various implications of hydrometeorology in an urban context are discussed, specifically the modifications to our climate and changes in the runoff regime due to urbanisation. First, temperature is clearly affected by urbanisation, resulting in the microclimatic 'heat island' effect. Second, there are indications that rainfall is increased by industrial pollution resulting in higher rainfalls downwind from urbanised areas. Third, urbanisation affects runoff by producing increased rates of runoff and higher flood peaks creating increased flood control problems.

CLARK, W.J. 1970: "The impact of water development on the ecology of river systems". In, Water for Texas, Proceedings of the 15th annual conference on Water for Texas. Texas A and M University, College Station; p49-54.

Key words: urbanisation; environmental effects; sediment transport; erosion; erosion control; sediment control; watershed management.

Ecological implications of modifying the natural course of events in any one part of the hydrological cycle, the river system, are discussed. The way man uses the land can modify the course of precipitation after impact. It can determine how much penetrates, how much runs off and how long the runoff takes and the nature and amount of transported material. Urbanisation and land use practices can cause ecological differences between permanent and intermittent streams. The aquatic populations can only survive in the pools remaining, if any, and temperature and other conditions become extreme. It is a strange experience to study an intermittent stream when there is water flowing. To all appearances, it is a good aquatic habitat, but sampling shows it to be a biological desert. The effects of poor land use practices extend to the permanent streams as well. Runoff comes faster and causes more erosion. Water development projects will have widespread ecological effects. The nature of these effects must be known if intelligent overall planning is to be done. Proper design, location and operation of dams and other structures may permit water supply goals to be obtained without serious ecological effects.

CLERC, G. LE. and SCHAAKE, J.C. 1973: "Methodology for assessing the potential impact of urban output on urban runoff and the relative efficiency of runoff control alternatives". Laboratory for Water Resources and Hydrodynamics, Dept. of Civil Engineering, Mass. Inst. Tech. (MIT), Report No.167; 257pp.

Key words: urban runoff; flood control; flood forecasting; analytical techniques; mathematical models.

A methodology was developed to assess the potential impact of urban development on urban runoff and to measure the relative efficiency of runoff control alternatives. The methodology utilises runoff frequency curves, derived at different stages of development of the urban catchment. Comparisons of these curves completely quantify the impact of urban development and/or the efficiency of a control structure. Runoff frequency curves are derived directly from the rainfall process. The method of solution utilises a stochastic model of the rainfall process and a deterministic model of the catchment. The method of solution, referred to as a stochastic/deterministic simulation, incorporates the stochastic rainfall model, the deterministic catchment model, and results of the infiltration estimator. Results show that the solution procedure and the methodology developed are practical and are recommended for urban drainage analysis.

CLEVEIAND, J.G. et al. 1970: "Evaluation of dispersed pollution loads from urban areas". Oklahoma University, Norman. Bureau of Water Resources Research; 224pp. (NTIS PB-203 746).

Key words: analytical techniques; urban runoff; surface runoff; water pollution; mathematical models; nutrients; bacteria; organic compounds; sediment yield; solid wastes.

The objective of this study was to develop a technique of evaluating the dispersed pollutional loads from urban runoff. The technique involved analytically determining several pollutant parameters from twelve separate drainage basins, and then correlating the pollution levels to land use practices. The study used the statistical tools of correlation coefficients, component analysis, and multiple regression analysis to develop predictor models for estimating urban dispersed pollutional concentrations and loads. Separate mathematical equations for estimating the expected seasonal bacterial, organic, nutrient, and solid matter concentrations from urban runoff were developed. The predictors used in the equations were common urban area variables, such as population, population density, commercial establishment density, percentage of streets, and environmental index. Twelve mixed land use drainage basins located in the city of Tulsa, Oklahoma, were used as the test areas.

CLEVELAND, J.C. et al. 1970: "Storm water pollution from urban land activity". In, Combined sewer overflow abatement technology. Water Pollution Control Research Series, Report 11024-06/70; p1-55.

Key words: storm runoff; water pollution; water pollution sources; urbanisation; landuse change; analytical techniques; chemical wastes; biochemical oxygen demand; chemical oxygen demand; total organic carbon; Kjeldahl nitrogen; solid wastes; bacteria; phosphorus compounds; faecal coliforms; chlorides.

An investigation of the pollution concentrations and loads from storm water runoff in an urban area was conducted in Tulsa, Oklahoma during the period from October 1968 to September 1969. The scope of the project included a field assessment of the storm water pollution by obtaining samples of the water resulting from rainfall and surface runoff from test sites in the metropolitan areas; development of an analytical procedure for correlation of storm water pollution with defined variables of land uses, environmental conditions, drainage characteristics, and rainfall; and development of an abatement plan for pollution in urban areas. Runoff samples were analysed in terms of quality standards for BOD, COD, TOC, organic kjeldahl nitrogen, soluble orthophosphate, chloride, pH, solids, total coliform, faecal coliform, and faecal streptococcus pollutants. Results of this investigation are detailed herein.

CIEVEIAND, J.G. et al. 1970: "A multi-phasic component study to predict storm water pollution from urban areas". Avco Economic Systems Corp., Washington, D.C. W71-83917, OWRR-C-1743(3164,1); 254pp.

Key words: storm runoff; water pollution; mathematical models; water pollution control.

The purpose of the study is to provide a procedure to enable prediction of storm water pollution from land activity, precipitation and runoff in an urban area. The procedures presented in the study will enable the city planner and civil engineer to predict quantitative and qualitative pollution loads resulting from surface storm water runoff to a receiving stream. The study presents ten mathematical models for this purpose and evaluates them by application to several selected demonstration cities. Also presented are criteria for pollution control strategies and for assessment of various structural and non-structural control measures, their general effectiveness and costs. Guidelines are discussed for the use of these procedures and development of an optimal water pollution control plan. The study concludes that: (1) storm water pollution prediction models are feasible but of limited application unless adequate data are available on hydrological, precipitation and runoff characteristics, as well as land activity detail for representative metropolitan areas, and (2) storm water pollution control for most effectiveness should relate to the specific characteristics of an urban area. Maximum economies will derive from pollution abatement measures taken during the early stages of area development.

COE, J.J. 1970: "Effect of solid waste disposal on ground water quality". J. American Water Works Assoc., Vol.62(12); p776.

Key words: solid wastes; ground water resources; aquifers; leachate.

Properly designed, constructed, and operated sanitary landfills can be an effective method of disposing of solid wastes and still not cause degradation of the quality of ground water as a result of leachate and gas production.

COLE, G.D. and SHUTT, J.W. 1976: "SWMM as a predictive model for runoff". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p193-201.

Key words: mathematical models; hydrographs; surface runoff; suspended solids; biochemical oxygen demand; urban runoff; flood control.

The USEPA sponsored Storm Water Management Model (SWMM) developed in 1970 has been used extensively to simulate rainfall occurrences on urban drainage areas ranging from 5 acres to 1,600 acres. Resulting runoff hydrographs and pollutographs (showing suspended solids and BOD versus time) have been used to analyse the effects of rainfall on the quality and quantity of flows into collection systems, overflows, and flooding. Six case studies are cited which explain the various ways in which SWMM has been used in engineering studies, designs, and resulting or intended construction. Methods used to reduce the polluting potential of urban runoff and sediment production are explained and evaluated; examples of such methods include the regulation of street sweeping operations, flow reduction techniques, and computer controlled systems which regulate the amount of inflow into a collection system. This paper places emphasis on the use of SWMM as a predictive model to be used in the study of urban runoff. Results from the model have been used in Infiltration/Inflow Analysis and Facilities Plans to meet USEPA and OSPA planning regulations. Extensive experience with the SWMM under a wide range of conditions has indicated that it is a valuable tool which can be used by urban communities of virtually every size to predict runoff occurrences for design rainfalls and actual rainfalls. Quantification of the runoff and its effects provide valuable data which can be used for engineering studies, design, and management decisions.

COLEMAN, R.N. et al. 1974: "Urbanisation and the microbial content of the North Saskatchewan River". Applied Microbiology, Vol.27(1); p93-101.

Key words: urbanisation; salinity; suspended solids; bacteria; sewage treatment; nutrients.

Studies on the effect of urbanisation on the microbial content of the North Saskatchewan River, Canada, with regard to physical parameters such as pH value, temperature, salt concentration, and the amount and nature of the suspended material, showed a slow increase in levels of total bacteria, total eosin methylene blue (EMB) plate count, and Esch. coli as the river flowed from its glacial source out into the

prairies. Results indicate that small hamlets, with or without sewage treatment facilities, contributed nutrients but no Esch. coli inoculum, while the large urban centre of Edmonton, Alta, utilising primary and secondary sewage treatment processes, contributed both nutrients and an inoculum of Esch. coli which resulted in a marked increase in all three microbial parameters studied, and whose effect was still discernible 300 miles downstream. A bibliography of 13 references is appended.

COLSTON, N.V. 1974: "Characterisation of urban land runoff". Paper presented at the ASCE National Water Resources Conference, Los Angeles, California, January 1974.

Key words: urban runoff; model studies.

COLSTON, N.V. 1974: "Characterisation and treatment of urban land runoff". EPA Technical Series EPA-670/2-74-096; U.S. EPA, Cincinnati, Ohio; 158pp.

Key words: waste water treatment; urban runoff; water pollution sources; chemical oxygen demand; biochemical oxygen demand; suspended solids; low flow; model studies.

Urban land runoff from a 1.67 square mile urban watershed in Durham, North Carolina, was characterised with respect to annual pollutant yield. Regression equations were developed to relate pollutant strength to hydrograph characteristics. Urban land runoff was found to be a significant source of pollution when compared to the raw municipal waste generated within the study area. On an annual basis, the urban runoff yield of COD was equal to 91 percent of the raw sewage yield, the BOD yield was equal to 67 percent, and the urban runoff suspended solids yield was 20 times that contained in raw municipal wastes for the same area. Downstream water quality was judged to be controlled by urban land runoff 20 percent of the time (i.e., the pounds of COD from urban land runoff was approximately 4-1/2 times the pounds of COD from raw sewage). It is conceivable that critical water quality conditions are not typified by the 10-year, 7-day low flow, but the period immediately following low flow periods when rainfall removes accumulated urban filth into the receiving watercourse. Specific urban land use did not appear to influence the quality of urban land runoff. The applicability and effectiveness of plain sedimentation and chemical coagulation of urban land runoff was evaluated. The EPA Storm Water Management Model (SWMM) was evaluated with respect to actual conditions as measured in the field. The model was judged to predict peak hydrograph flows and total hydrograph volumes with reasonable accuracy; however, it was not judged effective for predicting pollutant concentrations. In urban drainage basins, investments in upgrading secondary municipal waste treatment plants without

concomitant steps to moderate the adverse effects of urban land runoff are questionable in view of the apparent relative impact of urban land runoff on receiving water quality.

COLSTON, N.W. and TAPURI, A.N. 1975: "Urban land runoff considerations". Presented at AWRA Symposium on Urbanisation and Water Quality Control, Rutgers University, New Brunswick, N.J. Proc. No.20; p120-128.

Key words: urban runoff; water pollution sources; chemical oxygen demand; biochemical oxygen demand; suspended solids; storm runoff; dissolved oxygen; waste water treatment.

In 1971, the U.S. Environmental Protection Agency and the North Carolina Water Resources Research Institute jointly supported a two year research project at North Carolina State University for the purpose of characterising urban land runoff with respect to pollutant yield. This paper is a summary of portions of that project. Urban runoff is a significant source of pollution. When compared to the raw municipal waste generated within the study area, the annual urban runoff of COD was equal to 91 percent of the raw sewage yield, the BOD yield was equal to 67 percent, and the suspended solids yield was 20 times that contained in the raw municipal wastes. During storm flows, dissolved oxygen content of the receiving watercourse was found to be independent of the degree of treatment of municipal wastes beyond secondary treatment. Oxygen sag estimates were unchanged even if the secondary plant was assumed upgraded to zero discharge. In urban drainage basins, the beneficial effects of upgrading secondary municipal waste treatment plants may be uncertain in view of the apparent relative impact of urban land runoff on receiving water quality. Consequently, urban areas planning to upgrade secondary sewage treatment plants because of possible contravention of stream standards should carefully assess the potential contravention by urban runoff.

COLYER, P.J. 1977: "Performance of storm drainage simulation models". Proceedings of the Institution of Civil Engineers, Part 2, Vol.63; p293-309.

Key words: computer models; mathematical models; storm runoff; analytical techniques; waste water treatment.

Various storm drainage models were evaluated for accuracy in simulated observed storm events. Models examined included: rational (Lloyd-Davies) method; direct method; inlet method; lumped hydrologic methods; Transport and Road Research (TRRL) method; East African modification of TRRL (TRRL(EA)); Illinois urban drainage area simulator (ILLUDAS); Massachusetts Institute of Technology (MIT) method; University of Cincinnati urban runoff (UCUR) method; hydrograph volume method (HVM); EPA storm water management model (SWMM); and the Illi-

nois storm sewer system simulation (ISS) model. Numerical parameters were used to determine accuracy in performance using observed and calculated values for hydrologic variables such as peak discharge, time to peak, and total runoff volume. Among the numerical parameters used were: λ , the ratio between calculated and observed values; ϵ , the absolute error between individual calculated and observed values; and ϵ calculated for groups of positive and negative errors. Calculations indicated that storm sewer models can predict peak discharge and runoff volume within 10-20 percent. The TRRL method was capable of the most accurate overall performance of the models examined. Suggestions for improvement in storm drainage models include closer examination and field studies to better determine the limitations of simulation models, more efficient programming to reduce costs to the user, and the addition of other parameters such as surcharging, backwater effects, and surface flooding.

COLYER, P.J. and PETHRICK, R.W. 1976: "Storm drainage design methods - a literature review". Hydraulics Research Station Report INT 154, Wallingford, U.K.

Key words: urban drainage; storm runoff.

CONDON, F.J. 1973: "Methods of assessment of nonpoint runoff pollution". Diplomat of the Amer. Acad. Environmental Engineering, Vol.8(5); p4.

Key words: nonpoint pollution sources; analytical techniques.

CONDON, F.J. 1974: "Storm and combined sewer abatement technology in the United States - an overview". Paper in Proc. of Third U.S./Japan Conference on Sewage Treatment Technology, Tokyo, Japan; p505-546. (EPA-670/9-75-005.)

Key words: storm runoff; combined sewers; urban hydrology; water pollution control; mathematical models; waste water treatment; nonpoint pollution sources.

An overview of principal sources of runoff induced pollution as investigated by the Office of Research and Development of the United States Environmental Protection Agency is given. These include: combined sewer (domestic sewage and runoff) overflows, sewer storm water discharges, sanitary sewers surcharged by infiltration, treatment works or pump station bypass, and urban nonpoint or overland runoff. Remedial solutions for these specific causes must include urban hydrology as well as sanitary engineering. Schematic diagrams of urban hydrologic systems have been developed. In evaluating water pollution loading, strength and mass emission of pollutants from an event must be considered. Projects for con-

trol include quantity reduction (infiltration control), quality improvement (deicing methods), runoff rate attenuation (porous pavements), and improved materials (electro-magnetic subsurface profiling) for urban areas. Possible alternatives for effluent management facilities are also detailed. Treatment may be physical, physico-chemical, biological, or biophysical. The well-developed mathematical Storm Water Management Model and associated work are outlined as the prime tools for use in application of total system concept for selecting water pollution control alternatives.

CONDON, F.J. 1975: "Considerations in characterisation of urban runoff for PL 92-500 Section 202 planning". Office of Research and Development, EPA, Washington, D.C.

Key words: urban runoff; analytical techniques; water pollution.

CONSTANT, J.A. 1970: "A mathematical determination of the ordinates of the unit hydrograph". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.9; 12pp.

Key words: urban hydrology; hydrographs; urban runoff; storm runoff; peak discharge; rainfall-runoff relationships; flood forecasting.

An equation is given for the unit hydrograph, and a means of evaluating the parameters in terms of the time and magnitude of the unit hydrograph peak and the contributing area is presented. The method is easily programmed for use in an electronic computer as a program in itself or as part of a larger program, such as one for determining basin runoff during flood periods.

CONSTRUCTION INDUSTRY RESEARCH AND INFORMATION ASSOC'N. 1974: "Rainfall - runoff and surface water drainage of urban catchments". Proceedings of Bristol colloquium, April 1973. (From CIRIA, Storey's Gate, London, UK); 178pp.

Key words: surface runoff; rainfall-runoff relationships; urban drainage.

Problems in the design of systems for the surface water drainage of urban catchments involve meteorology, hydrology, hydraulics, planning, economics, and construction. These aspects were considered at a colloquium organised at Bristol University in April 1973. Research and design progress in the U.K. in the last decade was discussed, research in progress reviewed, and what further research and development is needed was assessed. The colloquium was mainly concerned with the quantity of runoff rather than its quality. Reprints of the papers are presented with an edited version of the discussion.

CORDERY, I. 1976: "Some effects of urbanisation on streams". Civil Engineering Transactions, CE18, No.1; p7-11.

Key words: urbanisation; sediment yield; water pollution; storm runoff; peak discharge.

The effects of urbanisation on streams is discussed with regard to catchment yield, sediment yield, and water quality. Flood peaks are increased up to three times and runoff volumes are approximately doubled. For limited periods during development of an area, stream sediment loads are increased by up to 50 times. The quality of urban runoff is similar to that of secondary sewage effluent. The economic and aesthetic impact of these effects of urbanisation are considerable. Research into, and implementation of, methods for alleviating the problems are advocated. Measures proposed overseas are discussed in terms of Australian conditions. A bibliography of 30 references is appended.

CORDERY, I. 1976: "Potential value of treatment of urban storm water". The Institution of Engineers, Australia, Vol.CE18(2); p60-63.

Key words: urban runoff; suspended solids; biochemical oxygen demand; surface runoff; water pollution sources; model studies; waste water treatment; ammonia; phosphorus compounds.

Storm water quality was examined for two sites in Sydney, Australia, to examine the feasibility of storm water treatment. Flow rate, suspended solids, BOD, phosphate, and ammonia were measured for approximately 100 water samples collected from 13 floods within a catchment area. Analyses indicated that pollutant loads were highest during the 'first flush' of the storm and also tended to be higher during morning storms than afternoon storms. Laboratory studies on settling for from 4 minutes to 24 hours as a treatment method for storm water showed that suspended solids could be reduced by as much as 87 percent with a settling time of only 15 minutes. A comparison of estimated annual loads indicated that settling of urban runoff could produce effluent qualities similar to those produced by tertiary treatment but at a much lower cost.

CORDERY, I. 1977: "Quality characteristics of urban storm water in Sydney, Australia". Water Resources Research, Vol.13(1); p197-202.

Key words: urban runoff; water pollution sources; water pollution; data collection; ammonia; nutrients; nitrates; bacteria; phosphorus compounds; suspended solids; biochemical oxygen demand; faecal coliforms.

Storm water samples collected from three urban watersheds in Sydney, show that in separately sewered areas the surface runoff has a greater concentration and carries a greater total load

of pollutants than effluent from secondary sewage treatment plants. Pollution and nutrient indicators are highly concentrated in the 'first flush' at the start of urban storm runoff, but these concentrations fall rapidly to quite low levels during the passage of each flood. An important exception to this trend is phosphate. The phosphate concentration remains approximately constant during each flood. Whenever the discharge increases sharply, the concentrations of suspended solids and phosphate increase slightly. However, the concentrations of BOD and ammonia do not usually increase after the first flush unless a later increase in discharge is extremely rapid. Faecal coliform concentrations in flood flows are usually about two orders of magnitude less than for raw sewage.

COSTA, J.DA. 1970: "Effect of urbanisation on storm water flows". J. Sanit. Eng. Divn., Proc. ASCE, Vol.96(SA2); p187-193.

Key words: storm runoff; urbanisation; rainfall-runoff relationships.

The rational formula, $Q = CIA$, may be considered a rough expression of the influence of urbanisation on storm water sewer flows. The unique runoff coefficient, C , is the product of three factors, each one having some correlation with the degree of urbanisation given to the watershed. The presented general rational formula is related to the other rainfall-runoff relationships derived by Snyder and Horner - Flynt. Results from the formula are compared with those obtainable by the Chicago method. Modifications by urbanisation are graphed. Variability of rainfall frequency is attributed to topographic and urban conditions.

COSTIN, A.B. and DOOGE, J.C.I. 1973: "Balancing the effects of man's actions on the hydrological cycle". In, Man's influence on the hydrological cycle, FAO Rome, Irrigation and Drainage Paper, Special Issue 17; p19-51.

Key words: landuse change; urbanisation; watershed management; surface runoff; weather modification; water pollution.

Water, the most manageable of the natural resources, is capable of diversion, transport, storage and recycling. However, great care must be taken in developing one aspect of the hydrological cycle so that other hydrologic components are not adversely affected. Hydrological changes resulting from land use practices are discussed, showing how readily terrain alterations affect precipitation, surface, and sub-surface waters. Man's attempts to control hydrological processes by weather modification, evaporation and transpiration controls, control of soil water movement, engineering techniques to increase availability, and irrigation and drainage often have considerable side effects. Natural hydrologic processes can be greatly upset by prac-

tices which seem superficially beneficial, including desalination, forestry practices and urbanisation. Examples of pollution effects are presented for the Thames and Mekong Rivers. The need for logical decisions in water management is vital and any alteration of one hydrological component must take into consideration all others.

COTO, S. and HATAZAWA, N. 1971: "On the water pollution in the area of urban development". Science Rep. Fac. Agric., Kobe University, Vol.10(1); p97-101. (In Japanese).

Key words: bacteria; water pollution; chlorides; sulphides; biological oxygen demand; chemical wastes; industrial wastes; agricultural pollution.

The amount of Cl increases in accordance with the increase of the population density. Cl contents of three rivers near Akashi City are practically equal, and also the concentration of Cl has a tendency to be in proportion to that of the SO₄. Biological O₂ demand is high in the water of the Hazetani, lower in the Akashi, and highest in the Igawa. The pollution of the Hazetani has its origin in the waste from the livestock industry and that of the Igawa is caused by waste from factories. The numerical value of bacterium/ml in the water of the Igawa is the highest and the least in the Akashi. While farmers use wells for the most part, it was found that the majority of well water is not fit to drink. The Osaka Group has several marine clay layers and in the case of Shempoku New Town these layers were exposed to the air by the earthwork. The runoff water over the surface was contaminated with the marine clay (pH 2.71) and fishes in the reservoir died from the inflow water. The amount of SO₄ was 110 ppm and the pH of the water was 4.2.

COUGHLIN, R.E. and HAMMER, T.R. 1973: "Stream quality preservation through planned urban development". Socioeconomic environmental studies series, EPA-R573-019, Washington; 238pp. (NTIS PB-222 177).

Key words: landuse change; watershed management.

The effects of a land use plan to restrict urban development in areas critical to the water resource system are identified through empirical studies. Specifically, relationships are established between amount, density, type, and location of urban development, on the one hand, and stream water quality and stream channel enlargement on the other. The amount of open space with such a plan as compared to that with normal development is determined.

COWEN, W.F. et al. 1976: "Nitrogen availability in urban runoff". J. Water Pollution Control Federation, Vol.48(2); p339-345.

Key words: urban runoff; nutrients; nitrogen compounds; algae.

Results are given of mineralisation tests on urban runoff from Madison, Wis., to estimate the availability to algae of the nitrogen loads in runoff. These showed that mineralisation at 21 degrees centigrade produced water with 57-82 percent algal-available nitrogen. In contrast, only 4-66 percent of nitrogen in fresh runoff is in the available form, indicating the importance of bacterial mineralisation in releasing inorganic nitrogen from the runoff, and it is stressed that this should be taken into consideration when assessing nitrogen loadings from urban runoff.

COWEN, W.F. and LEE, G.F. 1973: "Leaves as a source of phosphorus". Environ. Science and Technology, Vol.7(9); p853-854.

Key words: leaves; water pollution sources; phosphorus compounds; model studies; urban runoff; nutrients.

Oak and poplar leaves were leached with distilled water in laboratory columns to simulate the release of soluble phosphorus (P) forms to urban runoff. Most of the soluble phosphorus leached was reactive in a molybdenum blue analysis. The leaves tested yielded 54-230 micrograms P/g of leaves. Consecutive leachings of an oak leaf sample yielded soluble P in amounts related to the effective soaking period between leachings and to the number of preceding leachings. Cut up leaves released almost three times as much soluble P as intact leaves. Leaves collected from the littoral zone of Lake Mendota leached less P than control leaves collected on the shore nearby. The moisture retained on leaves after a rainstorm contained significant soluble reactive P. The results point to the importance of proper leaf pickup and control in order to minimise the phosphorus content of urban drainage during the fall of the year.

COWEN, W.F. and LEE, G.F. 1976: "Phosphorus availability in particulate materials transported by urban runoff". J. Water Pollution Control Federation, Vol.48(3); p580-591.

Key words: nutrients; phosphorus compounds; urban runoff; suspended solids; water pollution sources.

A study was carried out at Madison, Wis., to assess the availability of phosphorus associated with particulate matter in runoff from a variety of urban land uses, including residential areas with different housing densities, commercial areas, and urban construction. The forms of particulate phosphorus in the runoff from the different areas were similar; it is suggested that the dominant type of particulate phosphorus in the samples was derived from a common source, such as dustfall or eroded soil. Physico-chemical processes appeared to be more important than microbial mineralisation of parti-

culate phosphorus in releasing inorganic phosphorus to solution. Bio-assays showed that 30 percent of the particulate phosphorus was available to *Selenastrum* in 19-22 days.

COWEN, W.F. and LEE, G.F. 1976: "Algal nutrient availability and limitation in Lake Ontario during IFYGL, Part 1. Available phosphorus in urban runoff and Lake Ontario tributary waters". Texas University at Dallas, Richardson, Report No. EPA-600/3-76-094a; 216pp. (NTIS PB-262 974).

Key words: phosphorus compounds; urban runoff; algae; nutrients; eutrophication.

Urban runoff in Madison, Wisconsin was analysed to determine the availability of various phosphorus forms for algal growth, and methods for urban systems were applied to phosphorus availability in Lake Ontario tributary waters. Total phosphorus, soluble phosphorus, particulate phosphorus, and soluble reactive forms were measured. Data for the Madison experiments were gathered at eight city locations between August 1972 and March 1973; the test alga was *Selenastrum capricornutum*. Based on the Madison data, plus raingauge samples from 13 New York State locations, water samples from streams in the Genesee River Basin, and samples from four Lake Ontario tributaries in New York State, it was concluded that only about 20 percent of insoluble orthophosphate present in surface water drainage is available for algal growth. Recommendations are: (1) phosphorus available to aquatic plants as inputs into a water course can be computed by adding together soluble orthophosphate and 20 percent of insoluble orthophosphate; and (2) ion exchange incubation and algal assay techniques (used in this study) should be used to evaluate potentially available phosphorus in studies of all major U.S. rivers prior to designing a national phosphate control program.

CRAWFORD, N.H. 1968: "Infiltration and losses in urban hydrology". In, Urban Water Resources Research, first year report, ASCE, Chapter 3; pA22-A31.

Key words: rainfall-runoff relationships; model studies.

Urban watersheds include all watersheds where the hydrologic regime is substantially changed by the introduction of impervious areas, storm drainage, and channel improvements. Development ranges from widely spaced suburban homes to highly developed commercial-industrial areas. For highly developed conditions, runoff is entirely dependent on the precipitation regime, interception, and depression storage. Analysis of runoff from a fully developed watershed is not as complex as analysis of a low density suburban area, but the suburban area is the more common design problem. Losses from precipitation determine runoff volumes. Algorithms used for losses and infiltration are reviewed. Simulation

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methods are being studied in many universities. Improvements in the general accuracy of peak flow frequency estimates for urban drainage are possible from applications of simulation techniques.

CRAWFORD, N.H. 1970: "North Branch Chicago River runoff simulation". In, 25th Annual Midwestern States Flood Control and Water Resources Conference, Chicago; 10pp.

Key words: mathematical models; model studies; storm runoff; flood forecasting; rainfall-runoff relationships; urban drainage; watershed management.

The Hydrocomp Simulation Program (HSP) is a deterministic model for use in urban watershed engineering. The input includes precipitation, potential evapotranspiration, temperature, radiation, and where available wind movement and dewpoint. The calculations are made for all meteorologic conditions because the loss of water through evapotranspiration in dry weather is as important in the overall water balance as overland flow during storm periods. Applications include flood forecasting, urban drainage design, studies of land use and land management, and simulation of records for ungauged streams. In the North Branch of the Chicago River HSP programming was used to develop stage and discharge information to estimate flooded areas for storms of various frequency for future conditions of urbanisation. These simulation runs provide data for compliance with the National Flood Insurance Act of 1968.

CRAWFORD, N.H. 1971: "Studies in the application of digital simulation to urban hydrology". Hydrocomp International, Palo Alto, California; 109pp. (NTIS PB-206 715).

Key words: urban hydrology; computer models; mathematical models; network design.

The sensitivity of the Hydrocomp Simulation Program to changes in data interval, number of raingauges and watershed definition was studied using data from Waller Creek, Austin, Texas; Boneyard Creek, Champaign - Urbana, Illinois; and Echo Park, Los Angeles, California.

CRAWFORD, N.H. 1973: "Computer simulation for design criteria for urban flow storage systems". Hydrocomp International, January 1973, Palo Alto, California, Final Report; 118pp. (NTIS PB-218 827/4).

Key words: surface runoff; flood control; storm runoff; water pollution control.

Digital computer simulation models were used to examine the effects of storage in urban storm water runoff systems. Two specific cases of drainage problems are examined. The first is the problem

of designing a storm drainage system that flows into a reservoir from which the runoff is pumped or flows by gravity to a receiving water body with a variable stage. The second stage is that of determining the storage required for peak storm water runoff volumes to achieve a fixed outflow from a watershed. Examples illustrating each case and suggesting the best design approach for similar storm water drainage facilities are given. For the fixed outflow case, a relative cost comparison is undertaken to determine the possible economic advantages of including storage in urban storm drainage systems. A computer model was developed to assist a designer in evaluating the amount and return of transient storage within a proposed design system.

CRIPPEN, J.R. 1965: "Change in character of unit hydrographs, Sharon Creek, California, after suburban development". U.S. Geol. Survey prof. paper No.525-D; p196-198.

Key words: storm runoff; hydrographs; landuse change.

Unit hydrographs were derived from precipitation and streamflow records collected in a small basin in the coastal region of central California. Hydrographs representing conditions before and after suburban development are presented.

CRIPPEN, J.R. 1966: "Selected effects of suburban development on runoff in a small basin near Palo Alto, California". U.S. Geol. Survey open-file report; 19pp.

Key words: rainfall-runoff relationships; landuse change.

A study of the hydrology of three small drainage basins near Palo Alto, California, was started in 1959. Its purpose is to document hydrologic parameters before, during, and after the introduction of suburban development; to define changes caused by development; to relate the nature and degree of changes to their causes; and to describe the changes so that they can be extrapolated to other regions of development in a similar environment.

CRIPPEN, J.R. 1967: "Change in quantity of dissolved solids transported by Sharon Creek, California, after suburban development". U.S. Geol. Survey prof. paper, No.575-D; p256-8.

Key words: dissolved solids; sediment yield; storm runoff; water pollution sources.

In a small basin in the coastal region of central California studied before and after suburban development, the total load of dissolved solids carried from the basin by streamflow increased tenfold. The increased runoff from paved channels, pavements, and roofs ordinarily accompanying urbanisation is likely to have a lower concentration of

dissolved solids than the natural runoff. A higher concentration was observed in Sharon Creek after 1962 under developed conditions. The natural soil distribution was altered extensively during development, especially where cuts and fills were necessary to establish the desired golf course topography, and thus much material which had not been thoroughly leached in the past was exposed. Irrigation water is supplied to lawns and to the golf course at a rate as nearly as possible equal to the consumptive need. Dissolved solids may be retained in the irrigated area and later be leached away by any excess of water. It is also possible that the year-round active growth in the irrigated areas may produce carbon dioxide that would increase the solvent power of soil moisture.

CRIPPEN, J.R. 1969: "Hydrologic effects of suburban development near Palo Alto, California". U.S. Geol. Survey open-file report; 122pp.

Key words: data collection; rainfall-runoff relationships; landuse change; peak discharge; sediment yield.

Data were gathered for seven years in three small basins in the foothills west of San Francisco near Palo Alto, Calif., to detect changes in the hydrologic regime caused by suburban development. One basin remained in a natural state while another remained natural for the first three years, then suburban homes, offices, and a golf course were established. The third basin was unchanged for the first four years. Streamflow in the developed basins changed from ephemeral to perennial because of the introduction of imported water and an associated rise in the ground water table. Runoff increased from 5 to 10 percent of annual precipitation to more than 30 percent. Flow peaks of magnitudes that occurred only once or twice a year under natural conditions occurred with much greater frequency after development. Sediment production was markedly increased during times of construction activity but decreased after the developed areas became stable.

CROLEY, T.E. and BARNARD, J.R. 1976: "Ralston Creek flooding induced by South Branch urbanisation". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p257-269.

Key words: streamflow; flood discharge; urbanisation; landuse change; model studies.

Urbanisation-induced flood hazard estimates are desired for Ralston Creek in Iowa City, Iowa; but, the nonstationary streamflow record is difficult to analyse since urbanisation has been continuous in the past. The problem of nonstationarity, induced in streamflow records by urbanisation, is circumvented through analysis of the precipitation time series. The hourly precipitation

tation records of 33 continuous years from between 5 and 8 stations on the watershed and an adjacent watershed are combined as an estimate of watershed input. The Ralston Creek streamflow record, the weighted precipitation record, and watershed characteristics are used to estimate parameters for streamflow simulation models for both non-urban and urban conditions. The weighted precipitation record and the models are combined to estimate flood magnitude frequencies for both urban and non-urban conditions, preparatory to the estimates of urbanisation-induced flood hazard. Most of the urbanisation impact appears to be changes in low recurrence interval floods. By utilising backwater analyses for the creek to estimate the probability of flooding for each residential property, the impact of flood hazard can be estimated using an econometric model of property values. The difference in damages between the urban and non-urban conditions is to be integrated over all properties using the estimated change in probabilities to estimate the change in property values and total negative externality associated with flooding increases due to urbanisation.

CURTIS, D.C. 1976: "A deterministic urban storm water and sediment discharge model". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p151-162.

Key words: storm runoff; mathematical models; sediment yield; erosion; rainfall-runoff relationships; sediment control.

As a catchment is transformed from rural to urban in character, many qualitative and quantitative changes in catchment response to rainfall occur. Citizen and government reactions to these changes have resulted in many new local policies regarding the management of storm waters. These policies place increased emphasis on planning for changes in catchment response and on storm water drainage systems designed to minimise the impact of catchment changes. One of the problems occurring in an urbanising region is the generation and subsequent deposition of sediment resulting from eroding soils. Soils laid bare by various construction activities are extremely vulnerable to erosion resulting from direct impact of raindrops and accelerated surface flow velocities. Soil particles enter the drainage system where deposition can occur, thus decreasing the carrying capacity of the system. Diminished carrying capacities coupled with increased quantities of runoff from urban areas can cause serious flooding and related problems. If large amounts of eroded soil reach natural waterways, local stream ecology can be seriously impaired. A model is presented that utilises a physically based rainfall/runoff component and a set of relationships describing soil detachment and transport processes to simulate the discharge of sediment from an urban area. The model could be used to help assess the relative impact of pro-

posed watershed changes on the erosion/transport/deposition (ETD) system. Among the concepts that can be evaluated are: land use alternatives, distribution of impervious areas, channel improvements, sediment control practices, infiltration changes, changes in the surface roughness, and changes in slope. Since the model is physically based, it can be used as a tool to gain a better understanding of the physical processes taking place in the ETD system throughout a catchment.

CURTIS, D.C. and McCUEN, R.H. 1977: "Design efficiency of storm water detention basins". J. Water Resources Planning and Management Divn., Proc. ASCE, Vol.103(WR1); p125-140.

Key words: urban runoff; model studies; mathematical models; erosion; sediment control; storm runoff; flood routing; urban drainage.

In addition to increased flood runoff, urban development has caused a significant increase in sediment loads in streams. While many means of sediment and runoff control have been proposed, storm water detention has been shown to be one of the more cost effective means. Because detention facilities have not been used extensively in the past, a data base is not available for determining the effect of design factors on sediment trap efficiency and runoff control characteristics. A mathematical model, which includes erosion, sedimentation, and detention facility components, was developed from principles of hydraulics and classical settling mechanics. The model was used to examine the effect of: (1) detention basin location; (2) soil particle size distribution; (3) basin depth; (4) initial storage, and (5) orifice diameter. An understanding of the relative importance of these factors may lead to better design of storm water detention facilities.

CURTIS, L.W. et al. 1964: "Report of study of the Wolf Creek channel and flood plain". The Miami Conservancy District, Ohio, March 1964.

Key words: hydrographs; mathematical models; flood routing; flood discharge.

A flood routing model of the 69.5 sq mile Wolf Creek drainage basin in southwestern Ohio using one hour duration unit graphs and Muskingum channel routing techniques was developed and verified for floods observed during the period 1931-1961. Unit graphs were then modified according to the techniques discussed in the van Sickle discussion of the Eagleson paper in the J. Hydraul. Divn., ASCE, Nov. 1962, to simulate completely urbanised conditions. Results of studies with the revised unit graphs with no changes in channel routing coefficients show that little increase is to be expected for the relatively long duration 6 hour to 19 hour storms which now cause the annual floods. Study of one hour duration storms which can be expected to be

critical under urbanised conditions show that an increase of 50 percent is to be expected for a 10 year frequency flood. A trend toward convergence of the urbanised peaks is evident for frequencies over 100 years.

CYWIN, A. and ROSENKRANZ, W.A. 1971: "Advances in storm and combined sewer pollution abatement technology". Paper presented at the 44th Annual Conference of the WPCF, San Francisco, California.

Key words: water pollution control; water pollution sources; pollution abatement; waste water treatment; sewage treatment.

Research, development, and demonstration efforts sponsored by the Environmental Protection Agency since 1966 have resulted in advances in technology which can be applied as alternatives to sewer separation for abating pollution from combined sewers. The overall problem is caused by basic deficiencies in collection, transport, and treatment systems, which must be corrected to provide truly efficient sewerage facilities. All the sewerage facilities must be evaluated in order to plan modifications which will provide the capability to adequately control and treat waste waters during and immediately following storm events. Control facilities such as in and off system storage, flow regulation and routing, remote flow sensing and control, coupled with treatment, are applicable solutions. Physical, chemical, biological, and physical-chemical treatment methods are under investigation, with a screening, dissolved-air floatation process, and a high rate multi-media filtration process offering the best current potential for producing good quality effluents. Requirements for control of pollution from combined sewer overflows are rapidly becoming more stringent. Control of pollution caused by urban storm water discharges is on the horizon.

DAIBERG, K. 1977: "The effects of street cleaning on storm water quality". Master's Thesis, Dept. of Water Supply and Sewerage, Chalmers University of Technology. (In Swedish).

Key words: water pollution control; storm runoff.

DALRYMPLE, R.J. et al. 1975: "Physical and settling characteristics of particulates in storm and sanitary waste waters". EPA Cincinnati, Ohio, Report EPA-670/2-75-011; 32pp.

Key words: suspended solids; waste water treatment; overflows; combined sewers; solid wastes; model studies.

An investigation was conducted, as part of model studies utilising a swirl concentrator as a primary separator, helical combined sewer overflow regulator, and related studies, to characterise the properties of solids in sanitary sewage, combined sewer overflows, and storm water runoff. Material suitable for monitoring efficiencies in hydraulic models of the swirl concentrator unit has been developed. The approach taken by Beak Consultants Ltd., serving as a subcontractor to the American Public Works Association in the simulation sewage studies, was to match as closely as possible the settling characteristics of solids in three types of sewage and/or urban runoff with a well-defined, uniform artificial test material. An Amberlite Anion Exchange Resin (IRA-93), when ground and sieved to between 74 and 149 microns, was found to closely simulate the settling characteristics of domestic sewage. This material is of uniform density and appears to react according to Stokes' law for spherical particles at this size range. Arizona Road Dust, between 10 and 20 microns, was found to exhibit a similar-settling velocity distribution to that of the colloidal (or semi-colloidal) components of sanitary sewage flow. This report on these studies recommends that either or both of these materials be used in the scale-model efficiency trials. As background information for the selection of synthesised solids, the settling characteristics (including size and specific gravity distribution) of sanitary sewage, combined sewer overflow and storm water were determined. These values will be useful for future determination of physical treatment process design and associated treatability.

DAPPEN, G. 1974: "Pesticide analysis from urban storm runoff". Research project technical completion report, Nebraska Univ., Lincoln; 44pp. (NTIS PB-238 593/8ST).

Key words: surface runoff; pesticides; water pollution; organic compounds; herbicides; storm runoff.

Urban storm runoff was analysed for pesticide content. Hexachlorobenzene (HCB), pentachloronitrobenzene (PCNB), heptachlor, heptachlor epoxide, lindane, and dacthal were identified and

selected for monitoring. Lindane and dacthal were primarily used in the determination of the profile and runoff patterns during a rainstorm. Although pesticide concentrations were higher near the end of the runoff period, the largest amount of pesticide flushing from an area occurred during the maximum runoff period. Major rains, rains that followed periods of wet weather, or rains of longer duration produced higher quantities of pesticides running off than moderate rains of high intensity following dry periods. Much variation in the amount of pesticide running off was encountered.

DARBY, W.P. et al. 1976: "Urban watershed management using activity indicators to predict water quality". Water Resources Research, Vol.12(2); p245-252.

Key words: watershed management; analytical techniques.

The first step in the management of small watersheds by local regulatory agencies is the establishment of priorities for implementing the dictates of the 1972 Federal Water Pollution Control Act amendments. Although data requirements for establishing priorities are extensive, typically, very little water quality and streamflow data exist for small urban watersheds. Local regulatory agencies do not possess the resources to generate these data. To solve this problem, the use of indirect indicators is developed to describe watershed activity, predict water quality, and forecast the status of several individual water quality parameters. Stream quality is then predicted for watersheds for which no previous direct measurements had been made. The methodology is applied to Allegheny County in Pennsylvania, a region composed of 52 small urban watersheds. Indicators of watershed activity are used here to determine which streams should be sampled to provide a representative measure of water quality conditions existing throughout the County. The information from the monitoring program is currently being used by the Allegheny County Health Department to define implementation priorities for the small urban streams in the region.

DARBY, W.P. and SMALL, M.J. 1976: "Identifying urban flash flooding problems". J. Water Resources Planning and Management Divn., Proc. ASCE, Vol.102(WR2); p349-363.

Key words: flood control; flood forecasting; mathematical models.

The focus of flood control activities in urban areas has been the alleviation of problems associated with major river flooding. Meanwhile, unplanned urban development has caused flooding problems of small urban streams to worsen, and eventually to receive priority attention. Because of limited resources, flood control agencies must choose individual streams for immediate attention, while deferring flood control action on others. Very little direct information exists upon which to base an

evaluation of the relative flash flooding problems of individual streams. A methodology, based on multiple discriminant analysis, is presented to provide a decision-making tool to establish flash flood control priorities among a number of urban streams. The analysis is based on indirect measures of flash flooding problems (land use characteristics of the watershed, stream configuration, etc.) that are readily available to the flood control agency, instead of flood damage inventories and hydrologic data, which are often unobtainable. Using the discriminant models, individual streams can be singled out for priority action.

DAS, K.C. 1977: "Quality of combined sewer overflows from urban and semi-urban areas in Richmond, Virginia, USA". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p265-276.

Key words: combined sewers; water pollution sources; overflows; data collection; biochemical oxygen demand; suspended solids.

Until very recently waste loads from land, storm sewer, and combined sewer overflows have received very little in-depth evaluation as significant pollution sources. Studies indicate that the quality of pollutants entering the James River at Richmond, Virginia, is quite significant. Research has been under way for the past 36 months to determine the impact of 46 overflows at Richmond. The study consists of monitoring six of the representative sources utilising automatic samplers and special flow measuring devices to define runoff characteristics. These six points were selected on the basis of land use types including single family, multi-family, commercial, industrial, open space, and combinations thereof. Results indicate that the peak BOD concentrations for the storms considered at the single family sampling stations ranged from 80.0 to 434.0 mg/l and suspended solids from 109.0 to 1320.0 mg/l; for multi-family stations BOD ranged from 44.0 to 350.0 mg/l and suspended solids from 224.0 to 2240.0 mg/l; for multiple land use stations BOD ranged from 63.0 to 232.0 mg/l and suspended solids from 208.0 to 1620.0 mg/l. This clearly illustrates that the pollutional characteristics of combined sewer overflows are variable. 'First flush' of suspended solids and BOD is generally exhibited at each station including Shockoe which has the largest drainage area of 7300.0 acres (29.542 million sq metres). The first flush is usually more pronounced in smaller basins. Results of this investigation will aid in reducing pollutant loads from combined sewer overflows to the James River at Richmond.

DAVIS, E.M. et al. 1977: "Bacterial relationships in storm waters". Water Resources Bulletin, Vol.13(5); p895-905.

Key words: urbanisation; bioindicators; bacteria; faecal coli-

forms; storm runoff; water pollution; analytical techniques; waste water treatment; urban drainage.

Data were developed within a three-year period for indicator bacteria and three species of bacterial pathogens following rural storm event hydrographs. The first flush concept was confirmed in all hydrographs. Bacterial density peaking occurred at or before the hydrograph peaks. FC and FS values were higher in more developed areas than the primary rural test site and their numerical ratios followed similar trends. Chlorine demand of storm waters varied between 8 and 16 mg/l and the ozone requirement was greater than 32 mg/l in the same waters. Aftergrowth of total coliform bacteria occurred following chlorine and ozone doses of 16 mg/l and 32 mg/l respectively. Faecal coliform, faecal streptococci, *Salmonella* sp., and *Pseudomonas* sp. all were reduced to near detectable limits by the disinfectants up to 8 days. *Staphylococcus* sp. demonstrated a propensity to reestablish their populations. Multiple regression analysis of the bacterial groups and species in storm waters suggested the faecal streptococci to have been the most useful group in evaluating bacterial storm water quality, with staphylococci having been closely related insofar as their statistical significance was concerned.

DAVIS, J.A. and JACKNOW, J. 1975: "Heavy metals in waste water in three urban areas". *J. Water Pollution Control Federation*, Vol.47(9); p2292-2297.

Key words: heavy metals; industrial wastes; storm runoff; chemical wastes.

An examination was made of the sources of heavy metals discharged into municipal treatment systems and directly into receiving waters in three urban areas: New York City, Pittsburgh, Pa., and Muncie, Ind. Enough information was sought to categorise the heavy metals contribution into three categories: residential, industrial, and storm water runoff. The results showed that the industrial contributions, particularly from industries related to steel production and metal fabrication, may overwhelm the other two sectors, but that, when the industrial discharge is controlled, significant amounts of heavy metals are contributed by the residential sector and storm water runoff.

DAVIS, W.J. 1974: "Watershed management and sediment control in Montgomery County". In, *Proceedings National Symposium on urban rainfall and runoff and sediment control*, University of Kentucky, Lexington, Ky.; p211-217.

Key words: watershed management; sediment control; urbanisation; urban runoff; erosion; channel erosion; storm runoff.

Montgomery County, Maryland, immediately north of Washington, D.C., has

undergone since 1950 a three-fold increase in population, accompanied by a phenomenal intensity of urban development outward from Washington, the upshoot of heterogeneous, overlapping political jurisdictions, and a multitude and variety of physical problems, not the least of which are those related to the accelerated forces and pollution of storm water and their impacts upon the County's watersheds and the public and private interests therein. The County has embarked upon a comprehensive program for control of all the problems involving storm water and sediment and other aspects of water quality where possible. This paper addressed the economic, social, political and legislative problems associated with the development and implementation of this program. The primary thrust is toward a watershed management system designed to prevent damages due to increased runoff from urban development. A pilot study is in progress for a typical urbanising watershed in need of such a system. In addition, corrective measures are currently being developed in already urbanised watersheds experiencing severe channel erosion and flooding.

DAWDY, D.R. 1967: "Knowledge of sedimentation in urban environments". *J. Hydraul. Divn., Proc. ASCE*, Vol.93(HY6); p235-245.

Key words: sediment yield; urbanisation; landuse change.

The two kinds of sedimentation data are associated with: (1) gross drainage basin sediment yield; and, (2) time variability of sediment yield. For a given basin, the greater the forest area the smaller the sediment yield, and the effects of urbanisation may influence the base condition of a given area. Geomorphic changes may be induced by the increased variability of flow caused by urbanisation and highway construction.

DAWDY, D.R. 1969: "Considerations involved in evaluating mathematical modeling of urban hydrologic systems". *U.S. Geol. Survey water supply paper No.1591-D*.

Key words: mathematical models; model studies.

Interest in the hydrology of the urban environment leads to interest in modeling as soon as quantitative answers are desired to hydrologic questions. A stochastic model relates input to output statistically. It can also be a statistical simulation of a synthetic streamflow trace. A deterministic model relates input to output in such a manner that, once the input is known, the output is wholly predictable. The most often used deterministic models in hydrology are those based on the laws of hydraulics, which use equations of continuity and motion. An analytical model usually describes a restricted area of hydrology in which the laws governing the process are fairly well known and accepted. A synthetic model specifies a conceptual relating func-

tion, and system parameters are identified through the use of input and output data. Thus, an analytic model usually describes a narrow or restricted sub-system in hydrology so that the problem is made manageable, whereas a synthetic model can be made as complex and can cover as broad an area of hydrology as desired.

DAWDY, D.R. et al. 1969: "Rainfall - runoff simulation for predicting urban flood runoff". Presented at the October 1969 ASCE Annual and Environmental Meeting, Chicago, Illinois.

Key words: rainfall-runoff relationships; mathematical models; flood forecasting.

DAWDY, D.R. and BERGMANN, J.M. 1973: "Evaluation of effects of landuse changes on streamflow". In, Agricultural and urban considerations in irrigation and drainage: selected papers from the ASCE Irrigation and Drainage Divn., Speciality Conference, Fort Collins, Colorado; p619-626.

Key words: environmental effects; streamflow; computer models; landuse change; watershed management; hydrologic data.

Deterministic structure-imitating hydrologic models can be an invaluable tool for predicting the changes in streamflow that will result from changes in land use. The relative magnitude of the change in streamflow resulting from a given change in land use will vary inversely with storm severity. The user of the hydrologic model should be aware of its limitations - a degree of error is inherent in every model and that error is usually compounded by uncertainties in the prediction of change in land use.

DAY, J.P. et al. 1975: "Lead in urban street dust". Nature, London, Vol.253(5490); p343-345.

Key words: lead; heavy metals.

This investigation has two simple objectives: to determine the lead content of the dust and dirt likely to be encountered by children as a normal part of their environment in Greater Manchester, and to assess the importance of the dust as a component of the lead intake of urban children. Our results show an average lead concentration of 970 ppm, with little significant variation either with type of locality (main road, side street, playground, and so on), or with position within the urban area. Samples from nearby rural areas had average concentrations of 85 ppm. By comparison, typical values for rural soils in Britain fall in the range 50 to 100 ppm, whereas the lead content of 'uncontaminated' soils is approximately 10 ppm. Our results for urban dust are similar to those obtained in other cities.

DEBO, T.B. and ULRICH, B.O. 1977: "Storm management program is model for others". Public Works, Vol.108(7); p60-62.

Key words: bank erosion; surface runoff; streamflow; flood routing; erosion control; model studies; mathematical models; urban drainage.

Urbanisation and changes in land use have substantially altered the natural drainage and vegetation patterns in the area of Columbus, Georgia. Construction in previously undeveloped areas has led to increased surface runoff, sedimentation, streamflow, and stream bank erosion. The Columbus Storm Water Management Program (CSWMP) was designed to establish guidelines and procedures to alleviate flooding, erosion, and sedimentation and to protect existing natural areas. New computer techniques are used to augment traditional methods. The first phase of the three phase program included a comprehensive soils inventory and analysis to supplement existing data. The goal of the second phase was to conduct hydrologic studies and to develop a comprehensive erosion and sediment control program. Third phase of the program includes implementation of a two-part urban flood simulation model. The first component of the model generates flood hydrographs and frequency estimates, while the second component evaluates alternative flood mitigation measures using local physical characteristics and economic data.

DELLEUR, S.W. et al. 1975: "On modeling the runoff process in urban areas". Paper in the proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Ky.

Key words: computer models; urban runoff; urbanisation; rainfall-runoff relationships.

The hydrologic cycle is greatly modified by man's activities in urbanised environments. Urbanisation modifies in particular the runoff process. Several theoretical and empirical models of evaporation and infiltration processes are compared and evaluated. The parameter sensitivity of these models to changes is discussed. The sensitivity analysis leads to a recommendation of specific methods to estimate the rainfall excess in an urbanised environment. It was found that the proper estimation of the impervious areas directly connected to storm sewers is paramount in the estimation of urban runoff. The rainfall excess-direct runoff transfer is simulated by means of a quasilinear method which considers the process to be linear within a storm but nonlinear between storms. A dimensionless unit hydrograph (IUH) is given which may be rescaled by means of the peak value of the IUH and time to peak which are correlated to watershed and storm characteristics. A simplified lumped nonlinear second order model is studied and its performance is compared with the quasi-linear approach.

DEMPSEY, C.R. 1968: "The effects of geographical and climatic setting on the economic advantages of alternative flood control measures". Research Report 10, Kentucky Water Research Inst., Lexington, Ky.; 166pp.

Key words: hydrographs; flood forecasting; flood control; urbanisation; computer models.

Selection of the economic optimum combination of flood control measures by stage throughout project life and by location within the flood plain requires evaluation of the effects of urban development and channel improvement on the peak, volume, rising time, and shape of the flood hydrograph. Through application of the Stanford Watershed Model to a given watershed before and after an extensive period of urban development and channel improvement, a series of curves were developed for determining each of the effects on flood hydrographs. The end product is a computer program capable of generating flood hydrographs appropriate for any typical watershed surface, drainage area, urban development, and degree of channel improvement. Values are developed and compared between California and Kentucky to obtain some idea as to the effects of geographical and climatic setting on the results. The method of hydrograph generation is applied to an economic analysis of the optimum combination of structural and non-structural flood control measures within South Jefferson County, Kentucky.

DEMPSTER, G.R. 1974: "Effects of urbanisation on floods in the Dallas, Texas, Metropolitan area". U.S. Geol. Survey, Austin, Texas, Water Resources Division; 57pp.

Key words: flood forecasting; urbanisation; mathematical models.

The effects of urbanisation on flood characteristics of streams in the Dallas metropolitan area were studied by use of a digital model of the hydrologic system, which was calibrated by using observed data from 19 storms in six basins to estimate peak discharges and flood volumes and to simulate a 57 year record of annual peak discharges in 14 basins. The flood frequency characteristics were defined by fitting the simulated 57 year record to a Log-Pearson Type III distribution. The data indicated that in a fully developed residential area, with 37 percent impervious area, the average annual direct runoff is about double that of an undeveloped area.

DEMPSTER, G.R. and MASSEY, B.C. 1971: "Annual compilation and analysis of hydrological data for urban studies in the Dallas, Texas, metropolitan area, 1969". U.S. Geol. Survey basic data report; 136pp.

Key words: storm runoff; rainfall-runoff relationships; hydrologic data; data collection; urbanisation; hydrographs; watershed

management.

This report represents compilation and analysis of hydrologic data collected in urban or partly urban drainage basins in the Dallas, Texas, metropolitan area during the 1969 water year. The Dallas urban studies involve the collection of precipitation, runoff, and flood elevation data in seven drainage basins within the city of Dallas and in two drainage basins outside the city in Dallas County. Two of the seven study areas in Dallas have headwaters in rural areas outside the city limits, but the largest part of each drainage basin is within the city. Total precipitation and rainfall intensities were determined from measurements at 34 recording gauges. Runoff data were based on discharge measurements and stage records at eight continuous record stations and 13 crest-stage partial-record stations. Water surface elevations were obtained at 99 flood profile locations. Annual records of daily discharges at continuous record gauging stations, maximum discharge at crest-stage partial-record gauging stations, and documented peak elevations at flood profile, partial-record stations are tabulated.

DEMPSTER, G.R. and MASSEY, B.C. 1972: "Annual compilation and analysis of hydrologic data for urban studies in the Fort Worth, Texas metropolitan area, 1970". U.S. Geol. Survey open-file report; 89pp.

Key words: rainfall-runoff relationships; urban hydrology; storm runoff; hydrologic data; data collection; peak discharge; urban drainage; hydrographs.

Basic hydrologic data collected in four study areas near Fort Worth, Texas, during the 1970 water year are presented. The four study areas within the metropolitan area are Dry Branch, Little Fossil Creek, Sycamore Creek (above Interstate Highway 820), and Sycamore Creek tributary. The Sycamore Creek tributary study area includes the highly impervious area of the Seminary South Shopping Centre as a subarea. The investigations are designed to evaluate the factors affecting floods on small streams in the metropolitan area. The objectives of the program are: to determine, on the basis of historical data and hydrologic analyses, the magnitude and frequency of floods; to document and define the areal extent of floods of greater than ordinary magnitude; and to determine the effect of urban development on flood peaks and volume. The maximum discharge rates for selected storms in the 1970 water year ranged from 278 cfs at Seminary South Shopping Centre (drainage area, 0.38 sq ml) to 1,370 cfs at Little Fossil Creek at Mesquite Street (drainage area, 12.3 sq ml).

DEMPSTER, G.R. and MASSEY, B.C. 1972: "Annual compilation and analysis of hydrologic data for urban studies in the Dallas, Texas metropolitan area, 1970". U.S. Geol. Survey data

report; 122pp.

Key words: rainfall-runoff relationships; urban hydrology; hydrologic data; data collection; peak discharge; urbanisation; urban drainage; hydrographs.

The compilation and analysis of hydrologic data collected on urban or partly urban drainage basins in Dallas, Texas, metropolitan area during the 1970 water year are presented. The objectives of the program are: to determine, on the basis of historical data and hydrologic analyses, the magnitude, frequency, and areal extent of flooding; to document and define floods of greater than ordinary magnitude; and to determine the effect of urban development on flood peaks and volume. The studies involve the collection of data in seven drainage basins within the city of Dallas and in three drainage basins outside the city in Dallas County. Runoff data are based on discharge measurements and stage records at nine continuous-record stations and 13 crest-stage partial-record stations. Water surface elevations are obtained at 115 flood profile locations. Annual records of daily discharges at continuous-record gauging stations, maximum discharge at crest-stage partial-record stations and documented peak elevations at flood profile partial-record stations are given.

DENVER REGIONAL COUNCIL OF GOVERNMENTS. 1969: "Urban storm drainage criteria manual. Volume 1". Manual by Denver Regional Council of Governments, Colo., et al; 388pp. (NTIS PB-186 262).

Key words: storm runoff; flood control; rainfall-runoff relationships; watershed management; urban drainage; analytical techniques.

The manual was written to suggest techniques, methodology, and guidelines to facilitate the implementation of a new and more thorough approach to storm drainage problems in metropolitan Denver. The authors recommend adoption of the manual by government agencies in metropolitan Denver, and that the Denver Regional Council of Governments provide coordinated drainage activities. The manual is a review of the most comprehensive treatment of urban storm drainage criteria available.

DENVER REGIONAL COUNCIL OF GOVERNMENTS. 1969: "Urban storm drainage criteria manual. Volume 2". Manual by Denver Regional Council of Governments, Colo., et al; 143pp. (NTIS PB-185 263).

Key words: storm runoff; flood control; rainfall-runoff relationships; watershed management; urban drainage; analytical techniques.

See abstract given above for Volume 1.

DENVER REGIONAL COUNCIL OF GOVERNMENTS. 1972: "Urban storm drainage and flood control in the Denver region - final Water & soil technical publication no. 15 (1979)

report". Final Report, Denver Regional Council of Governments, Colorado; 219pp.

Key words: urban drainage; urbanisation; flood control; storm runoff.

Realising that urbanisation affects society and the quality of life, both positively and negatively, Project REUSE (Rewinding the Environment through Urban Systems Engineering) was concerned with two aspects of the urban environment in the Denver region - storm drainage and flood control, and solid waste management. This report includes a 20 year regional program for major drainage in the study area. Included are discussions of major drainage systems, management responsibilities, criteria, assumptions and uncertainties, four alternative concepts or programs for consideration, and an evaluation of these programs. Basically the four plans are: (1) the current 1970-1974 program, (2) master planning with initial emphasis on preventive master planning followed by design master planning, (3) master planning with construction to be implemented on a county basis as soon as master planning is accomplished, and (4) the same plan as item number three except that all preventive master planning would be completed by 1975. The latter is evaluated to be the best plan and costs are estimated to be more than \$8,500,000 for all planning and construction.

DESBORDES, M. 1975: "Estimation of the coefficients of urban runoff". Ia Tribune du CEBEDEAU, Vol.28(376); p106-110. (In French).

Key words: urban runoff; model studies; rainfall-runoff relationships.

The author discusses the calculation of the coefficients of urban runoff which are used in developing hydrological models of the type developed by Caquot, M., in the late 1940s. Studies of 6 French and 4 American sloping urban basins, the main characteristics of which are tabulated, were used in calculations to obtain a linear relationship between rainfall and runoff, and consequently a simple definition of the runoff coefficients. In discussing the results of the studies of flow in these urban basins it is concluded that the coefficients of runoff in models of the type developed by Caquot, are perhaps best represented by the ratio of the impermeable surface of a basin to the total surface area of the basin. A bibliography of 10 references is appended.

DETWILLER, J. and CHANGNON, S.A. 1976: "Possible urban effects on maximum daily rainfall at Paris, St. Louis and Chicago". J. Applied Meteorology, Vol.15(5); p517-519.

Key words: urbanisation; weather modification.

The seasonal maximum daily rainfall va-

lues for the 1870-1971 period at these three large cities in different climates were studied to discern trends. Upward trends of 19-38 percent were found in the warm season values at all cities, but no significant up or down trends were found in the cold season values. The upward trends in the warm season appear to reflect both natural climatic changes and inadvertent urban effects on local convective precipitation.

DEVEY, D.G. and HARKNESS, N. 1973: "The significance of man-made sources of phosphorus: detergent and sewage". Water Research, Vol.7(1/2); p35-54.

Key words: phosphorus compounds; detergents; water pollution sources; industrial wastes; nutrients.

The aims of this paper have been to establish the significance of detergents and sewage as sources of phosphorus to the aqueous environment. Information has been obtained as to the composition of washing powders and liquids containing phosphates and the reasons for the use of phosphates. Current and past consumption data shows that the trends for detergent use are still very much upward, with a consequent increasing load of phosphates into the aqueous environment based on present formulation. The section of the paper on sewage has given details of the varying levels of phosphates that are found at differing works and the various sources from which these arose. Variations over the day of phosphorus and detergent in sewage show the expected usage pattern for households. Some data has been obtained on the phosphorus content of industrial effluents, but at present these do not appear to be a major source overall. Discussion of the total phosphorus contribution to the aqueous environment per annum shows the tremendous amount of nutrient phosphorus which is discharged to the river system from sewage, even when detergent phosphate is not taken into consideration.

DHARMADHIKARI, V.V. 1970: "Quality of runoff from diversified urban watersheds". M.A. Thesis for University of Arizona, Department of Civil Engineering Mechanics; 197pp.

Key words: storm runoff; water pollution sources; chemical oxygen demand.

Quality of water data are presented from analysis of samples collected during the summer and winter rainy seasons of 1969 from three different types of watersheds in Tucson, Arizona. Continuing expansion and intensification of urban and metropolitan development in semiarid regions of the southwestern United States are adding to the problems associated with water supply and management. Urban runoff shows values of COD (chemical oxygen demand) even larger than that of secondary sewage treatment plant effluent. In residential and commercial watersheds, this pollution appears to be suspended organic material, and its concentration

ranges from 91 to 347 mg per litre. The range observed in runoff from an industrial watershed is from 141 to 1,693 mg per litre. Tests indicate that runoff from domestic or commercial areas can be used for recreational or domestic uses after treatment with alum and adequate chlorination.

DHRUVANARAYANA, V.V. and RIEY, J.P. 1968: "Application of an electronic analog computer to the evaluation of the effect of urbanisation on the runoff characteristics of small watersheds". In, The use of analog and digital computers in hydrology, IASH Publication No.81, Vol.1.

Key words: analog models; model studies; urban runoff; urbanisation.

DIETEMANN, A.J. 1975: "An analysis of the effect of urbanisation on stream quality in tributaries of the Potomac River in Maryland". M.S. Thesis, Dept. of Civil Engineering, University of Maryland, (August 1975).

Key words: water pollution sources; urbanisation; watershed management.

DILLION, P.J. and KIRCHNER, W.B. 1975: "The effect of geology and landuse on the export of phosphorus from watersheds". Water Research, Vol.9; p135-148.

Key words: phosphorus compounds; landuse change.

The export of total phosphorus from 34 watersheds in Southern Ontario was measured over a 20-month period. The annual average export for igneous watersheds (i.e. those of the Canadian Shield) that were forested was 4.8 mg per m² yr⁻¹, significantly different from the average (11.0 mg per m² yr⁻¹) for watersheds that included pasture as well as forest. Similarly, on sedimentary rock, the mean export from forested watersheds (10.7 mg per m² yr⁻¹) differed significantly from those with forest and pasture (28.8 mg per m² yr⁻¹). The differences between watersheds of different geology but similar land use were also highly significant.

Additional data from the literature supported our conclusion. Other forested igneous watersheds of plutonic origin averaged 4.2 mg per m² yr⁻¹ of total phosphorus exported; forested igneous watersheds of volcanic origin, however, averaged 72 mg per m² yr⁻¹. The overall average export from each type of watershed as classified by geology and land use was very similar to that for the same classification found in our study.

The effects of agriculture and urbanisation were to greatly increase the total phosphorus exported. Wide ranges of values probably reflect the intensity of land use.

DINIZ, E.V. 1976: "Quantifying the effects of porous pavements on urban runoff". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p63-70.

Key words: urban runoff; flood control; model studies; flood routing.

Porous pavements have been suggested as a means to reduce volume of runoff as well as peak flows resulting from urbanisation. The use of porous pavements allows for infiltration into the ground from paved areas which would otherwise be impermeable. Porous pavements can also be used to reduce the overload on existing storm sewers. The effects on runoff quality and quantity from porous pavements have been quantified by a modeling scheme which considers the pavement and subgrade as two hydraulically connected control volumes forming a single system. Inflow to the system are direct rainfall and an overland flow hydrograph from contributing impervious areas. Outflows from the system include vertical seepage, horizontal drainage, evaporation, and surface flow in the case of a surcharged porous pavement. Model input requirements include physical dimensions of the porous pavement, rainfall intensities, and impermeabilities of the pavement, subgrade, and natural ground. A depth-storage function for the pavement and subgrade is also necessary. A comprehensive temporal accounting of flow and storage in each element of the system is output from the model.

DINIZ, E.V. and CHARACKLIS, W.G. 1976: "Modeling urban runoff from a planned community". EPA Conference on Environmental Modeling and Simulation; p367-371.

Key words: watershed management; urban runoff; computer models; suspended solids; biochemical oxygen demand; chemical oxygen demand; Kjeldahl nitrogen; nitrates; phosphorus compounds.

The temporal and spatial distribution of several key water quality and quantity parameters were defined at selected sites on Panther Branch which flows through The Woodlands, a planned community near Houston, Texas. The characteristics of overland runoff from the urbanising area and an upstream undeveloped site were quantified. The capacity of the Storm Water Management Model (SWMM) to model urban runoff water quantity was improved to include the "natural" drainage concepts of The Woodlands. The predictive capabilities of SWMM, with regard to suspended solids and BOD were verified for the Panther Branch watershed, and the model was modified and expanded to include the prediction of COD, Kjeldahl N, nitrates, and phosphates.

DINIZ, E.V. and MOORE, W.I. 1974: "Changes in the sedimentation characteristics of an urbanising watershed, Dallas and Collin Counties, Texas". In, Proceedings National Sym-

posium on urban rainfall and runoff and sedimentation control, University of Kentucky, Lexington, Ky.; p189-198.

Key words: sediment yield; erosion; urbanisation; lakes.

White Rock lake, on White Rock Creek, in Dallas and Collin Counties, Texas has a sediment contributing area of 97.4 sq. mi, of which over 55 percent is urbanised. Storage of water in White Rock Lake was started in 1910. The effects of continuing urbanisation on the sedimentation characteristics of the watershed were studied by use of three sedimentation surveys conducted in April 1935, March 1956, and October 1970. The relationships among reservoir capacity loss, sediment density, reservoir trap efficiency, watershed climate, and watershed land use were analysed. In spite of an increasing reservoir capacity loss and an increase in average annual rainfall, it was found that the average dry weight of sediment in lbs per cu ft decreased with increasing urbanisation. In the case of White Rock Creek, urban sediment created localised problems, but did not cause increased sediment production for the total watershed.

DISKIN, M.H. et al. 1978: "Parallel cascades model for urban watersheds". J. Hydraul. Divn., Proc. ASCE, Vol.104(HY2); p261-276.

Key words: mathematical models; computer models; hydrographs; surface runoff.

The conversion of rainfall to surface runoff in urbanised watersheds is represented by a model composed of three main elements. The first element receives the total rainfall hydrograph as input and produces two rainfall excess hydrographs as output. These are used as inputs to the other two elements which are in parallel. The two elements, representing the impervious and the pervious portions of the watershed, were taken to be composed of cascades of linear reservoirs. The elements produce as their outputs two hydrographs that are added to produce the direct surface runoff hydrograph of the watershed. The first element of the model is nonlinear but the other two are linear. The model, viewed as one unit covering total rainfall to runoff, is thus nonlinear. Data from a semi-arid urban watershed in Arizona were used to demonstrate the use of the model.

DOBBINS, W.E. 1962: "Quality and composition of storm sewage overflows". Paper presented at the Metropolitan Section, ASCE Sanitary Engineering Division Symposium, New York University, Bronx (April 1962).

Key words: storm runoff; overflows; water pollution.

DOEHRING, D.O. et al. 1975: "Modeling the dynamic response of flood plains to ur-

banisation in the southeastern New England. Completion Report". Massachusetts University, Amherst, Water Resources Research Centre, Publication No.53; 35pp.

Key words: model studies; landuse change; flood forecasting.

The relation between landuse changes and flood expectancies in southeastern New England is examined.

DONIGIAN, A.S. and CRAWFORD, N.H. 1976: "Modeling nonpoint pollution from the land surface". Final report, Hydrocomp Inc., Palo Alto, Calif.; 294pp. (NTIS PB-257 089/3ST).

Key words: water pollution; streamflow; landuse change; mathematical models; sediment transport; nonpoint pollution sources; organic compounds; model studies; sediment yield.

Development and initial testing of a mathematical model to continuously simulate pollutant distributions to stream channels from nonpoint sources is presented. The Nonpoint Source Pollutant Loading (NPS) Model is comprised of subprograms to represent the hydrologic response of a watershed, including snow accumulation and melt, and the processes of pollutant accumulation, generation, and washoff from the land surface. The simulation of nonpoint pollutants from both pervious and impervious areas is based on sediment as a pollutant indicator. The calculated sediment washoff is multiplied by user specified 'potency factors' that indicate the pollutant strength of the sediment for each pollutant simulated. Both urban and rural areas can be simulated. Initial testing of the NPS model was performed on three urban watersheds in Durham, North Carolina; Madison, Wisconsin; and Seattle, Washington.

DONIGIAN, A.S. and CRAWFORD, N.H. 1977: "Simulation of nutrient loadings in surface runoff with the NPS model". Hydrocomp, Inc., Palo Alto, Ca., Report EPA-600/3-77-065; 110pp. (NTIS PB-270 967).

Key words: organic compounds; mathematical models; nutrients; urban runoff; computer models; phosphorus compounds; nitrogen compounds; suspended solids; waste water treatment; nonpoint pollution sources; Kjeldahl nitrogen.

The Nonpoint Source Pollutant Loading Model (NPS) was evaluated for simulation of nutrient loading in surface runoff with one urban and two small agricultural watersheds. The NPS model was used to simulate total solids, total Kjeldahl nitrogen, total phosphorus, and iron for storm runoff over an 18-month period. Phosphorus, total nitrogen, and iron values predicted by the model compared favourably with observed values. Other parameters such as ammonia nitrogen, nitrate nitrogen, and phosphate phosphorus, which are

transported in solution rather than in the sediment fraction of surface runoff, were not predicted as accurately. The NPS model is suggested as an adequate means of simulating nutrient loadings on the basis of sediment loss. Application of the model may be limited if subsurface flow in the area being considered is a major portion of total runoff.

DONSEL, D.J.VAN. et al. 1967: "Seasonal variations in survival of indication bacteria in soil and their contribution to storm water pollution". Appl. Microbiol., Vol.15(6); p1362-1370.

Key words: bioindicators; bacteria.

A three year study was made on the survival of selected strains of *Escherichia coli* and *Streptococcus faecalis* in shaded and exposed outdoor plots. The soils were dosed periodically, and subsequent reductions in survival are shown graphically as seasons vary. Periods for 90 percent reduction of *Esch. coli* ranged from 3.3 days in summer to 13.4 days in autumn and for *S. faecalis* from 2.7 days in summer to 20.1 days in winter. During the fall, the survival periods for the organisms were the same, but in spring and winter *Streptococcus* survived longer. Both organisms could be isolated from runoff during periods of heavy rainfall in spring; however, isolation during summer and autumn months was sporadic. On account of these results and other factors, it was considered that *Esch. coli* was the better indicator of pollution.

DOUGLAS, I. 1975: "Flood waves and suspended sediment pulses in urbanised catchments". In, preprints of papers, Institute of Engineers, Australia, Hydrology Symposium, Armidale; p61-64.

Key words: flood discharge; urbanisation; urban runoff; sediment yield; storm runoff; sediment transport; rainfall-runoff relationships.

Analysis of storm event sediment transport using dimensionless sediment concentration graphs reveals contrasts between runoff and sediment yield from urban areas and that from adjacent rural lands. For a catchment in New South Wales (Australia) which is 15 percent urbanised, the contrasts are marked for short-duration local storms, but not for major rainfall events. In the vicinity of Kuala Lumpur (Malaysia) a tropical area 40 percent urbanised, the contrast is so great that even in extreme events urban runoff and sediment yields are greater than those from rural areas. In estimating the hydrologic effects of urbanisation, account must be taken of the original character of the ground surface and the proportion rendered impermeable by urbanisation.

DOYLE, J.R. et al. 1976: "Efficient storage of urban storm water runoff". In, Proceedings of the conference on envi-

ronmental modeling and simulation, Cincinnati, Ohio. Report EPA 600/9-76-016; p139-143.

Key words: urban runoff; mathematical models; flood routing.

Mixed integer linear programming is used to evaluate alternatives for use of storm water detention in flood plains and developing areas. This model is suitable where a refined analysis is needed. Mixed integer programming is appropriate when it is necessary to handle fixed charge problems. This added feature significantly increases the computational complexity of the model as compared to standard linear programming procedures. Given an inventory of available storage sites, both in and out of the flood plain, and costs for other flow reduction measures, the optimisation model determines the least costly combination of storage reservoirs. Application to the Hogtown Creek drainage basin in Gainesville, Florida is included to demonstrate the techniques. In solving the problem, the model allocates the specified total potential runoff volumes from each sub-basin among the subbasin and flood plain storage sites, while allowing only a specified volume of runoff to flow downstream. All storage allocations and costs are given. Results show that the fixed costs for providing storage within the flood plain and the subbasin are a small percentage of the total costs.

DRACUP, J.A. et al. 1973: "Synthesis and evaluation of urban - regional hydrologic rainfall - runoff criteria". Environmental Dynamics, Inc., Los Angeles, California. Completion Report, OWRRC-C-2182, 3407, 1; 116pp.

Key words: mathematical models; rainfall-runoff relationships.

Mathematical models of the hydrologic rainfall-runoff process are applied, evaluated and compared, using data from urban and natural watersheds. Criteria are developed for use in the selection of an appropriate hydrologic rainfall-runoff model for specific watershed needs. This study is oriented specifically at closing the gap between research and its application by practicing engineers and hydrologists in the water resources field. New models are not developed, but the use of existing models is clarified through a selection display tableau and user oriented computer programs implementing a wide range of rainfall-runoff models.

DROSTE, R.L. and HARTT, J.P. 1975: "Quality and variation of pollutant loads in urban storm water runoff". Canadian J. of Civil Engineering, Vol.2(4); p418-429.

Key words: urban runoff; storm runoff; water pollution; chemical analysis; chemical wastes; biochemical oxygen demand; suspended solids; oil wastes.

Research into the pollutional loading
Water & soil technical publication no. 15 (1979)

of urban storm water was carried out on samples of 13 storms throughout a year in the heavily industrialised town of Windsor, Ontario. Stage levels in the sewers were continuously monitored. Samples of discharge were taken and analysed for such qualities as pH, alkalinity, hardness, BOD, presence of suspended solids, chemical content, and determination of grease and oil. Seasonal and annual average concentration values were calculated.

DSIR CENTRAL LIBRARY. CNT: "DSIR Case II: a current awareness service on environmental pollution and control". Fortnightly bulletin, DSIR Central Library, Wellington.

Key words: water pollution control; environmental effects; bibliographies.

DSIR CASE II is a fortnightly current awareness bulletin available to users engaged in environmental research. The primary purpose of this bulletin is to announce the availability of current U.S. Government sponsored environmental pollution and control research and development reports. The reports are received by Central Library in microfiche form.

DURBIN, T.J. 1974: "Digital simulation of the effects of urbanisation on runoff in the Upper Santa Ana Valley, California". U.S. Geol. Survey water resources investigations, 41-73; 44pp.

Key words: urban hydrology; urban runoff; urbanisation; storm runoff; peak discharge; mathematical models; rainfall-runoff relationships.

The Stanford Watershed Model was used to simulate the effects of urbanisation on the discharge from five drainage basins in the Santa Ana Valley, California, an area with an average annual precipitation of 15 inches. The drainage areas ranged in size from 3.72 to 83.4 square miles. Using the model, synthetic records of streamflow for each watershed were generated to represent various degrees of urban development. Examination of the synthetic records indicated that urbanisation has the following effects on streamflow in the area: (1) average annual runoff from a watershed covered by 10 percent effective impervious area is approximately 2 inches, and increases by 1 inch for each increase in effective impervious cover equal to 10 percent of the drainage area; (2) urbanisation can increase the magnitude of peak discharge with a recurrence interval of 2 years by a factor of three to six; and (3) peak discharges and daily mean discharges that have recurrence intervals greater than a limiting value ranging from 50 to 200 years or more are little affected by urbanisation.

DURBIN, T.J. 1975: "Selected effects of suburban development on runoff in South Coastal California". Paper in proceedings of the National Symposium on Urban Hydrology and Sediment Control, Univer-

sity of Kentucky, Lexington, Ky.

Key words: mathematical models; urban runoff; storm runoff; peak discharge.

The Stanford Watershed Model was used to simulate the effects of suburban development on the runoff from five drainage basins in the south-coastal area of California, a region with a semi-arid climate and an annual average precipitation of 15 inches (381 millimeters). The drainage basins ranged in size from 3.72 to 83.4 square miles (9.64 to 216 square kilometers). Using the model, synthetic records of runoff for each basin were generated to represent various degrees of urban development. Examination of the synthetic records indicated that suburban development has the following effects on runoff: (1) Average annual runoff from a drainage basin with an effective impervious area of 10 percent of the drainage area is approximately 2 inches (51 millimeters). The average annual runoff from a fully developed basin with an effective impervious area of 30 percent is approximately 4 inches (102 millimeters). (2) Suburban development can increase the magnitude of peak discharge with a recurrence interval of 2 years by a factor of three to six. (3) Peak discharges that have recurrence intervals greater than a limiting value ranging from 50 to 200 years or more are little affected by suburban development.

DUSPER, T.A. 1966: "The impact of urbanisation on watershed development". J. of Soil and Water Conservation, Vol.21(1); p24-26.

Key words: watershed management; urbanisation; landuse change; erosion.

A shift in land use from agriculture to urban development not only creates problems for community planners but presents an equally challenging problem to watershed planners, especially in an area prone to flooding. In this article the author explains why possible future land use changes must be considered in planning a watershed project.

EAGLESON, P.S. 1962: "Unit hydrograph characteristics for sewered areas". J. Hydraul. Divn., Proc. ASCE, Vol.88(HY?); p1-25.

Key words: hydrographs; surface runoff; storm runoff.

Hydrographs of measured storm sewer outflow from five urban areas ranging up to 7.5 sq miles in size in Louisville, Kentucky, are analysed along with simultaneous recordings of point rainfall. The ease of application of this technique, once an estimate of the rainfall-"surface" runoff ratio has been made, encourages further investigation into the generality of the correlations presented.

EAGLESON, P.S. 1968: "Modeling surface runoff in urban hydrology". In, urban water resources research, first year report, American Society of Civil Engineers, app. A, chap.4; pA32-A78.

Key words: rainfall-runoff relationships; model studies; mathematical models.

Computation of surface runoff by numerical solution of approximations to the momentum and continuity equations is both feasible and accurate, and the development of general computer programs for performing these computations is well advanced. Numerical analysis allows consideration of areal as well as temporal variation in both storm and catchment parameters. Analysis experiments with these equations demonstrate the quantitative effect of simplifications in either the equations themselves or in the boundary and initial conditions for which they are solved. The coefficients which appear in these equations have a well recognised physical significance; their evaluation, through careful field observation, insures the establishment of a generally applicable technique.

EAGLESON, P.S. and MARCH, F. 1965: "Approaches to the linear synthesis of urban runoff systems". Hydrodynamic Laboratory Report No.85, M.I.T., Cambridge, Mass.

Key words: urban runoff; mathematical models; hydrologic systems.

EALY, C.D. et al. 1973: "Environmental aspects of runoff and siltation in the Anacostia Basin from hyperaltitude photographs". N.A.S.A. Goddard Space Flight Centre, Greenbelt, Md., Report No. NASA-TM-X-70888, X-644-73-352; 49pp. (NTIS N75-24067/1ST).

Key words: environmental effects; aerial photography; sediment transport; water pollution; erosion; peak discharge; chemical wastes.

The effects of urbanisation and highway construction on runoff, erosion and siltation in the Anacostia watershed were analysed. The analysis was based on changes in land use patterns demon-

strated by aerial photographs, geologic and hydrologic data. Subwatersheds were studied in terms of three hypothetical storms of different magnitudes. An approximately 10 percent increase in impervious surface can cause a 12 percent increase in peak discharge for storms of the magnitude of tropical storm Agnes, a 20 percent increase for a 10 hour storm and a 150 percent increase for a thunderstorm. The early discharge from a storm of Agnes' magnitude can be increased by 107 percent. Corresponding effects were observed on soil erosion and siltation from bare construction sites. These effects are interrelated with sewage, oil, and chemical pollution and inadequate public transportation. The net result is steady degradation of the local environment, the estuary and the bay.

EARL, C.T. et al. 1976: "Urban flood warning and watershed management advances in metropolitan Melbourne". ASCE Urban Water Resources Research Program, Tech. Memo. No.30; 72pp. (NTIS PB-259 549).

Key words: urbanisation; sediment control; computer models; urban drainage; combined sewers.

Advances made in institutional arrangements and flood warning systems are reported. Outlined in Part I are functions of the Melbourne and Metropolitan Board of Works, flood problems it encounters, and its mitigative procedures, including non-structural measures. Part II describes a computer-operated and telemetered rainfall and flow gauge-network for flood forecasting and prediction recently installed in metropolitan Melbourne. Part III describes the Dandenong Valley Authority, a unique organisation having responsibilities for planning, flood protection, drainage, pollution abatement and aesthetic/recreational aspects in its 286 sq.mi, jurisdiction. A number of ideas utilised and lessons learned are relevant in the U.S.

EDISON WATER QUALITY LABORATORY. 1971: "Environmental impact of highway deicing". Edison Water Quality Laboratory, EPA Edison; 124pp. (NTIS PB-203 493; EPA 11040 GKK06/71).

Key words: water pollution; surface runoff; ground water resources; aquifers; chlorides; environmental effects.

Deicing agents for removal of ice and snow from highways and streets are essential to wintertime road maintenance in most areas of the U.S. Due to the ever increasing use of highway deicing materials, there has been growing concern as to environmental effects resulting from these practices. The state-of-the-art report critically reviews the available information on methods, equipment and materials used for snow and ice removal; chlorides found in rainfall and municipal sewage during the winter; salt runoff from streets and highways; deicing compounds found in surface streams, public

water supplies, ground water, farm ponds and lakes; special additives incorporated into deicing agents; vehicular corrosion and deterioration of highway structures and pavements; and effects on roadside soils, vegetation and trees. Highway deicing can cause injury and damage across a wide environmental spectrum. Recommendations describe future research, development and demonstration efforts necessary to assess and reduce the adverse impact of highway deicing.

EIFFERT, W.T. and FLEMING, P.J. 1969: "Pollution abatement through sewer system control". J. Water Pollution Control Federation, Vol.41(2); p285-291.

Key words: waste water treatment; pollution abatement.

Concurrent with a major waste water treatment plant expansion program in Dayton, Ohio, for effluent release into the Great Miami River, a four point program has been initiated to eliminate pollution from storm sewers. Although Dayton has a separate sewer system, untreated industrial plant wastes and municipal by-passes must be eliminated to insure the 90 to 95 percent pollution reduction required by water quality standards.

ELLIS, J.B. 1975: "Urban storm water pollution: research report 1: back ground review, objectives and preliminary considerations". Research Report 1, Middlesex Polytechnic; 61pp.

Key words: water pollution; network design; instrumentation; analytical techniques; data collection.

The aims of a research program to investigate the water pollution of the Silk Stream and River Brent catchments, north London, are outlined, together with the sampling design and methodology, catchment characteristics, field instrumentation and analytical procedures for the monitoring of water quality and sediment characteristics.

ELLIS, J.B. 1976: "Sediments and water quality of urban storm water". Water Services J., Vol.89(970); p730-734.

Key words: storm runoff; urban runoff; water pollution sources; heavy metals; organic compounds; bacteria; suspended solids; phenols; detergents; oil wastes.

The author discusses the potential pollution hazards resulting from the discharge of storm water runoff to surface waters in urban areas. To illustrate these problems a study of the catchment area of the Silk Stream, the largest tributary of the River Brent, and which drains some 3323 ha of north London, is described. The results of a study of the hydrology, water quality, dissolved oxygen levels, and nature of the storm water sediments in the area are described with the aid of graphs. A sec-

tion is also devoted to the origins and levels of heavy metals in the sediments. It is concluded that fine grained sediment sludges derived from storm water runoff can release and sorb ions to and from solution, thereby determining the mode and pattern of pollutant transport and deposition for any given hydraulic flow condition. It is also noted that these forms of studies have an important implication for water quality monitoring and prediction within urbanised catchments.

ELIIS, J.B. 1977: "The characterisation of particulate solids and quality of water discharged from an urban catchment". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p283-291.

Key words: storm runoff; solid wastes; suspended solids.

The pollution loads resulting from storm water discharges to receiving streams in urban areas are primarily exerted by high concentrations of particulate materials. Chemographs for a separately sewered development in the northwest suburbs of Greater London show a double peaking of solids and a strong 'first-flush' phenomenon. Occasional lags of the flood wave behind the sediment wave are explained in terms of flow characteristics and the growth of fungal mats in the sewer system. Pollutants are examined in terms of the characteristics, components and sizes of particulates discharged, and the importance for water quality of the solids fraction below 0.06 mm is demonstrated.

EMERY, R.M. et al. 1973: "Enriching effects of urban runoff on the productivity of a mesotrophic lake". Water Research, Vol.7(10); p1505-1516.

Key words: urban runoff; lakes; algae; nutrients.

Sewage was diverted from Lake Sammamish in September 1968, and since then there have been no significant responses by trophic indicators which indicate the lake is beginning to recover. To explain this delay in response, extensive urban development in the lake's watershed was considered as a factor which might be acting to inhibit the lake's recovery. In vitro uni-algal experiments water from 13 streams stimulated algal growth significantly, but these streams constitute less than 14 percent of the lake's total water income. Of these streams only two drain urban areas and account for less than 2 percent of the water income. In situ experiments showed that no streams were significantly stimulatory to natural populations of phytoplankton. Other in situ studies showed that one urban stream and two from undeveloped areas caused substantial increases in periphyton growth after a 12 day period, although these increases were not statistically significant. Additional in situ nutrient limitation experiments in August of 1970 and 1971 revealed that P

and N were limiting only in combination. Results from these studies do not support the contention that urban runoff is seriously enriching the limnetic region of Lake Sammamish.

EMMETT, W.W. 1974: "Channel changes". Geology, Vol.2(6); p271-272.

Key words: channel erosion; urbanisation; urban hydrology; alluvial channels.

Environmental impacts may alter the quantities of water and sediment carried in a stream and thus may increase or diminish naturally occurring rates of channel changes and the pre-impact frequency of flows. Repetitive cross-channel surveys to determine changes in channel size or location measure the response of stream to environmental impact and may provide data necessary before corrective measures can be taken to minimise the effects of the impact. One effect on stream channels from the impact of urbanisation can be shown, by example from one stream, to be a loss in channel size due to deposition of sediment. After 17 years of urbanisation encroaching on the area, the channel was only 66 percent of the size it was at the beginning of that period.

ENGELEN, G.B. and KAI, B.F.M. 1977: "Hydrological setting and water quality of the urban artificial sandpit lake 'Sloterplas' at Amsterdam". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p315-323.

Key words: lakes; water pollution sources; eutrophication; algae.

The Sloterplas is a lake covering an area of 86 ha with a maximum depth of 38 m, situated in the centre of the western post-war extension of the city of Amsterdam, within an independent unit in the water management system, viz. the Sloterpolder. Sources of pollution are street refuse washed into the canals through the sewer system, and the inflow of polluted water from the city centre through some sluices. The holomictic lake therefore is eutrophic, which is reflected in occasional algal blooms and anaerobic conditions at the bottom during summer stratification. The investigation conducted from April 1974 to March 1975 examined the water balance of the Sloterpolder, the pattern of water quality in the entire surface water system of the polder, and the evolution of the temperature-oxygen stratification in the Sloterplas. The results lead to distinguishing seven hydrological units within the Sloterpolder.

ENVIROGENICS COMPANY. 1971: "Urban storm runoff and combined sewer overflow pollution". EPA Water Poll. Control Res. Series, 11024 FRM 12/71; 204pp. (NTIS PB-208 989).

Key words: surface runoff; water pollution; mathematical models; combined sewers; waste storage; sewage treatment.

Necessary data are not available in most areas to determine or predict distributions of storm water runoff and combined sewage flows and pollutant concentrations. To alleviate this problem, a procedure was developed to permit rapid, economical, and accurate assessments of system performance based on three different and important water quality criteria. The first criterion establishes an absolute maximum pollutant concentration which cannot be exceeded. The second criterion establishes an acceptable distribution of pollutant concentration by specifying the greatest frequency of occurrence for a particular concentration value. The third criterion establishes the maximum acceptable excession frequency for a particular pollutant frequency. A computer model was then used with a modified rational runoff method to perform preliminary design tasks and weigh alternatives to the designs. The least costly system was developed for the Sacramento, California area as an example.

ERIE AND NIAGARA COUNTIES. 1973: "Water quality management study". Erie and Niagara Counties, Regional Planning Board, 2085 Baseline Road, Grand Island, New York, 14072, U.S.A.

Key words: urban runoff; water pollution sources; industrial wastes; waste water treatment; waste water disposal; water pollution control.

Portions of Lake Erie, Lake Ontario, all of the Niagara River (international boundaries), and virtually all of the land streams flowing through the urbanised areas of the region have been heavily polluted with municipal and industrial waste water and other wastes. The problem of pollution in the Niagara River is magnified by the fact that the Niagara Falls and Niagara River Gorge area is a principal national and international tourist attraction. Also, Lake Erie and Lake Ontario are heavily devoted to water - oriented recreation.

The purpose of this study is to present a plan for the development of a Water Quality Management Program which will restore and maintain the water quality in accordance with the standards set forth by the Stream Classifications. Its objective is to improve the quality of the water within the region by: (1) Identifying the sources of pollution resulting from inadequate waste water treatment and assigning priorities for their improvements. (2) Expanding and coordinating existing surveillance and monitoring programs for detecting sources of pollution and collecting data needed by State, Federal and International Joint Commission regulatory agencies to enforce their requirements. (3) Encouraging experimentation and research of new disposal and treatment systems and techniques. (4) Encouraging cooperation of governmental agencies at the local, State, and Federal level, in the development and im-

plementation of an effective regional water pollution control program.

ESCRIT, L.B. 1973: "Coordination of British and American methods of estimating rainfall - runoff to sewers". Survey Local Government Technol. (G.B.), Vol.141(4226); p40.

Key words: analytical techniques; rainfall-runoff relationships.

There are great differences between the Lloyd-Davis method and the 'rational' method, but it is shown that these can be resolved and a variety of the 'rational' method used for all parts of the world, provided that suitable rainfall and runoff coefficients can be found.

ESPEY, W.H. 1968: "Evaluation of hydrologic effects of urbanisation". Paper presented at 49th AGU of AGU, March 1968. Surface water Hydrology. (See Trans. AGU, Vol.49(1); p170).

Key words: peak discharge; storm runoff; urbanisation; analytical techniques.

Previous studies have indicated that urbanisation results in a change in the response of an urban watershed; the flood peak is increased and the time sequence of runoff is shortened. The objective of this paper is to evaluate and extend a previous study to determine the effects of urbanisation on several small watersheds located in Houston, Texas. Equations derived by Espey evaluate certain unit hydrograph characteristics for underdeveloped conditions and predict the same characteristics for future urban conditions on a small urban watershed located in Austin, Texas. The applicability of these equations to other watersheds is evaluated by comparison with historical data from several small watersheds in Houston, Texas. The hydrologic data from the Houston, Texas, area and the data used to derive the original unit hydrograph equations by Espey are combined, and modified equations having broader application are derived through multiple linear regression analysis.

ESPEY, W.H. et al. 1965: "A study of some effects of urbanisation on storm runoff from a small watershed". Centre for Research in Water Resources, University of Texas, Austin, Texas, Report 23; 109pp. (HYD 07-6501, CRWR-7).

Key words: peak discharge; analytical techniques; mathematical models.

A linear regression analysis was applied to data from 24 urban and 11 rural watersheds to derive equations which might predict future urban conditions for the Waller Creek watershed. The watershed contains two gauges. The 2.31 sq miles above the upper gauge are rural while the 1.82 sq miles between the two gauges are basically urban. Results show that urbanisation leads to higher peak flows occurring in shorter

time intervals with greater unit yields (inches per square mile).

ESPEY, W.H. et al. 1969: "Urban effects on the unit hydrograph". In, Effects of watershed changes on streamflow, (eds. W.L. Moore; C.W. Morgan), Water Resources Symposium No.2, Centre for Research in Water Resources, University of Texas; p215-228.

Key words: hydrographs; peak discharge.

The effects of urbanisation on the unit hydrograph of 'mean annual' flood are examined in the development of a simple prediction equation. This suggests that peak flows of the unit hydrograph may be tripled and time of rise may be reduced by a factor of a third due to urban development, although it is pointed out that there may be many exceptions due to detention structures, flow capacity of secondary drainage and non-homogeneous development.

ESPEY, W.H. et al. 1975: "Application of the Storm Water Management Model to a 'natural' drainage system in a planned community". In, Second Annual National Conference on Environmental Engineering Research, Development and Design; 3pp.

Key words: surface runoff; landuse change; total organic carbon; chemical oxygen demand; bacteria; biochemical oxygen demand; suspended solids; dissolved solids; heavy metals; algae; organic compounds; nitrogen compounds; phosphorus compounds; model studies.

The characteristics of overland runoff from an urbanising area and an undeveloped site were comprehensively quantified. Parameters whose temporal and spatial distribution were defined at selected sites on the major drainage network include discharge, TOC, COD, BOD, suspended solids, dissolved solids, P, N, indicator bacteria, pathogenic bacteria, heavy metals, chlorinated hydrocarbons, and algae. A management strategy for the utilisation of water resources within the community will be developed using the EPA storm water management model. This plan will include the use of storm water, ground water, and treated waste water in a manner compatible with the natural environment and existing natural drainage network. The purpose of the plan is maximisation of the water resources within the community. The study site is The Woodlands, a new community under development in Montgomery county, Texas.

ESPEY, W.H. and WINSLOW, D.E. 1968: "Time response of urban watersheds". Paper presented at 7th National Fall Meeting of AGU, December 1968; Surface Water Hydrology. (see Trans. AGU, Vol.49(4); p677).

Key words: analytical techniques; model studies; peak discharge.

A summary of previous work concerning the time response of urban watersheds and the results of a recent study on the effects of urbanisation on watersheds in Houston, Texas, are presented. Equations which predict the unit hydrograph for urban and rural watersheds were obtained by multiple linear regression analysis of data from 33 urban and 17 rural watersheds. They indicate that the time to peak for the unit hydrograph of a watershed may decrease 50 to 90 percent as the watershed changes from rural to highly urban conditions. Factors in urban development which influence the time to peak as predicted by the equations are the amount of impervious cover, the type of channel improvement, the amount of vegetation in the channel, and the type of secondary drainage system. An analysis of one Houston watershed indicates that an inadequately sized secondary drainage system may radically limit the change in the time response of the watershed which would be expected from increased urbanisation.

ESPEY, W.H. and WINSLOW, D.E. 1968: "The effects of urbanisation on unit hydrographs for small watersheds, Houston, Texas. Vol.I". A report to OWRR, TRACOR Document No.68-975-U, Austin, Texas; 78pp. (NTIS PB-183 049).

Key words: urban drainage; hydrographs; analytical techniques.

The purpose of this study was to determine the past and future effects of urbanisation on several small watersheds in Houston, Texas, and to develop equations which describe the effects of urbanisation on the unit hydrograph. Rainfall and runoff data from 11 urban and 6 rural watersheds in Houston were reduced and the thirty-minute unit hydrographs obtained. This data was combined with previously reduced data for 22 urban and 11 rural watersheds. Multiple linear regression analysis was then performed to develop equations which describe the thirty-minute unit hydrograph for both urban and rural conditions. The equations were applied to watersheds in Houston, Texas, and indicate that in changing from a rural to a highly urbanised watershed the thirty-minute unit hydrograph may experience an increase in peak discharge of up to 500 percent and a decrease in time of rise of up to 90 percent.

ESPEY, W.H. and WINSLOW, D.E. 1974: "Urban flood frequency characteristics". J. Hydraul. Divn., Proc. ASCE, Vol.100(HY2); p279-293.

Key words: flood forecasting; surface runoff; analytical techniques.

This paper presents the results of a study concerning the occurrence and factors affecting floods from small urban watersheds. Based on log-Pearson Type III flood frequency analysis on four urban watersheds located in Texas, urbanisation has significantly increased peak discharge. However, data on the Waller Creek watershed (Austin, Texas) and Wilbarger Creek watershed

(near Austin, Texas) suggest that the effect of urbanisation on peak discharge decreases after a certain recurrence interval. Data from 27 urban watersheds in Texas, combined with 33 urban watersheds located in Virginia, Maryland, Delaware, Illinois, and Mississippi, form the basis for the derivation of empirical flood frequency equations for small urban watersheds. These equations relate the flood discharge for recurrence intervals of 2.33 yr., 5 yr., 10 yr., 20 yr., and 50 yr. to physiographic, urban, and climatic factors. The significant urban factors were found to be the impervious cover and a channel urbanisation factor.

ESPEY, W.H. and WINSLOW, D.E. 1974: "Quantity aspects of urban storm water runoff". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p83-137.

Key words: analytical techniques; urban runoff; peak discharge; flood routing.

Consideration must be given in designing drainage facilities to the required design of storm rainfall, the rainfall-runoff relationship as affected by the surface, and geometric characteristics of the watershed. The system must adequately dispose of all surface runoff from the design storm without serious damage to physical facilities or serious interruption of normal traffic. Runoff from storms exceeding the design storm must be disposed of with minimum damage to physical facilities and traffic interruption. The system must have maximum reliability of operation. The concept of rainfall excess, methods of determining rainfall excess, overland flow analysis, runoff hydrographs, urban drainage systems, open channel flow, and methods of routing are discussed. Many urban design techniques consist of a combination of empirical, statistical, and theoretical methods. Urban hydrology literature is characterised as empirical/statistical formulas, flood frequency analysis, and simulation methods. Empirical formulas are generally based on some form of hydrologic hypothesis; resulting relationships are developed by empirical derivation of equations and/or coefficients. Flood frequency equations have been developed which predict the peak flow for urban basins for selected recurrence intervals. Simulation methods generally attempt to describe in a somewhat analytical fashion the various physical processes involved in the generation of runoff.

EVANS, F.L. et al. 1968: "Treatment of urban storm water runoff". J. Water Pollution Control Federation, Vol.40(5), Part 2; pR162-R170.

Key words: biochemical oxygen demand; chemical oxygen demand; faecal coliforms; waste water treatment; bioindicators; storm runoff; suspended solids.

Recent studies by the Cincinnati Water Research Laboratory, U.S. Department of the Interior, have indicated that urban storm water runoffs contain constituents of a character hazardous to public health. Samples of storm water runoff from a separately sewered residential-light commercial area of Cincinnati taken from 50 storms over 2 years contained suspended solids, 5 to 1,200 mg/l; volatile suspended solids, 1 to 290 mg/l; BOD, 1 to 170 mg/l; and COD, 20 to 610 mg/l. Total coliform densities exceeded 2,900/100 ml in 90 percent of the samples. Laboratory bench scale settling and chlorination studies of storm water runoff from nine storms on the same area in Cincinnati are reported. Faecal organisms in varying densities were found in the runoff. Two to 5 mg/l of chlorine and 27 minute contact time were necessary to kill 99.9 percent of total coliforms, faecal coliforms, and faecal streptococci. There was no significant after-growth in total coliforms. The results of these studies emphasise the importance of faecal coliforms, rather than total coliforms, as a more realistic microbial indicator of pollution.

EVANS, J.O. and DUSEJA, D.F. 1973: "Herbicide contamination of surface runoff waters". Environmental Protection Series, Utah State University, Logan, Utah; 106pp. (NTIS P3-222 283; EPA R2-73-266).

Key words: water pollution; chlorides; herbicides; surface runoff; leachate; erosion.

Field and laboratory studies of the movement of herbicides were conducted to determine their potential as contaminants in irrigation return flow. Special emphasis was given to the use of herbicides for vegetation control along ditches, canals and watersheds where high dosages are required to control the excessive growth of grasses and broadleaved weeds. The following herbicides have been studied: substituted urea (diuron), triazines (summitol and atrazine), phenoxyacetic acid (2,4-D and 2,4,5-T) and a substituted pyridine (picloram).

EVELYN, J.B. et al. 1970: "Hydrograph synthesis for watershed sub-zones from measured urban parameters". Utah Water Research Lab. Report PRWG74-1, Logan, Utah.

Key words: hydrographs; flood control; streamflow; flood routing; analog models.

An analog computer program was developed to simulate the outflow hydrographs at four locations within the 38th Street Waller Creek urban watershed at Austin, Texas. Actual outflow was gauged at the final outlet of the watershed. This provided a check-point for comparing the simulated and observed final outflow hydrographs. The outflow hydrographs for each subzone were obtained by chronologically abstracting interception, infiltration, and depression storage from their

precipitation hystographs. These outflow hydrographs were then routed through Waller Creek to obtain the hydrographs at the four desired locations. The advantages of this model are the flexibility in varying the precipitation inputs to each subzone and the ability to obtain the contribution to the final flood hydrograph for each subzone.

EWING, R.L. 1977: "The water quality effect of urbanisation and the reuse of waste water in the Phoenix, Arizona (USA) urban area". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p457-466.

Key words: ground water resources; storm runoff; leachate; agricultural pollution; watershed management; water pollution sources.

Water has probably been the single most important factor contributing to the phenomenal growth of the Phoenix urban area (5959 sq km - 1,200,000 population) in the midst of the arid Arizona deserts. However, this tremendous population growth, accompanying domestic requirements and continued agricultural demand have resulted in a ground water depletion rate of close to 780 million cubic metres per year with an accompanying deterioration of the already poor water quality. Agricultural applications of fertilisers and leaching operations coupled with urban storm water runoff have further aggravated the problem by providing a poorer quality recharge water. To help alleviate this problem a comprehensive water and water-related land resources management programme has been initiated to ensure the availability of acceptable quality water for the future. This programme includes the evaluation of both point and nonpoint sources of pollution in the urban area and in addition it addresses the re-use of reclaimed waste water for the enhancement of local water conditions by the use of land application systems and industrial re-use. This includes the use of 173 million cubic metres per year for atomic power plant cooling.

FALKOVSKAYA-CHEPNYSHEVA, I.N. 1977: "Methods of forecasting the entry of pollutants into water bodies". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p358-364.

Key words: surface runoff; mathematical models; water pollution sources; industrial wastes.

Predicting the amount of pollutants brought to surface water bodies in urban areas by municipal and industrial waste water and overland flow from the area of cities is discussed.

FARRIS, G. et al. 1974: "Environmental planning for the metropolitan area Cedar-Green River Basins, Washington. Part II. Urban drainage study. Appendix C. Storm water monitoring program". Kcm-Wre/Yto Seattle, Washington; 107pp.

Key words: storm runoff; bacteria; biochemical oxygen demand; chemical oxygen demand; oil wastes; heavy metals; nutrients.

The quantity and quality of storm water runoff in the Seattle, Washington area was measured over a seven month period. Survey sites were selected on the basis of land use and included single and multiple family residential, commercial and industrial areas. The pollutants of major concern were solids, BOD, COD and oil. Nutrient and heavy metal loading values with some exceptions, were relatively low. Coliform values were high but not of apparent sanitary significance.

FEDDES, R.G. et al. 1970: "A hydrometeorological study related to the distribution of precipitation and runoff over small drainage basins - urban versus rural areas". Tech. Rept. No.28, Water Resources Inst., Texas A and M University, Bryan; 74pp. (NTIS P3-192 635).

Key words: urbanisation; surface runoff; hydrographs; analytical techniques.

The effects of urbanisation on streamflow are investigated for two adjacent similar watersheds located in and near Bryan, Texas. The Burton Creek watershed is 84 percent urbanised and the Hudson Creek watershed is completely rural. Storms observed within each basin are used for comparison of pertinent hydrograph parameters. Simultaneous events are compared between the watersheds and the urbanisation effect noted. A synthetic procedure for predicting hydrographs on both watersheds is developed. Reproduction of actual events indicates better results in the rural watershed. There is conclusive evidence that the urbanisation of a watershed decreases time-to-peak and increases the peak discharge.

FEDERAL WATER QUALITY ADMIN.
1970: "Combined sewer overflow abatement technology". Federal Water Quality Administration, Washington, D.C. Symposium on Storm and Combined Sewer Overflows, Chicago, Illinois; 330pp. (NTIS PB-193 939).

Key words: water pollution; pollution abatement; sewage treatment; erosion; surface runoff.

The compilation of papers contains results of the current demonstration grants and contracts that are being supported by the FWQA. The papers discuss: (1) alternatives to storm and combined sewer pollution in small urban areas; (2) screening and air floatation for solids removal; (3) underflow deep tunnel system concept; (4) urban erosion and sediment control; (5) sewer monitoring and remote control; (6) combined sewer overflow regulators; (7) use of fine mesh screens; and, (8) land use and urban runoff pollution.

FELDMAN, A.D. and ABBOTT, J.W. 1974: "Use of the computer program 'STORM' for analysis of the quantity and quality of urban storm water runoff". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p125-134.

Key words: model studies; urban runoff; storm runoff; overflows; mathematical models; water pollution; snowmelt; erosion; waste storage; waste water treatment.

The quantity and quality of urban storm water runoff can be analysed on a continuous (hourly) basis by the computer program STORM, to aid in the selection of the storage capacities and treatment rates required to achieve desired control of urban storm water runoff. The model considers the interaction of eight storm water elements: precipitation, snowfall and snowmelt, runoff, land surface erosion, pollutant accumulation, storage capacity, treatment rate, and overflows from the storage/treatment system. In this approach, dust and dirt and the associated pollutants are washed from the watershed into gutters and storm sewers. The resulting storm water runoff is diverted (for treatment) at rates not exceeding the specified treatment rate. Runoff in excess of the treatment rate is diverted into storage for subsequent treatment. Runoff in excess of both the treatment rate and storage capacity (overflow) is diverted directly into receiving waters. The quantity and quality of this untreated water (for each combination of storage capacity and treatment rate) is assessed. The quantity and quality of overflows from the storage-treatment facility were assessed for an urban watershed near Oakland, California.

FELL, W.J. 1977: "Planning for urban storm water control". Public Works, Vol.108(8); p81-85.

Key words: hydrographs;

rainfall-runoff relationships; hydrologic data; mathematical models; waste water treatment.

The elements of hydrograph construction and the use of hydrographs are discussed with respect to storm water management and the Soil Conservation Service (SCS) unit hydrograph. Hydrographs are graphical presentations of storm flow or discharge rates with respect to storm duration, with the unit hydrograph representing the flow from one inch of rainfall over the entire catchment area. The Soil Conservation Service (SCS) unit hydrograph relates ratios of discharge and time, the shape of the curve being determined by field observations from actual watershed flows. Applications of the unit graph in constructing discharge hydrographs for actual storms are discussed. A series of equations relating rainfall, peak discharge, time to peak, and runoff is presented. An area of 160 acres in Tulsa, Oklahoma is used in a numerical example for hydrograph construction.

FELTON, P.M. and IUII, H.W. 1963: "Suburban hydrology can improve watershed conditions". Public Works, Vol.94; p93-94.

Key words: erosion; storm runoff; data collection.

To determine how suburbanisation affects the capacity of the soil to absorb water in the Wissahickon Valley, Pa., ring infiltration tests were made in woods, fields, and lawns. In all, 108 tests were made in the summer of 1961, mostly in groups of three at each site. Average depths of water infiltrated per minute were, for woods, 0.58 inch; for fields, 0.28 inch; and for lawns, 0.10 inch. Infiltration into the lawns was slow. In 8 of the 34 runs only 0.1 inch or less infiltrated in a 5-minute period. Relatively low infiltration rates of the lawns are attributed to the high density of suburban soil, usually man mixed and bulldozed into position and further compacted by frequent mowing and trampling. Surface runoff from these compacted lawns, when concentrated, can be responsible for much soil erosion.

FERGUSON, D.E. 1972: "Annual compilation and analysis of hydrologic data for urban studies in the Houston, Texas metropolitan area, 1970". U.S. Geol. Survey open-file report; 275pp.

Key words: hydrologic data; data collection; urban hydrology; rainfall-runoff relationships; peak discharge.

Basic data of the urban hydrology of Houston, Tex., are compiled. Surface water records are from gauging stations, crest-stage partial-record stations, raingauges, and miscellaneous sites. Each gauging station record includes location, drainage area, gauge type and history, average discharge, extremes, remarks, daily discharge, total discharge, mean discharge, annual

maximum and mean discharges, and peak discharges. Runoff and rainfall are computed for each drainage basin, and hydrographs and mass curves are drawn. A map of each basin shows locations of all gauges. The objectives are to provide basic runoff data for small urban drainage areas which differ in topography, soil, vegetation, tributaries, basin shape, and degree of urbanisation; to provide related rainfall data with consideration of variation in intensity and location; and to provide data showing the effects of progressive urbanisation on flood peaks and volume.

FERGUSON, D.E. 1973: "Annual compilation and analysis of hydrologic data for urban studies in the Houston, Texas metropolitan area, 1971". U.S. Geol. Survey open-file report; 244pp.

Key words: urban hydrology; hydrologic data; storm runoff; data collection; rainfall-runoff relationships; streamflow.

Hydrologic investigations of urban watersheds in Texas were begun by the U.S. Geological Survey in 1954. This report, the eighth in a series of reports to be published annually, presents the basic hydrologic data collected in the Houston urban area for the 1971 water year (October 1970 to September 1971). Rainfall for the year was unevenly distributed over the area. Individual station totals ranged from 29.2 inches at the Sims Bayou at Hiram Clarke Street gauge to 49.8 inches at the Houston-Alief rain gauge. The largest amounts of rainfall for an individual storm were 7.15 inches at the Houston-Alief rain gauge and 6.25 inches at the Stafford rain gauge on October 11. Runoff data are based on discharge measurements and stage records at 16 continuous-record stream-gauging stations, 16 partial-record stream-gauging stations, and two reservoir-content stations. Annual records of daily discharges at continuous-record stream-gauging stations, maximum discharge at crest-stage partial-record stations, and daily contents of reservoirs are given. The high-runoff periods of the 1971 water year occurred during October 1970, and August and September 1971. Only a small amount of runoff resulted from rainfall during the intervening months.

FERGUSON, G.E and GUY, H.P. 1970: "Stream sediment; an environmental problem". J. Soil and Water Conservation, Vol.25(6); p217-221.

Key words: sediment transport; sediment control; urbanisation; erosion control.

Although the problem of sediment runoff is an old one, people have been aroused recently because of the awareness of the effects of sediment runoff from urban construction sites. The authors describe the program for sediment control developed in the Washington metropolitan region. The authors suggest that more research needs to be done on

this problem and explain that the cost of protecting denuded surfaces at construction sites in high-cost land areas 'appears to be within reason'.

FERNANDEZ, D. 1976: "Urban storm runoff: a two-fold problem". Eastern Water Law Centre, University of Florida, Gainesville, Florida; 49pp.

Key words: storm runoff; urbanisation; surface runoff; water pollution sources; watershed management.

Storm water runoff is a serious problem in urban areas and may constitute a significant source of water pollution. The solution to storm water runoff difficulties seems to be the detention of waters in higher lands for longer periods, coupled with drainage improvements in lower areas. Detention of water in upper land areas, however, involves the possibility of constitutional taking of property. In addition, increased drainage on lower lands often requires costly acquisitions of flood easements over private property. Flood insurance legislation has led to a new awareness of flood plain zoning, and the local responses indicate that the problems can be solved. Flood water pollution is another matter. Zero pollution goals prevent runoff into waterways but detention of water often results in pollution of ground water. Probably technological advances will provide a solution.

FEUERSTEIN, D.L. 1970: "A method for assessing the extent of pollution from storm water runoff from an urban area". In, Selected unbound papers from the WPCF Conference, October 1970; 32pp.

Key words: storm runoff; waste water treatment; water pollution sources.

A method is presented to assess the extent of water pollution occurring from storm water runoff and combined sewage overflows from an urban area from readily available data and information. Temporal distributions of storm water runoff flows and compositions are established from long-term historical rainfall records by means of hydrographic techniques and a storm water runoff quality simulation model. Temporal distributions of sanitary sewage are established by projection of available data, and are synchronously admixed with storm water runoff for combined sewage distributions. Waste water characteristics are modulated and reduced by various water pollution control systems, and the distribution of receiving water quality characteristics are determined following discharge from the systems by computer simulation of transient conditions. Three system water quality criteria - maximum value criterion, cumulative distribution criterion, and excretion frequency criterion - are applied to identify acceptably performing systems.

flows". Civil Engineering, Vol.43(2); p57-60.

Key words: combined sewers; overflows; water pollution control; waste water treatment.

A basic overview of the EPA's involvements in developing countermeasures for combined sewer overflow pollution is presented. Combined sewers are a source of water pollution problems, but even flows of storm water alone can seriously affect water quality. Current approaches involve control of combined sewer overflows, treatment, and combinations of the two. Control can involve maximising treatment with existing facilities, control of infiltrates and extraneous inflow, surface sanitation, and addition of flow increasing polymers, as well as flow regulation and storage, and use of porous pavement. A number of treatment methods have been evaluated, among the most promising of which are microstraining at high rates, ultrahigh rate filtration of various media, screening, and dissolved-air floatation. High rate disinfection processes including new disinfectants can also be adapted to storm flows.

FIELD, R. 1975: "Coping with urban runoff in the United States". Water Research, Vol.9(5/6); p499-505.

Key words: storm runoff; waste water treatment; pollution abatement.

Combined sewers are a source of water pollution problems, but even flows of storm water alone can seriously affect water quality. Sewer separation is very costly and solves only about 50 percent of the problem. Current approaches involve control of combined overflows, treatment, and combinations of the two. Control can involve maximising of treatment with existing facilities, improvement of regulator maintenance, control of infiltration and extraneous inflows, surface sanitation, and addition of flow-increasing polymers, as well as flow regulation and storage, use of porous pavement, and vacuum and pressure type sewer systems. A number of treatment methods are being evaluated, among the most promising of which are microstraining at high rates, ultrahigh rate filtration on various media, screening and dissolved air floatation, and the rotating biological contactor. Disinfection processes can also be adapted to storm flows.

FIELD, R. 1976: "Microorganisms in urban storm water - a U.S. Environmental Protection Agency program overview". Municipal Environmental Research Lab., Cincinnati, Ohio. Report EPA-600/2-76-244; p1-7. (NTIS PB-263 030).

Key words: urban runoff; analytical techniques; bioindicators; bacteria; waste water treatment.

The analysis and disinfection of microorganisms in storm water is discussed. The highly variable flow, temperature,

pollutant load, and hydraulic quality of storm water discharge makes the analysis and disinfection of microorganisms difficult. The direct adoption of waste water analysis methods which utilise total coliform, faecal coliform, and faecal streptococcus methods can produce misleading conclusions. On-site disinfection generation by raw materials batching and electrolysis is necessary to economically provide the highly unpredictable quantities of disinfectant which are required. High rate disinfection means and disinfection facility designs to accommodate the variable character of storm water should be developed.

FIELD, R. et al. 1974: "Water pollution and associated effects from street salting". J. Environmental Engineering Divn., Proc. ASCE, Vol.100(EE2); p459-477. (See also EPA Report R2-73-257; NTIS PB-222 795/7; 57pp).

Key words: environmental effects; chlorides; point sources (pollution).

The bare pavement policy has resulted in a great increase in the use of deicing salts. They are more efficient and economical than abrasives. However, there is excessive application leading to environmental problems. Besides chemical melting, various methods for deicing exist. Some of these are stationary and mobile thermal units, alternate deicing compounds, snow adhesion reducing pavements, electromagnetic energy for ice shattering, and drainage systems designed to capture snowmelt for treatment or control. Salt storage facilities often become a major contributing source of local ground water and surface water salt contamination. Coverage of salt piles is becoming prevalent. High chloride concentration levels have been found in roadway runoff. The special additives in deicing salts may create more severe pollutional problems than the chloride salts.

FIELD, R. et al. 1976: "Urban runoff and combined sewer overflow". J. Water Pollution Control Federation, Vol.48(6); p1191-1206.

Key words: urban runoff; urban drainage; overflows; combined sewers; storm runoff; model studies; bibliographies.

A literature review of documents dealing with urban runoff and combined sewer overflow is presented. General topics covered include: urban runoff quality, receiving water impacts, the monitoring of urban runoff pollutants, water quality control planning, runoff pollution modeling, flow regulation and control, and legislation for controlling urban drainage. Specific subjects discussed under the above general headings include: the effects of suburban development on runoff, a comparison of urban, watershed pollutant levels with those in forested watersheds, the use of coliform and orthophosphate levels as indicators of storm water impact, the suitability of automatic sampling

and monitoring equipment for storm and combined sewer systems, required elements of a master plan for water quality control of combined sewer systems, data required for verifying storm water models, design procedures for calculating settleable solids removal efficiency for combined sewer overflow regulators, and a model urban drainage ordinance.

FIELD, R. et al. 1976: "Proceedings of workshop on microorganisms in urban storm water". Municipal Environmental Research Lab., Cincinnati, Ohio. Report EPA-600/2-76-244; 128pp. (NTIS PB-263 030).

Key words: urban runoff; bacteria; viral factors; analytical techniques; water pollution control; waste water treatment.

The proceedings of a workshop on microorganisms in urban storm water were reported. The major objective was to exchange EPA data on such microorganisms, in order to understand their behaviour and occurrence in urban storm runoff and combined sewer overflow. Assay procedures for pathogenic microorganisms were reviewed. Studies were conducted on the relationship between pathogenic and coliform microorganisms. Disinfection and aftergrowth of microorganisms were investigated and viruses in storm water were studied.

FIELD, R. et al. 1976: "Urban runoff pollution control program overview FY76". Storm and combined sewer section, Municipal Environmental Research Lab. Edison, NJ.; 77pp. (EPA/600/2-76-095; PB-252 223/3WP).

Key words: urban runoff; water pollution control; pollution abatement; waste storage.

The report reviews EPA's Urban Runoff Pollution Control Research, Development, and Demonstration Program for the fiscal year of 1976. The basic pollution, flood control and soil erosion problems created by urban runoff; governmental administration and incentive problems; EPA R and D organisational structure; nationwide cost requirements to abate urban runoff pollution; available abatement technology along with ongoing and perceiving developments. General cost comparisons for urban runoff pollution control/treatment are given along with a specific example of a cost-effective solution for urban runoff pollution control by in-line storage in Seattle, Washington, and a simplified hypothetical plan for wet-weather flow pollution abatement for the Des Moines, Iowa area.

FIELD, R. et al. 1977: "Urban runoff pollution control - technology overview". Municipal Environmental Research Lab., Waste Water Research Divn., Cincinnati, Ohio. Report EPA-600/2-77-047; 103pp. (NTIS PB-264 452).

Key words: urban runoff; overflows; combined sewers; pollution abatement; sewage treatment; waste water treatment.

An overview was presented of methods for handling and treating urban runoff and the pollution problems which result from it. Discharge types considered were combined sewer overflow, storm drainage in separate systems, and overflows from infiltrated sanitary sewers. The report describes completed work, ongoing work, and future work needed to combat wet-weather flow pollution. Various study areas included user assistance tools (instrumentation and computers), management alternatives, collection system control, and storage and treatment. Highlights were presented from more than 150 research projects. Capital cost comparisons were provided for storm and combined sewer control and treatment. In-line storage in Seattle was used to demonstrate a cost-effective solution for urban runoff pollution control. Cost-effective control alternatives for Des Moines were also considered in comparison with the costs of frequent violations of dissolved oxygen standards.

FIELD, R. et al. 1977: "Urban runoff and combined sewer overflow". J. Water Pollution Control Federation, Vol.49(6); p1095-1104.

Key words: storm runoff; combined sewers; urban runoff; mathematical models; waste water treatment; water pollution control.

A literature review is presented of the various aspects related to the control and treatment of storm water discharges and combined waste water overflows from urban areas. Various methods for determining the quantity and quality of urban runoff are discussed, including descriptions of field and laboratory studies. Hydrologic studies and mathematical models for simulation of storm and combined sewer systems are considered for urban watershed management. The use of infiltration-flow analysis and flow meters is outlined for sewer system management and evaluation. Previous studies of construction costs for combined sewer overflow treatment plants and erosion control programs are described.

FIELD, R. and KNOWLES, D. 1975: "Urban runoff and combined sewer overflow". J. Water Pollution Control Federation, Vol.47(6); p1352-1369.

Key words: urban runoff; combined sewers; storm runoff; water pollution control.

A literature review of documents which deal with urban runoff and combined sewer overflow is presented. The review principally covers reported studies for 1974.

FIELD, R. and LAGER, J.A. 1974: "Counter measures for pollution from overflows".

EPA, Cincinnati, Ohio,
EPA-670/2-74-090; 30pp.

Key words: sewage treatment; overflows; combined sewers; mathematical models; storm runoff; water pollution control; pollution abatement; storm runoff; waste water treatment.

Control and/or treatment of storm water discharges and combined sewage overflows from urban areas are important problems in the field of water quality management. Over the past decade much research effort has been expended and a large amount of data has been generated. Presented are selected results of a comprehensive investigation and assessment of promising, completed and ongoing projects, representative of the state-of-the-art in abatement theory and technology; a look at recent legislation; and the identification of program needs and emphasis. Combined sewer overflows are major sources of water pollution problems, but even discharges of storm water alone can seriously affect water quality. Current approaches involved control over overflows, treatment and combinations of the two. Control may involve maximizing treatment with existing facilities, control of infiltration and extraneous inflows, surface sanitation and management, as well as flow regulation and storage. A number of treatment methods have been evaluated including high rate screening and microstraining, ultrahigh rate filtration, dissolved air floatation, physical/chemical treatment, and modified biological processes. A swirl flow regulator/solids separator of annular shape construction with no moving parts has been developed. High rate disinfection methods including new disinfectants have been applied. Promising approaches involve integrated use of controls and treatment.

FIELD, R. and LAGER, J.A. 1975: "Urban runoff pollution control - state of the art". J. Environmental Engineering Divn., Proc. ASCE, Vol.101(EE1); p107-125.

Key words: urban runoff; storm runoff; waste water treatment; waste storage; overflows; combined sewers; sewage treatment; water pollution; bacteria.

Combined sewer overflows are major sources of water pollution problems, but even discharges of storm water alone can seriously affect water quality. Current approaches involve control of overflows, treatment, and combinations of the two. Control may involve maximizing treatment with existing facilities, control of infiltration and extraneous inflows, surface sanitation and management, as well as flow regulation and storage. A number of treatment methods were evaluated including high rate screening and microstraining, ultrahigh rate infiltration, dissolved air floatation, physical/chemical treatment, and modified biological processes. A swirl flow regulator/solids separator of annular shape construction with no moving parts was developed. High rate disinfection

methods including new disinfectants were applied. Promising approaches involve integrated use of controls and treatment.

FIELD, R. and STRUZESKI, E.J. 1972: "Management and control of combined sewer overflows". J. Water Pollution Control Federation, Vol.44; p1389-1415.

Key words: combined sewers; overflows; storm runoff; waste water treatment.

Combined sewers are a source of water pollution problems, but even flows of storm water alone can seriously affect water quality. Sewer separation is very costly and solves only about 50 percent of the problem. Current approaches involve control of combined overflows, treatment, and combinations of the two. Control can involve maximizing of treatment with existing facilities, improvement of regulator maintenance, control of infiltration and extraneous inflows, surface sanitation, and addition of flow increasing polymers, as well as flow regulation and storage, use of porous pavement, and vacuum and pressure type sewer systems. A number of treatment methods are being evaluated, among the most promising of which are microstraining at high rates, ultrahigh rate filtration on various media, screening and dissolved air floatation, and the rotating biological contactor. Disinfection processes also can be adapted to storm flows.

FIELD, R. and SZEELEY, P.J. 1974: "Urban runoff and combined sewer overflow". J. Water Pollution Control Federation, Vol.46(6); p1209-1226.

Key words: urban runoff; combined sewers; overflows; water pollution control.

A literature review of documents which deal with urban runoff and combined sewer overflow is presented. The review principally covers reported studies for 1973.

FIELD, R. and WEIGEL, P. 1973: "Urban runoff and combined sewer overflow, annual literature review". J. Water Pollution Control Federation, Vol.45(6); p1108-1115.

Key words: urban runoff; combined sewers; overflows; water pollution control.

A literature review of documents which deal with urban runoff and combined sewer overflow is presented. The review principally covers reported studies for 1972.

FIELDING, M.B. 1966: "Proposed procedure for determining quantity and quality of storm flow". Water Resources Commn. Divn., Res. Paper No.2002.

Key words: storm runoff; data collection; suspended solids; biochemical oxygen demand.

The author outlines a suitable procedure for measuring the flow of storm sewage and for collecting samples for the determination of BOD and suspended solids. A graphical form is proposed for reporting the results.

FILIPPI, J.A.DE. and SHIH, C.S. 1971: "Characteristics of separated storm and combined sewer flows". J. Water Pollution Control Federation, Vol.43(10); p2033-2058.

Key words: water pollution sources; overflows; storm runoff; waste water treatment; chemical analysis.

Most U.S. cities are served by both combined sewers and separated sanitary and storm sewers. The hydraulic capacity of the District of Columbia combined system is often exceeded during periods of precipitation, and raw waste water mixed with surface runoff is spilled into the watercourses of the District. The overflows have been recognised as a significant source of pollution. Therefore, an investigation was sponsored by the Federal Water Quality Administration (FWQA) [now Environmental Protection Agency - Office of Water Programs (EPA-OWP)] to assess alternative methods for control and/or treatment of combined sewer overflows for the District of Columbia. The investigation had three major parts: (a) problem definition, (b) the study of the feasibility of ultrahigh rate filtration for treatment of combined sewer flows, and (c) the evaluation of alternative feasible solutions. This paper presents the results of the part of the study that dealt with the determination of the quality and quantity of combined and storm sewer flows by sampling and laboratory analyses.

FISHER, J.C. and KING, H.D. 1975: "Hydrologic data for urban studies in the Houston, Texas metropolitan area, 1973". U.S. Geol. Survey open-file report; 264pp.

Key words: urban hydrology; rainfall-runoff relationships; streamflow; data collection; hydrologic data; storm runoff; hydrographs.

This report contains rainfall and runoff data collected during the 1973 water year for drainage basins in the Houston, Texas metropolitan area. The information will be useful in determining the extent to which progressive urbanisation will affect the yield and mode of occurrence of storm runoff. Detailed rainfall-runoff computations, including hydrographs and mass curves, are presented for nine storm periods during the 1973 water year. The most significant storm event of the year occurred in June. Widespread showers of moderate to low intensities fell June 5-10. On June 11, 12 and 13 widespread, moderate to high intensity rains fell on the entire study area. A three day

total rainfall average of 10 inches (254mm), together with high antecedent soil moisture and moderate to high rainfall intensities, produced high rainfall-runoff ratios. Runoff data are based on discharge measurements and stage records at 14 continuous-record stream-gauging stations, 7 partial-record stream-gauging stations, and 2 reservoir content stations.

FITCH, W.N. et al. 1976: "Urban flooding response to landuse change". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p271-286.

Key words: landuse change; flood discharge; model studies.

The effect of changing land use on the frequency and severity of urban flooding has been studied in the area of Four Mile Run, a small urban watershed (19.5 sq ml) in metropolitan Northern Virginia. The land use during the last three decades has changed from predominantly rural to urban. The result has been increased flooding with the seven largest floods occurring in the past 12 years. Local governments are mandated by the U.S. Congress to develop and implement a land use planning program to insure that future landuse change will not cause flood flows which exceed the capacity of the flood control project currently under construction by the U.S. Army Corps of Engineers. This paper describes the application of a storm water management model and supporting techniques to be used in the implementation of the land use planning program.

FLEETWOOD, A. 1969: "Effects of urbanisation on ground water". Vatten, Vol.25; p107-112 (In Swedish, English summary).

Key words: urbanisation; ground water resources; aquifers; leachate; nitrogen compounds.

To determine the effect of urbanisation on the quality of the ground water, studies have been made on the composition of ground water in the Stockholm area, with particular reference to the concentration of mineralised nitrogen. The results indicate that in urban areas the ground water is contaminated by infiltration of sewage and waste waters.

FLETCHER, J.E. and CHEN, C.L. 1976: "Urban storm runoff inlet hydrograph study. Volume 3. Hydrologic data for two urban highway watersheds in the Salt Lake City area, Utah". Utah Water Research Lab., Logan; 116pp. (PRWG-106-3, PRWA/RD-76-118; NTIS PB-263 9870WN). (See also Vol. 1, 2, 4 and 5 by C.L. Chen).

Key words: urban runoff; data collection; storm runoff; hydrologic data; analytical techniques.

The main objective of this study is to

develop an accurate design method for computing inlet hydrographs of surface runoff, with average recurrence intervals of 10, 25, and 50 years, from typical urban highway by flood routing technique. Hydrologic data such as the rainfall intensity, runoff flow rate, air temperature, wind velocity, and soil moisture content were collected during rainfall seasons in 1972 and 1973 on two urban highway watersheds in the Salt Lake City area, Utah. These data were used in the verification of a mathematical model simulating the surface runoff from such highway watersheds. The difficulties and inherent problems associated with field data collection from urban highway cross-sections are discussed and possible remedies recommended. Hyetographs and the corresponding hydrographs of major storms which occurred in 1972 and 1973 at both sites are presented.

FLOWERS, E.S. 1975: "Measurement and management aspects of water toxicology: the Mabbu watershed, a mixed residential and wilderness area". In, Short course proceedings: applications of storm water management models, Dept. of Civil Engineering, University of Massachusetts, Amherst, Mass. (NTIS PB-247 163).

Key words: toxicity; data collection; environmental effects; watershed management.

In this project, the Malibu watershed was selected as a particularly suitable area for the study of toxic substances and their possible influences on water quality and beneficial uses of the region. The collection of data on water quality, vegetation, possible environmental interactions occurring between wilderness and residential areas, land use and general geographical characteristics of the Malibu Creek drainage area has been useful in providing opportunities for training of students in evaluation and planning aspects of water quality, while the information developed in the project has provided baseline data for future studies. The objectives of this project were to determine water quality in the Malibu watershed, to evaluate possible influences resulting from the introduction or removal of toxic substances, and to provide training in watershed management, planning, and protection.

FLYNN, J.M. 1961: "Impact of suburban growth on ground water quality in Suffolk County, New York". In, Ground water contamination, Proc. U.S. Dept. Health, Education, and Welfare 1961 Symposium, Cincinnati, Ohio; p71-82.

Key words: ground water resources; leachate; detergents; water pollution sources; aquifers.

Information is given on the pollution of ground water by sub-surface sewage disposal systems in Suffolk County, Long Island, N.Y., including tabulated data showing the increasing pollution by synthetic detergents. Alkylbenzenesulphonate is slow in pol-

luting a well, but once a breakthrough is accomplished the concentration of alkylbenzenesulphonate in the water increases rapidly. It is believed that continued use of sub-surface disposal systems will steadily increase the synthetic detergent concentration in water from the Glacial stratum until it is no longer acceptable. Once contaminated, the recuperative powers of the ground water are weak; none of the waters from contaminated strata in Suffolk County are known to have improved in quality following treatment or cessation of discharge of a contaminating waste water.

FOERSTER, E.P. 1972: "The effect of urbanisation on watershed runoff". Thesis, University of Arizona; 123pp. (Diss. Abstr., 33, B; p2180-2181).

Key words: rainfall-runoff relationships; urban runoff.

To determine the effect of urbanisation on the rainfall-runoff relation in a semi-arid region, runoff from part of Tucson, Ariz., and from a nearby non-urban area was investigated; runoff from the urban area was 4.75 times greater per square unit of area than that from the non-urban watershed. Significant factors were intensity of precipitation and the amount of impervious cover. The cost of treating the runoff water for use as domestic supply would be greater than the present cost of obtaining water from wells; it is suggested that use of runoff to recharge ground water would be the most feasible method at present.

FOGEL, M.M. et al. 1974: "Modeling the hydrologic effects resulting from land modification". Trans. American Society of Agricultural Engineers, Vol.17(6); p1036-1010.

Key words: model studies; watershed management; erosion rates; sediment yield; rainfall-runoff relationships.

A methodology was presented for predicting the long-term hydrologic effects of land modification in ungauged watersheds. The essential components of this procedure are an event-based stochastic model of precipitation as input and a deterministic watershed model that transforms the input into such desired hydrologic variables as water yield, peak runoff rate, and sediment yield. Land use can cause changes in water yields, flood probabilities, erosion rates, and sediment transport. Commonly used procedures for estimating runoff from watersheds are engineering design approaches, statistical approaches, regional analysis, and simulation. Simulation provides a continuous hydrograph, and allowances for changes in precipitation, land use, etc., to be made in the model. The proposed procedure uses soil conservation service methods for relating runoff to rainfall and estimating the peak rate of surface runoff. The distribution of peak runoff considers all possible combinations of rainfall and storm duration. Sediment yield is considered as a func-

tion of both peak flow rate and the volume of runoff. The proposed procedures can be used to determine the effect of watershed treatment and the optimum size of floodwater retarding structures.

FOK, Y.S. 1973: "A preliminary report on urban hydrology and urban water resources; Oahu, Hawaii". Technical Report No.74, Hawaii University, Water Resources Research Centre; 44pp. (NTIS PB-233 783).

Key words: urban hydrology; hydrographs; model studies; data collection; rainfall-runoff relationships.

Project objectives were to evaluate several watershed simulation models for their applicability to local conditions, expand the data collection in the research watersheds, and identify problem areas for subsequent study. The instantaneous unit hydrograph theory was explored in detail with results indicating the Nash method to have best applicability. The Kentucky Watershed Model's principle of continuous balancing of the water budget within a given watershed is applicable to Hawaiian conditions, but would require two to three years for its modification. The Road Research Laboratory Model was tested using three storm events, but the input data seemed inadequate to provide the desirable simulation. The Multiple Regression Model was applied to correlate peak flow to the drainage, urbanised area, rainfall, and time to peak. Results indicated that the model is very promising. Several mathematical conceptual models were also tested, and the nonlinear time variant watershed model was found to be the best. Some water quality elements were measured during 1971-73. Only a few samples were taken due to the very dry weather. The data collection program has been expanded to include evaporation, soil moisture, wind speed, solar radiation, and water quality in addition to rainfall and streamflow records gathered since initiation of the project.

FOOD AND AGRICULTURAL ORGANISATION. 1973: "Man's influence on the hydrological cycle". Irrigation and drainage paper No.17, FAO, Rome; 71pp.

Key words: watershed management; environmental effects; urbanisation.

This book consists of three parts prepared by different specialists with long experience in hydrology and water development problems. Each part is a review of one aspect of the broad problem of the influence of man on the hydrological cycle. While the papers were written so as to be self-contained contributions to the understanding of man's relations with water, they are nonetheless presented in a logical sequence, starting with a description of the physical components, followed by a review of the interactions between these components and man, and ending with a discussion of the human obsta-

cles to successful water control. Part One shows how the heat of the sun supplies the enormous energy needed to keep the cycle turning. The physical, chemical and biological roles of water in the environment are also described in this section. Part Two discusses the many ways in which man's actions affect the hydrological cycle. Part Three analyses the obstacles in man himself to the realisation of his goals in water development.

FORSGATE, J.A. and TEMIYABUTRA, S. 1971: "Rainfall and runoff from an industrial area in Nairobi, Kenya". Road Research Lab. Report LR408, Dept. of Environment; 12pp.

Key words: rainfall-runoff relationships; storm runoff; urbanisation; hydrographs; flood routing; flood forecasting; peak discharge; mathematical models.

Data were collected and analysed from one urban catchment in Nairobi. Modifications to the Road Research Laboratory method for sewer design were introduced to allow its use under conditions of tropical rainfall. The percentage runoff from unpaved areas may be estimated using an antecedent precipitation index, and the resulting contribution to the storm hydrograph is attenuated by routing through a linear reservoir.

FOX, H.L. 1976: "Channel alteration in an urbanising watershed: a case history in Maryland". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p105-113.

Key words: flood discharge; landuse change; channel erosion; bank erosion; erosion control; erosion rates.

Changes in channel size and shape on the Patuxent River between Washington, D.C., and Baltimore, Md., measured in 1972 and 1973 reflect the effects of flooding and urbanisation on the channel system. The channels are altering cross-sectional parameters describing size and shape at rates of 2.8 percent per month and 9.8 percent per month in rural and urban areas respectively. Urban reaches without bank protection, flow regulation, or other channel controls are becoming individual sections at rates up to 33.4 percent per month. The highest rate of change at rural sites is 4.9 percent per month, which is mainly due to post-flood channel recovery. The highest rates of channel change in urban reaches are due to post-flood adjustments combined with other channel adjustments in response to the excess sediment loads and altered flow regimes resulting from urbanisation. A channel change index (the sum of channel size and shape changes) documents these alterations conveniently, and has high values on channel sections within 1.6 km of constrictive road crossings or construction sites in the contributing watershed. While changes in the channel

sections are consistently greater in urban reaches than in rural ones, there is a seasonal variation in the rates of change between the winter-spring period and the summer-fall period, which may be related to the different patterns and intensities of precipitation typical of the two seasons.

FRANKLIN INSTITUTE RESEARCH LAB.
1969: "Selected urban storm water runoff abstracts. A compilation of selected abstracts on storm water discharges and combined sewer overflows". Science Information Services Department, Clean Water Report DI-14-12-467; 337pp. (NTIS PB-228 164/0).

Key words: surface runoff; bibliographies; urban hydrology; storm runoff; abstracts.

Selected Urban Storm Water Abstracts is a compilation of abstracts summarising articles from a variety of technical publications, covering the subjects of urban runoff, storm water discharge, storm sewers, and combined sewers - together constituting "the problem of urban drainage". Articles on more general subjects, such as "sewerage" or "sanitary engineering", and topics not closely related to storm water, such as "agricultural runoff", have been excluded. The present work represents an effort to index, expand and update the annotated bibliography, Storm Water Runoff From Urban Areas, issued in April 1966 by the Cincinnati Water Research Laboratory of the Federal Water Pollution Control Administration. Among the 573 abstracts presented are 386 not previously included, which summarise articles dated both earlier and later than 1966, so that the present compilation represents as complete as possible a bibliographic record of storm water articles, up to - and to some extent including - 1968. The 187 abstracts from the 1966 edition were indexed, but not otherwise edited or re-evaluated. For convenience, the abstracts are classed in eleven sub-topic categories, and arranged alphabetically by author within each category.

FRANKLIN INSTITUTE RESEARCH LAB.
1969: "Selected urban storm water runoff abstracts". Federal Water Pollution Control Administration, Water Pollution Control Research Series No. WP-20-21, WRSIC 69-102, G.P.O., Washington, D.C.; 113pp. (NTIS PB-185 314; 11020DES06/69).

Key words: abstracts; water pollution; flood control; flood forecasting; ground water resources; overflows; sewage treatment; bibliographies.

The publication contains abstracts summarising articles from a variety of technical publications, covering the subjects of urban runoff, storm water discharge, storm sewers, and combined sewers - together constituting "the problem of urban drainage".

FRANKLIN INSTITUTE RESEARCH LAB.
1970: "Selected urban storm water runoff abstracts, first quarterly issue". EPA Water Pollution Control Research Series, G.P.O. Washington, D.C.; 46pp. (NTIS PB-198 229; EPA 11024 EJCl0/70).

Key words: surface runoff; abstracts; water pollution control; combined sewers; overflows; bibliographies.

The first quarterly supplement to Selected Urban Storm Water Abstracts is a compilation of abstracts summarising articles from a variety of technical literature concerning the problem of urban drainage published from July 1970 through September 1970. The 36 abstracts covering a range of eight sections are arranged alphabetically by author and numerically by abstract number within each category. Each item includes a bibliographic citation, an abstract, and a set of indexing descriptors and identifiers. A cumulative subject index at the end of the volume provides the necessary access to individual concepts. An author index and journal list are also included.

FRANKLIN INSTITUTE RESEARCH LAB.
1970: "Selected urban storm water runoff abstracts, July 1968 - June 1970". EPA Water Pollution Control Research Series, G.P.O., Washington, D.C.; 385pp. (PB-198 228; EPA 11024 EJc07/70).

Key words: surface runoff; bibliographies; water pollution; abstracts; sewage treatment; urbanisation; overflows; combined sewers; flood control.

Selected Urban Storm Water Abstracts is a compilation of abstracts summarising articles from a variety of technical publications, covering the subjects of urban runoff, storm water drainage, storm sewers, and legislation together constituting "the problem of urban drainage". Articles on more general subjects, such as "sewerage" or "sanitary engineering", and topics not closely related to storm water have been excluded. The present work includes 599 abstracts of documents published from July 1968 through June 1970. A few abstracts summarise material published before this period that were not included in the previous volume of Selected Urban Storm Water Abstracts, published in June 1969.

FRANKLIN INSTITUTE RESEARCH LAB.
1971: "Selected urban storm water runoff abstracts, second quarterly issue". EPA Water Pollution Control Research Series, G.P.O., Washington, D.C.; 54pp. (NTIS PB-198 312; EPA-11024-EJc01/71).

Key words: surface runoff; abstracts; urban drainage; water pollution control; overflows; combined sewers; bibliographies.

The second quarterly supplement to Selected Urban Storm Water Runoff Abstracts is a compilation of abstracts

summarising articles from a variety of technical literature concerning the problem of urban drainage published from October 1970 through December 1970. The 50 abstracts covering a range of ten sections are arranged alphabetically by author and numerically by abstract number within each category. Each item includes a bibliographic citation, an abstract, and a set of indexing descriptors and identifiers. A cumulative subject index at the end of each volume provides the necessary access to individual concepts.

FRANKLIN INSTITUTE RESEARCH LAB.
1971: "Selected urban storm water runoff abstracts, July 1970 - June 1971". EPA Water Pollution Control Research Series, G.P.O., Washington, D.C.; 173pp. (EPA 11024 FJE07/71.)

Key words: abstracts; bibliographies; storm runoff; urbanisation; urban hydrology; water pollution.

The July 1970 - June 1971 supplement to Selected Urban Storm Water Runoff Abstracts is a compilation of abstracts summarising articles from a variety of technical literature concerning the problem of urban drainage published from July 1970 through June 1971. The 234 abstracts covering a range of ten sections are arranged alphabetically by author and numerically by abstract number within each category. Each item includes a bibliographic citation, an abstract, and a set of indexing descriptors and identifiers. A subject index at the end of the volume provides the necessary access to individual concepts. An author index and a journal list are also included.

FRANKLIN INSTITUTE RESEARCH LAB.
1971: "Selected urban storm water runoff abstracts, third quarterly issue". EPA Water Pollution Control Research Series, G.P.O., Washington, D.C. (EPA 11024FJE04/71).

Key words: abstracts; overflows; storm runoff; urbanisation; combined sewers; rainfall-runoff relationships.

The third quarterly supplement to Selected Urban Storm Water Runoff Abstracts is a compilation of abstracts summarising articles from a variety of technical literature concerning the problem of urban drainage published from January 1971 through March 1971. The 89 abstracts covering a range of ten sections are arranged alphabetically by author and numerically by abstract number within each category. Each item includes a bibliographic citation, an abstract, and a set of indexing descriptors and identifiers. A cumulative subject index at the end of the volume provides the necessary access to individual concepts. An author index and a journal list are also included.

FRANKLIN INSTITUTE RESEARCH LAB.
1972: "Selected urban storm water runoff abstracts, July 1971-June 1972".

EPA Water Pollution Control Research Series, G.P.O. Washington, D.C.; 99pp. (EPA-R2-72-127; NTIS PB-214 411).

Key words: surface runoff; bibliographies; water pollution; overflows; sewage treatment; combined sewers; abstracts; urban hydrology.

The July 1971 - June 1972 supplement to Selected Urban Storm Water Runoff Abstracts is a compilation of 215 abstracts summarising articles from a variety of technical literature and conferences, both domestic and foreign, primarily related to the problems of urban runoff caused by storm water discharges, combined sewer overflows, and non-sewered urban runoff. All aspects related to this topic fall under the selective areas of: design criteria and construction materials for sewers or apparatus employed in the flow of combined sewage and/or storm runoff; regulation devices for overflow or infiltration from urban runoff of storm water, combined sewage, or highway salt runoff which can cause water pollution; water quality, legislation, or treatment methods based on problems caused from storm water; and, current tunnel technology and equipment used in the construction of sewer tunnels.

FRIED, J.J. 1975: "Ground water pollution". Elsevier Scientific Publish. Co., New York. Developments in Water Science, 4; 336pp.

Key words: bibliographies; mathematical models; ground water resources; aquifers; water pollution sources.

This book on methods for solving ground water pollution problems includes chapters on the general characteristics of ground water pollution (including justification for the foundation of ground water pollution studies on miscibility-displacement theories); theory of dispersion in porous media; methodology of technical studies on ground water pollution and determination of pollution parameters; mathematical models; specific case studies on pollution of ground water by mining and radioactive waste waters and salt water intrusion and on protection of aquifers; effects of pollution on water resources management; and numerical expression of pollution problems for solving by computer. A bibliography of 284 references and a subject index are provided.

FRIEDLAND, A.O., et al. 1971: "Quantity and quality relationships for combined sewer overflows". In, Advances in water pollution research, Proc. of the 5th Int. Conference of the IAWPR held at San Francisco and Hawaii, 1970, paper I-1; pI-I/1-16.

Key words: mathematical models; hydrographs; storm runoff; waste water treatment; water pollution; nitrogen compounds; chemical oxygen demand; suspended solids; phosphorus compounds.

The results of a one year program of wet and dry weather monitoring of five combined sewer systems and one storm sewer system in San Francisco, are presented. The time concentration profiles of combined sewage constituents follow a definite three-phase variation initially having characteristics of raw sewage increasing in the second phase to 125 to 200 percent of the characteristics of raw sewage, and receding in the third phase to levels of 10 to 25 percent of the characteristics of raw sewage. No correlation was found between the mass emission of constituents due to storm and the antecedent dry period, land use character, or rainfall intensity. Storm runoff emission equations for COD, total suspended solids, total nitrogen, and ortho-phosphate are included. Hexane extractable material and floatables can be used in conjunction with dry weather flow, waste load coefficient, rainfall history, basin acreage, and population to estimate waste water loads. Wet weather diversions contain twice the total nitrogen and ortho-phosphate phosphorus, 50 to 60 percent more total nitrogen and COD, 23 percent more floatables, and 10 percent more suspended solids than the storm runoff fraction of the diversion alone would contain. The nitrogen and phosphorus emissions from secondary forms are significantly greater than emissions of these constituents from combined or storm sewage flows on an annual basis.

FRIZZOIA, J.A. and BAIER, J.H. 1975: "Contaminants in rainwater and their relation to water quality, Part II". Water and Sewage Works, Vol.122(9); p94-95.

Key words: air pollution effects; ground water resources.

Contaminants of rainwater are shown to have an effect on ground water quality, by analysis of data collected at 3 stations on Long Island, New York. Background concentrations of 2 mg/litre total nitrogen enter ground water as precipitation. Ammonia can act to reduce acidity in rainwater, but since pH values of 4 and 5 are common, it seems the ammonia is either removed or dominated by stronger acid reactions. Sulphur compounds, especially sulphur dioxide formed from fossil fuel combustion, were found to be the predominant cause of acid precipitation over Long Island. Chloride-sodium ratios were less than the expected seawater values, perhaps as a result of the composite collection method. It is suggested that the term total acid effect be used when discussing the composite sample and that scavenging acid effect be used to refer to pH obtained directly from natural precipitation. In this study, all ion concentrations in precipitation were reported higher at urban than rural stations.

FRUH, E.G. 1969: "Urban effects on quality of streamflow". In, Effects of watershed changes on streamflow, (eds. W.L. Moore; C.W. Morgan), Water Resources Symposium No.2, Centre for Re-

search in Water Resources, University of Texas; p255-282.

Key words: waste storage; algae; dissolved oxygen; urban runoff.

Impoundments are a result of urbanisation. The water quality of a series of impoundments on the (Texas) Colorado River is investigated. Temperature, algal, and chemical (in particular dissolved oxygen) properties are studied, showing the importance of the seasonal movement of the thermocline. The effects of water releases from upstream impoundments and of urban runoff on the system are illustrated, together with the long term effects of impoundment.

GANN, E.E. 1971: "Generalised flood-frequency estimates for urban areas in Missouri". U.S. Geol. Survey open-file report; 18pp.

Key words: flood forecasting; urbanisation; environmental effects; streamflow; peak discharge; flood control; hydrologic data; mathematical models.

A method is presented for estimating flood-frequency information for urban areas in Missouri. Flood-frequency relations are presented which provide an estimate of the flood-peak discharge for floods with recurrence intervals from 2.33 to 100 years for basins with various degrees of existing or projected urban development. Drainage area sizes for which the relations are applicable range from 0.1 to 50 square miles. These generalised relations will be useful to the urban planner and designer until more comprehensive studies are completed for the individual urban areas within the state. The relations will also be of value in the definition of flood-hazard areas in Missouri.

GARIAND, J.H.N. 1976: "Effects of storm discharges on river water quality". Berichte der Abwassertechnischen Vereinigung e.V., No.28; p593-602.

Key words: storm runoff; water pollution sources; sewage treatment; suspended solids.

In 1963 about 37 percent of the storm overflows in Wales and England were considered unsatisfactory. Pollution problems from storm sewage most frequently appeared where overflow settings were below six times dry-weather flow, usually in older industrial urban areas where substantial parts of sewage systems had outlived their original design capacity. Considerable deterioration of water quality in the River Tame resulted from storm overflows and surface drainage. A realistic approach to the problem is that of treating the entire river below the last large effluent outfall using a series of several settling basins. The effect of storm sewage discharge on a river depends primarily on the discharge's duration and strength and the dilution provided by the river. Its strength depends on dry-weather sewage, time of day, time since the last storm, and the flow. In combined sewerage systems, a flood wave precedes the mixed sewage and may cause spillage of dry-weather sewage. If a long time has elapsed since the last rainfall, storm runoff in the first flush may contain very large amounts of suspended solids which had accumulated on surfaces. Discharge duration depends on intensity and duration of the rainfall, how the overflow weir is set, and the drainage system's storage capacity. The overflow weir setting has the greatest effect on the frequency of pollution episodes. Another problem is posed by metals, such as zinc, copper, and lead, contained in dust entering urban rivers with runoff. The River Tame shows two types of polluted conditions: one caused by inadequate treatment of effluents, and the other caused

by additional pollutants entering during storms.

GATES, C.D. 1975: "Urban runoff in Binghamton, New York". In, Urbanisation and water quality control. Proc. Symposium American Water Resources Assoc., No.20; p38-44.

Key words: data collection; urban runoff; water pollution sources.

The purpose of the study is to estimate the amount of waterborne biodegradable wastes that is generated in, and reaches the Susquehanna River directly from the Binghamton urban study area, but not through the public sewerage system. The first year was directed toward identifying and characterising the study area by evaluating data and information previously collected or being collected by others; developing a sampling and testing program to verify and complement existing information; and collecting baseline stream quality data which, when combined with data to be collected during the second summer (1975) study period, would provide a means of measuring urban runoff from the study area.

GATES, C.D. and HAITH, D.A. 1975: "Influence of land development and land use patterns on water quality". Completion report, Cornell University, Ithaca, New York, Water Resources and Marine Sciences Centre; 60pp.

Key words: biochemical oxygen demand; analytical techniques.

Field, laboratory, and statistical methods were used to study the influence of certain land uses on the waterborne export of certain wastes from a sewered urban area and from unsewered rural watersheds. Comparison, by means of mass balance analysis, of the amounts of biodegradable wastes in the Susquehanna River at stations above and below a 20.6 square mile developed area indicated that the study area contributed carbonaceous BOD at the rate of 390 pounds per day per square mile to the river averaged over the June - August 1973 and 1974 periods.

GATZ, D.F. 1972: "Washout ratios in urban and non-urban areas". Preprint, Conference on Urban Environment. American Met. Soc., Philadelphia, Pa.; p124-128.

Key words: air pollution effects; surface runoff; metals.

The research reported here was an attempt to measure washout ratios for several airborne elements simultaneously, on a daily basis, and as part of Project Metromex, in which extensive measurements of precipitation, cloud physics, and aerosol parameters were available. Washout ratios for Cu, Fe, Mg, Mn, and Zn were found to remain constant from upwind to downwind across the St. Louis Metropolitan area, al-

though concentrations in both air and precipitation were substantially higher downwind. Differences in mean washout ratio among the several elements are apparent, with Mg showing the highest ratio, and Pb the lowest. Although the variations are consistent with those to be expected from literature data on particle size distributions, the cause is not yet certain. Large positive correlations were found among washout ratios for a few pairs of elements.

GEIGER, C.O. 1973: "Effect of urbanisation on flood runoff, Wichita area, Kansas". Lawrence, Kansas. U.S. Geol. Survey.

Key words: landuse change; flood discharge; storm runoff.

The report investigates the relation of changes in land use in urban areas to corresponding changes in high-water discharge characteristics.

GEIGER, W.F. 1975: "Urban runoff pollution derived from long-time simulation". Paper in proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Ky.

Key words: urban runoff; water pollution; mathematical models.

Urban storm water runoff pollution is determined by randomly distributed processes. Thus meaningful and realistic conclusions concerning urban runoff pollution may not be derived from the simulation of singular rainstorm events. The method presented allows for continuous simulation of several pollutants. Runoff and its pollution from catchment areas, characterised as residential, commercial, industrial, or mixed areas, are calculated by an unit hydrograph method, modified for the calculation of water quality. Flow routing through the network is based on the dynamic wave equations. Statistical analysis of the results provides annual and monthly frequency and duration curves for flows and pollutants at any node of the network. Still, single event simulation is possible providing pollutographs and hydrographs at any node of the network. First verification tests of the model produced satisfactory results.

GEIGER, W.F. 1977: "The impact of sewer system overflows on receiving waters as defined by mathematical modeling". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p303-310.

Key words: mathematical models; overflows; computer models; pollution abatement.

Storm runoff causes the same magnitude of pollution loads entering receiving waters as secondary treatment effluent. The impact of these loadings is intermittent and cannot be defined with reasonable costs by measurements only.

Computerised mathematical simulation models were recognised to aid the assessment of pollution loads and decision making in selection of overflow abatement alternatives. But, as the processes involved in urban runoff have statistically the properties of random events, it follows that meaningful and realistic conclusions on urban runoff and its pollution can only be derived from the investigation of long precipitation records. For a simulation model, sufficient detail is necessary to represent the rapidly varying runoff processes. In addition to monthly and yearly totals, statistical analyses of continuous simulation results provide frequencies and durations of overflows and overflowing pollution loads. These results assess the impact of sewer system overflows on receiving waters. Predicting the impact of future conditions, a technical basis for cost-benefit considerations is provided supporting storm water management decisions.

GELDREICH, E.E. et al. 1968: "The bacteriological aspects of storm water pollution". J. Water Pollution Control Federation, Vol.40(11), Part I; p1861-1872.

Key words: faecal coliforms; bacteria; water pollution; bioindicators.

Storm water can be a major source of intermittent pollution to bathing beaches and to water supply reservoirs opened to limited public recreational uses. The bacteriological evidence indicates faecal contamination in separate storm water systems is derived from the faecal material deposited on soil by animal pets (particularly cats and dogs) and rodents in the urban community. Seasonal differences in the bacterial densities for total coliforms, faecal coliforms, and faecal streptococci were noted in the study of median values. The faecal coliform segment of the total coliform population for all storm water samples averaged 8.6 percent. The sanitary significance of faecal coliform bacteria in storm water is further confirmed by the quantitative isolation of 4,500 *Salmonella thompson* per 100 ml in one storm water sample that also contained 450,000 faecal coliforms per 100 ml.

GIANO, F.A.DI. et al. 1975: "A projection of pollutional effects of urban runoff in the Green River, Massachusetts". In, Urbanisation and water quality control. Proc. Symposium American Water Resources Assoc., No.20; p28-37.

Key words: urban runoff; benthic fauna; storm runoff; biochemical oxygen demand; total organic carbon; phosphorus compounds; chlorides; turbidity; faecal coliforms; oil wastes; metals; water pollution.

An Office of Water Research and Technology Grant to Rutgers University in March 1974 provided for coordinated studies of pollutional effects of urban runoff to be conducted simultaneously

in five states over a 20 month period, to compare and contrast mass loadings of pollutants generated by urban runoff. From April 1974 to the present, data has been collected on water quality and on the distribution of benthic macroinvertebrate communities in the Green River. Water quality data consists mainly of weekly measurement of specific parameters at six sampling stations in the river's urban reach and measured impact of several storm events. Parameters of most interest are biochemical oxygen demand (BOD), total organic carbon (TOC), total phosphorus (total P), chloride, turbidity, total and faecal coliforms and oil and grease. The benthic macroinvertebrate communities have been enumerated at the same sampling stations on a monthly basis. For the latter portion of the study, analyses were made of metals (Fe, Cu, Cr, Ni, Zn, Pb, Cd, and Ag) in the overlaying water, and in sediments, detritus, and benthic organisms. The specific objectives of the University of Massachusetts research effort are: (1) comparison of mean dry and wet weather in-stream pollution concentrations, (2) relationship of in-stream pollutant concentrations to specific meteorological factors influencing urban runoff characteristics as determined by multiple regression analysis, (3) estimation of the average mass input rate of urban runoff constituents, for example, pounds of BOD per square mile per day, (4) measurement of mass loadings during individual storm events, and (5) assessment of changes in species diversity index of the benthic macroinvertebrate community as a result of urban runoff.

GIANO, F.A.DI. et al. 1975: "Characterisation of urban runoff in Greenfield, Massachusetts - phase 1". Massachusetts University, Amherst, Dept. of Civil Engineering Publication No.50; 102pp. (NTIS PB-268 984).

Key words: water pollution sources; urban runoff; phosphorus compounds; chlorides; biochemical oxygen demand; carbon; total organic carbon; nonpoint pollution sources; bacteria; miscellaneous chemicals; turbidity; faecal coliforms; oil wastes.

The primary interest in this research focuses on the importance of both the short term impacts on water quality requirements and the longer term disruptions to normal stream ecology that may be caused by urban runoff. This report includes water quality data obtained from April 1974 to June 1975. Sample points in the Green River were selected such that the contribution of urban runoff from various sources and land use patterns could be measured. Water quality data consist mainly of weekly measurement of specific parameters at 6 sampling stations in the river's urban reach and measured impacts of several storm events. Parameters of most interest are BOD, TOC, total P, Cl, turbidity, total and faecal coliforms, oil and grease. Increases in concentrations of most pollutant parameters were noted during wet weather. Mean loading rates were 269, 26, 15, and 717 lb/sq

ml/day for BOD, TOC, total P, and chloride, respectively. However, combined sewer overflows increased loadings on several days and prevented accurate assessment of the urban runoff contribution.

GIANO, F.A.DI. et al. 1977: "Applications of storm water management models 1976: short course proceedings". Massachusetts University, Amherst, Dept. of Civil Engineering, Proceedings Report June 1975 - August 1976; 447pp.

Key words: computer models; storm runoff; model studies; rainfall-runoff relationships.

This is a follow-up to one sponsored by the U.S. EPA and now available as EPA Report 670/2-75-065. The objective is to provide practitioners with the capability to apply specific models directly. A discussion of the common components of storm water management models first gives an overview of modeling needs. The U.S. EPA Storm Water Management Model (SWMM) is described in detail and an illustrative case study presented. The methodology for data preparation is outlined and sample input and output data given for the Rainfall-Runoff, Transport, Storage/Treatment and Receiving Water Blocks of the EPA SWMM. A discussion of criteria for selecting models for application as either planning or design tools is then presented along with illustrations of the use of two simplified models. Finally, the techniques for collecting field data for model calibration are presented and the performance of commercially available sampling equipment assessed.

GIANO, F.A.DI. and COLER, R.A. 1974: "Definition of procedures for study of river pollution by nonpoint urban sources". Termination Report, Massachusetts University, Amherst, Water Resources Research Centre; 20pp. (NTIS PB-237 972).

Key words: water pollution sources; water pollution; storm runoff; urban runoff; benthic fauna; nonpoint pollution sources; chlorides; phosphorus compounds; nitrogen compounds; snowmelt; Kjeldahl nitrogen; carbon.

A limited field investigation was conducted at three sampling stations on the Green River, Greenville, Massachusetts, to provide a preliminary characterisation of nonpoint urban sources of pollutants originating from storm water and snowmelt. Also included was an examination of the impact of pollutants on the benthic macroinvertebrate community. Sample station 1 was upstream of the urban area and station 2, downstream of the urban area, was three miles from station 1. Station 3 was on a tributary a short distance downstream from station 1. At each station the discharge and temperature were measured and grab samples were taken to analyse for pH, total phosphorus, Kjeldahl nitrogen, inorganic and organic carbon, chloride, and total coliforms. Basket

type artificial substrates, submerged and anchored in the river for one month, were gradually colonised by macroinvertebrates. Between stations 1 and 2, large increases in concentrations were found of total nitrogen, total phosphorus, chloride, and total coliforms. Benthic macroinvertebrate studies at stations 1 and 2 did not reveal a large shift to pollution tolerant species at station 2. A more detailed study of the Green River was recommended by increasing number of sampling stations, installing stream gauge recorders, more frequent sampling, and maintaining accurate rainfall records.

GIANO, F.A.DI. and MANGARELLA, P.A. (eds). 1975: "Applications of storm water management models". In, Short course proceedings, Department of Civil Engineering, University of Massachusetts, Amherst, Mass. (NTIS PB-247 163).

Key words: mathematical models; combined sewers; water pollution; waste water treatment; peak discharge; urban runoff; water pollution control.

This short course was sponsored by the U.S. Environmental Protection Agency. The specific objectives were to encourage the consulting profession to implement storm water models in solving the problem of storm and combined sewer overflows and to make state pollution control agencies aware of this tool in their pollution abatement efforts. Emphasis was placed on presentations of various types of models, their data requirements and case studies of their use. The EPA Storm Water Management Model (SWMM) was highlighted. It is hoped that this compilation of instructional papers, prepared by the Short Course faculty, will enable practicing engineers to broaden their use of storm water management models. The Short Course was held at the University of Massachusetts August 19-23, 1974.

GIBSON, M. et al. 1975: "Variation of urban runoff quality and quantity with duration and intensity of storms". Phase III. Vol. 1. Dry weather flows". Texas University, Lubbock, Water Resources Centre; 81pp. (See also Phase III, Vols. 2,3,4).

Key words: data collection; streamflow; chemical oxygen demand; solid wastes; biochemical oxygen demand; suspended solids; phosphorus compounds; nitrates; mathematical models; peak discharge.

Water samples and flows were obtained from storm events and dry weather flows occurring on a 1,499 acre urban watershed in Lubbock, Texas, over a nine month period from September 1974 through May 1975. Hourly flow samples from 59 precipitation events and 199 dry weather flows were combined into daily composites which were analysed for chemical oxygen demand, total solids, biochemical oxygen demand, total suspended solids, orthophosphate and nitrate. The predictive flow models utilised were the rational method, the Viessman and Miller method, the Viess-

man, Keating and Srinivasa method, and the British Road Research method. Using three storms of varying characteristics, the total runoff volume and peak flows from the predictive models were compared to the observed total runoff and peak flows in each case.

GIEGE, F.W. 1975: "Simulation of urban runoff pollution using a modified unit hydrograph and a non-steady routing method". Paper in proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Ky.

Key words: computer models; mathematical models; urban runoff.

GLANCY, P.A. 1971: "A reconnaissance of streamflow and fluvial sediment transport, Incline Village area, Lake Tahoe, Nevada". First progress report, 1970, Nevada Div. of Water Resources, Water Resources Inf. Ser. Rept. No.8; 28pp.

Key words: sediment yield; sediment transport; snowmelt.

Runoff during the 1970 water year from the five major streams in the Incline Village area, Lake Tahoe, Nev., was about 17,600 acre-feet. Sediment transported to Lake Tahoe was estimated to be about 10,000 tons, of which about three-fourths was from Incline and Third Creeks. About 85 percent of the sediment was delivered to the lake during the snowmelt runoff period. The annual sediment load was estimated to be about 68 percent sand, 20 percent silt, and 12 percent clay. Estimated annual sediment yields ranged from 50 to 650 tons per square mile from undeveloped areas, and 1,600 to 3,000 tons per square mile from developed areas. The estimated annual yield from the developed area was about 12 times that from the undeveloped area. Nitrogen transported by streams to the lake during periods of heavy sediment transport was largely in organic form, and the phosphorus at those times was mostly attached to the sediment particles.

GLOYNA, E.F. and BUTCHER, W.S. (eds). 1972: "Conflicts in water resources planning". Centre for Research in Water Resources, University of Texas. Water Resources Symposium, No.5.

Key words: watershed management.

In water resources, as in many other fields, environmental concerns have come into prominence. Values represented by this new concern are in many cases in conflict with the notion of water resources development as a desirable and universally acceptable public activity. The lectures recorded in this volume examine the conflicts in water resources planning in the belief that an understanding of the issues is essential if the basic conflicts are to be resolved. The first section of the volume deals with such important issues as conservation of resources and the

relation of water resources planning to land use policy. The second section deals with the government's role in the water resources planning at the Federal, State and local levels. Ecology, an important part of water resources planning, is the subject of section three. These essays were presented by their authors at a conference held at the University of Texas at Austin in November 1970, and cosponsored by the College of Engineering and the Centre for Research in Water Resources.

way. This supposes however that atmospheric pollutants can be sufficiently characterised concerning their origin, their amounts and their quality.

GLUCK, W.R. and McCUEN, R.H. 1975: "Estimating land use characteristics for hydrologic models". Water Resources Research, Vol.11(1); p177-179.

Key words: model studies; rainfall-runoff relationships.

Equations for estimating land use characteristics used in many hydrologic models were presented. The method presented was intended as a reliable alternative to the more costly, time-consuming process of aerial photography interpretation. Application of the equations permits prediction of future land use configurations. Data input takes the form of demographic characteristics (e.g. population density or housing density) which are frequently available from planning agencies or others.

GOLDBERG, M.C. 1971: "Sources of nitrogen in water supplies". In, Agricultural practices and water quality (eds. T.L. Willrich; G.E. Smith), Ames, Iowa, Iowa State Univ. Press; p94-124.

Key words: nitrogen compounds; storm runoff; water pollution sources; urban runoff; agricultural pollution; industrial wastes.

Sources of nitrogen in water supplies are atmospheric, geologic, and biogenic, resulting from rural runoff, urban runoff, sewage, irrigation, return flow, pollen, rural waste, industrial waste, pond waters, deforestation, and land stripping, among others. Generally, salts of nitrogen applied as fertiliser do not move. Nitrate in a nonsalt form seems to have higher soil infiltration capacity than salt nitrogen. This is dependent, however, upon the physical conditions of the soil and the hydrology of the region. In general, industrial waste, rural runoff, farm animal waste, and domestic waste are the dominant sources in surface waters. In ground water supplies the usual sources of nitrogen are feedlots, privies, septic tanks, and farm wastes.

GODDEN, D. 1973: "Urban water farming". In, proceedings of the urban water economics symposium 1973, (ed. C. Aislabie), University of Newcastle Research Associates Limited; p80-81.

Key words: surface runoff; urban runoff.

This paper examines the advantages and disadvantages of gathering urban roof runoff for water supply. It is noted that roof runoff cannot satisfy total water requirements and that no research regarding the economic feasibility of such schemes has been undertaken.

GOLDEN, H.G. 1977: "Preliminary flood frequency relations for urban streams, metropolitan Atlanta, Georgia". Geological Survey, Doraville, Ga., Water Resources Divn., Water Resources Investigations 77-57; 16pp. (NTIS PB-272 504).

Key words: peak discharge; urban hydrology; flood forecasting; analytical techniques; hydrologic data; storm runoff.

A method is presented for estimating the magnitude and frequency of floods for urban streams in metropolitan Atlanta. The method is based on adjustments to the natural stream flood-frequency and rainfall-frequency characteristics of the local area as defined by urban flood studies in other areas. The effects of urbanisation on flood-peak runoff are estimated from the percentage of drainage basin that is impervious and the percentage of drainage area served by storm sewers. Equations are presented for estimating the 2-, 5-, 10-, 25-, 50-, and 100-year flood peak discharges for basin sizes from 0.5 to 100 square miles in the Atlanta metro area. Data from 12 urban streams in the Atlanta area were used to obtain a qualitative verification of the 2- and 100-year estimating equations. Hydrologic data are presently being collected for a study that will provide a data base for use in hydrologic models to develop more reliable urban flood-frequency relations.

GOETTLE, A. 1978: "Atmospheric contaminants, fallout and their effects on storm water quality". Prog. Wat. Tech., Vol.10(5/6); p455-467.

Key words: air pollution effects; storm runoff.

Concerning the interrelations between the pollution concentrations in air and the resulting contamination of rain and storm water runoff, satisfactory results are missing. To get a clear picture of the influence of air contaminants on storm water quality, the different parts of the chain process of atmospheric pollutants, beginning from their emission into the air, dispersion and reactions in the atmosphere, particulate uptake in precipitation and sedimentation by the influence of gravity, chemical reactions until their deposition and reactions in the water recipients must be studied in a more detailed

GOLDREICH, E.E. et al. 1968: "The bacteriological aspects of storm water pollu-

tion". J. Water Pollution Control Federation, Vol.40(11); p1861-1872.

Key words: water pollution sources; faecal coliforms; bacteria.

The bacteriological composition of storm water from a variety of areas was compared and seasonal differences noted. Higher numbers of organisms appear to persist during winter than during summer. The faecal coliform segment of the total coliform population for all storm water samples averaged 8.6 percent; however, 21.1 percent faecal coliforms were observed in storm water taken in autumn from a suburban business district. Evidence indicates that faecal contamination in separate storm water systems originates from cat and dog deposits on soil and from rodent deposits in urban areas. Thus regulations to prohibit pets on public beaches and improved garbage control plans to discourage rodent proliferation are recommended. Also, diversion of storm drains and land drainage away from beaches and reservoirs would aid in reducing bacterial contamination.

GOLDREICH, E.E. and KENNER, B.A. 1969: "Concepts of faecal streptococci in stream pollution". J. Water Pollution Control Federation, Vol.41(8); pR336-R352.

Key words: storm runoff; faecal coliforms; bacteria; bioindicators.

Results of an intensive study on the occurrence and strain distribution for 12,536 faecal streptococcus strains found in warm blooded animal faeces and numerous water sources from a wide geographical area reveal several new factors that must be understood for a proper interpretation of the sanitary significance of this bacterial group in water studies. These studies were conducted in streams, agricultural waters, recreational and public water sources, and on domestic waste water and food processing wastes. The ubiquity of *Streptococcus faecalis* var. *liquifaciens* in the water environment and the occasional occurrence of an atypical *S. faecalis* associated with vegetation shows the need for including the faecal coliform examination in recreational water quality measurements. Applications of the faecal streptococcus indicator system in stream pollution are the development of faecal coliform to faecal streptococcus ratios that will further define possible sources of the faecal discharge into the stream; and the detection of the *S. bovis* and *S. equinus* subgroup which was not found in human faeces and may be considered a specific indicator of non-human animal pollution.

GONZALEZ, D.D. and DUCRET, G.L. 1971: "Rainfall-runoff investigations in the Denver metropolitan area, Colorado". U.S. Geol. Survey open-file report 71003; 27pp.

Key words: rainfall-runoff relationships; model studies; storm runoff; flood forecasting; analytical techni-

ques.

Definition of the magnitude and frequency of floods on small urbanised watersheds in the Denver metropolitan area requires the collection and analysis of rainfall-runoff data needed to synthesise long-term runoff records from precipitation records. Hydrologic models and synthetic unit hydrographs are the primary analytical methods used. Analytical applications of the rational method are also useful. Dual digital recorders provide the detailed records of rainfall and runoff required in a form convenient for computer translation and tabulation.

GONZALEZ, V. 1976: "Hydrologic data for urban studies in the San Antonio, Texas metropolitan area, 1974". U.S. Geol. Survey open-file report; 109pp.

Key words: rainfall-runoff relationships; urban runoff; hydrologic data; streamflow; peak discharge; hydrographs.

Runoff data from San Antonio urban study area for the 1974 water year are based on discharge measurements and stage records at six continuous-record stream-gauging stations, seven crest-stage partial-record stations (flood hydrographs obtained), and water-surface elevations at eleven flood-profile partial-record stations. Storms producing the highest peak discharges in the San Antonio metropolitan area occurred on the following days: Oct. 11, 1973, and Aug. 8, 30, 1974. Weighted rainfall for these storm periods upstream from continuous-record gauging stations and selected crest-stage partial-record stations are given. Water-quality data have been collected from watersheds in various stages of urban development at most of the gauging stations in the San Antonio urban area. This water-quality program provides data on the concentration of pollutants as a result of runoff from these watersheds. In addition these data provide a relationship of water-quality parameters to discharge and seasonal conditions.

GOYEN, A.G. and AITKEN, A.P. 1976: "A regional storm water drainage model". In, Inst. Engineers Hydrology Symposium, Sydney, Australia, preprints of papers; p40-44.

Key words: mathematical models; flood routing; urban drainage; urban runoff; rainfall-runoff relationships; storm runoff.

A model is presented which analyses trunk storm water systems involving retarding basins, natural storages and natural or artificial channels and pipes for a given storm situation. The model employs a modification of Laurenson's Runoff Routing Model for hydrograph estimation in urban and partly urbanised catchments, a modified version of the Muskingum-Cunge method for channel routing and Pul's method for the level pool routing of flood flows through storages. Hydrographs, water

levels within basins, flow velocities and inundation periods are computed at defined points within the catchment. Sufficient data are available from the model to define flood plain reservations.

GRACE, R.A. and EAGLESON, P.S. 1967: "Scale model of urban runoff from storm rainfall". J. Hydraul. Divn., Proc. ASCE, Vol.91(HY3); p161-176.

Key words: urban runoff; model studies; storm runoff; urban drainage.

The response of a small urban watershed to four storms is generated in the laboratory by a scale model consisting of a programmed rainfall generator, vertically distorted scaled topography, and a weighing device for recording the cumulative runoff. Comparison of these results with prototype measurements through use of derived scaling laws shows reasonable agreement.

GRAF, W.L. 1975: "The impact of suburbanisation on the stream channel networks of Ralston Creek and South Branch, Iowa". Institute of Urban and Regional Research, University of Iowa, Iowa City, Technical Report No.62; 37pp.

Key words: urbanisation; peak discharge; urban drainage; erosion; streamflow; mathematical models.

Drainage channels change their cross-sectional shape as a result of increased runoff from impervious suburban surfaces. Stream discharge represents energy responsible for environmental change or continuity. Channel networks spatially control hydrological activity, and thus also control distribution of energy, called the energyscape. This study is concerned with how the effect of artificial channels created during suburbanisation alter the character of stream networks and influence flooding, erosion and deposition problems. Twenty-three variables are used to describe the effects suburbanisation has on stream networks and stream flows. Principal variables are the number and length of exterior and interior links and channels, drainage area, drainage density, bifurcation ratio and arrangement index. It was concluded that network changes have contributed to flooding and consequences on fluvial landforms are expected. Future research will attempt to determine the relationship between network parameters and hydrologic parameters, and link network characteristics to flood characteristics by regression models.

GRAF, W.L. 1975: "The impact of suburbanisation on fluvial geomorphology". Water Resources Research, Vol.11(5); p690-692.

Key words: aerial photography; surface runoff; channel erosion; sediment yield.

Analysis of aerial photography for the
Water & soil technical publication no. 15 (1979)

period 1950-1971 and field data collected from 1970 to 1974 indicate that in the Denver area suburban development has caused significant changes in fluvial systems. By first introducing large quantities of sediment and later by increasing surface runoff as suburban development increases, greater percentages of stream lengths are dominated by transportation, and lesser percentages are dominated by erosion and deposition.

GRAF, W.L. 1976: "The impact of suburbanisation on stream networks". Final Report No.14; 34pp. (ISWRR1-75; NTIS PB-256 229).

Key words: urbanisation; hydrographs; flood discharge.

Analysis of geomorphic, hydrologic, and suburbanisation data from a small instrumented drainage basin near Iowa City, Iowa, indicates that channel networks are radically altered when suburban development overtakes a drainage basin. Change in channel networks are generally such that the network becomes much more efficient in collecting water quickly, so that lag time and kurtosis of storm hydrographs are altered to produce the familiar flash floods of urban areas. The data show that network changes are most closely associated with kurtosis of storm hydrographs and suggest that corrective measures be concentrated on the internal linkages of the network.

GRAF, W.L. 1977: "Network characteristics in suburbanising streams". Water Resources Research, Vol.13(2); p459-463.

Key words: urbanisation; hydrographs; analytical techniques.

Analysis of hydrologic, geomorphic, and suburbanisation data from a small instrumented drainage basin near Iowa City, Iowa, indicates that channel networks are radically altered when suburban development overtakes a drainage basin. Changes in channel networks are such that the network becomes much more efficient in collecting water quickly, so that lag time and kurtosis of storm hydrographs are altered to produce the familiar flash floods of urban areas. The data show that network changes are closely associated with lag time and kurtosis of storm hydrographs and suggest that corrective measures should be concentrated on the internal links of the network. Changes in characteristics of channel networks should be considered in addition to changes in areas of impervious surfaces when the hydrologic impact of suburbanisation is assessed.

GRAHAM, P.H. et al. 1974: "Estimation of imperviousness and specific curb length for forecasting storm water quality and quantity". J. Water Pollution Control Federation, Vol.46(4); p717-725.

Key words: storm runoff; model studies; flood forecasting; aerial pho-

tography; remote sensing.

The purpose of this work is to develop a method for estimating the imperviousness and specific curb length (curb length per unit area) of a watershed for subsequent input into a storm water model. A sensitivity analysis is presented to establish the importance of these parameters on the quantity and quality of storm water runoff from a watershed. Methods are presented to obtain specific curb length and imperviousness values from colour infrared imagery, with values for the latter parameter obtained by means of an electronic planimeter. The functional relationships with watershed household, population, and employment densities are reported. With the ability to infer imperviousness and specific curb length from demographic data commonly projected by planners, it is now convenient for the environmental engineer to make estimates of future runoff volume per storm and BOD5 washoff per storm in expanding urban areas.

GRAVA, S. 1969: "Urban planning aspects of water pollution control". Columbia University Press, New York; 232pp.

Key words: water pollution control; watershed management; waste water disposal.

This book is one of the first of a series of works dealing with urban affairs to be published by the Institute of Urban Environment, Columbia University. It is a study that examines one dimension of the total physical planning dilemma facing cities throughout the world. The major thrust of the work has been to analyse the problem of waste disposal as it imposes a constraint on the policy choices available to the urban planner. Thus, the basic engineering difficulties involved are treated as an adjunct to planning issues. In discussing water pollution control measures, the author moves from detailed technical information and its planning implications to the question of its effects on community organisation. Particular attention is given to the special problems of disposal in developing countries.

GREENBERG, M.R. et al. 1974: "Water quality monitoring and river basin planning: a critique and some recommendations". J. of Environmental Management, Vol.2(4); p319-330.

Key words: data collection; water pollution control; hydrologic systems; network design.

The validity of water related policies based on sophisticated system designs, which in turn, are based on erratic data collection and inconsistent sampling, is faulted. The water monitoring system in the densely developed portion of northeastern New Jersey is evaluated and recommendations are suggested for its improvement. For example, the data represent too few parameters and show a bias toward indices related to human wastes; groundwater,

estuarine, and effluent data are completely inadequate. There is a lack of information on nonpoint water pollution sources, and sewage effluent is chosen only on the degree of accessibility. Sampling frequency varies from 15-minute automatic monitors, to three to four times a year at effluent sources, to once to every two years in wells, all at random intervals. Manual monitoring results are inconsistent between and within some agencies in laboratory procedures, in sampling frequency, and the break-up of data sets when new techniques are introduced. Automatic monitors frequently malfunction. Data recording on field sheets and in files differed widely reflecting the special interest of the collecting agency, random choice, and indifference. Data bookkeeping and formal arrangement for machine processing present analytical difficulties.

GREGA, M.D. LA. and KEENAN, J.D. 1975: "Characterisation of water quality from combined sewage discharges". In, Urbanisation and water quality control. Proc. Symposium American Water Resources Association, No.20; p153-161.

Key words: combined sewers; storm runoff; overflows; data collection.

The study involved characterisation of the combined sewage discharges for the city of Chester, Pennsylvania. This was accomplished through a program of sampling and analysis of combined sewer overflows to the Delaware River estuary for three different intensity storms. The results indicated typical waste characteristics of combined sewage discharges from the regulators and provided order-of-magnitude estimates for the load on the receiving stream. The ultimate goal was the prediction of the quantity and quality of combined flows from Chester and the effect of these discharges on the receiving stream, the Delaware River estuary.

GREGORY, K.J. 1974: "Streamflow and building activity". In, Fluvial processes in instrumented watersheds, (eds. K.J. Gregory; D.E. Walling). Inst. British Geographers Special Publication No.6; p107-122.

Key words: analytical techniques; rainfall-runoff relationships; peak discharge; urban runoff.

A small drainage basin on the margin of Exeter, Devon, has been instrumented for four years since 1968 to monitor rainfall and streamflow during building activity. Contemporary building operations have hitherto directly affected 12.25 percent of the catchment area. In 1971-72 this included building completed on 3.7 percent of the catchment area, 4.9 percent undergoing building operations and 3.6 percent unvegetated. The installation of a system of road drains had effectively increased the drainage density by 4.26 km/sq km. Four years of records are analysed in terms of 659 individual storm events and it is concluded that building oper-

ations have led to an increase of peak discharge by two times, a decrease of lag time to half its former values, and an increase of runoff varying between 1.1 and at least three times former values. Percentage runoff is increased by at least 0.9 percent consonant with the area sewered, but the net effect of a modified pattern of contributing areas is demonstrated by runoff percentages up to 20 percent greater than formerly.

GREGORY, K.J. and WALLING, D.E. 1973: "Drainage basin form and process. A geomorphological approach". Edward Arnold, London; p351-358.

Key words: urban hydrology; urbanisation; urban runoff; landuse change.

During the past decade several general works and an unprecedented expansion in specialist publication and research by geographers, hydrologists and others have added fundamentally to the understanding of rivers and drainage basins. No one work has hitherto concentrated exclusively on the latter. The drainage basin is visualised increasingly as the fundamental unit of study in fluvial geomorphology, and this work reviews the methods whereby it may be studied, describes the results which have been achieved and indicates the significance which these results may have both for future research and study and for the physical environment as a whole. This approach seems warranted by the dependence of fluvial processes upon the drainage basin unit, and at least partly justified by the increasingly critical effect of human interference on the drainage basin and the river network it contains.

GRIFFITHS, J.P. and GRIFFITHS, M.J. 1974: "Bibliography of the urban modification of the atmospheric and hydrologic environment". National Oceanic and Atmospheric Administration, Washington, D.C., Environmental Data Service, Technical Memo.; 100pp. (COM-74-10962/0).

Key words: bibliographies; weather modification.

The growing emphasis on urban problems is illustrated in this bibliography wherein the number of bibliographic entries for each year has increased rapidly in the seventies. The intent is to have this publication give a representative cross section of the literature, not a completely comprehensive compilation. Only those references to city climates that actually contain comparisons with adjacent rural climates are included; it is the change under city influence which is stressed. Separate sections have the following headings: city, cloud, cooling power, dust and nuclei, electricity and ions, humidity, light, models, pollution, precipitation, radiation, temperature, visibility, wind, floods, ground water, runoff, sedimentation, stream temperature, and water quality.

GRIFT, H.M. and SYMONS, G.E. 1968: "How to estimate storm water quantities". Water and Wastes Eng., Vol.5(3); p46-50.

Key words: flood discharge; mathematical models; analytical techniques.

The rate of flow for storm drain design is dependent on the runoff rate and frequency. Drained areas are usually small, so movements of storms or uneven rainfall rates have little influence on the resulting flood flows. It is for these reasons that estimation of storm sewer designs is based on rainfall data. Considering the relative importance of the various influences, the degree of accuracy required, the importance of the structures being designed, and the accuracy of the available data, the rational method for estimating extreme rates of surface runoff appears to be the most logical for the design of storm drains. The greatest weakness of the rational method is the difficulty of estimating the duration of storms that will produce peak flow. Imperviousness is logically compensated for by assuming a coefficient representing the proportion of the rainfall that does not soak into the ground. The length of storm required to produce peak conditions also has an effect in that the percent of runoff may increase as the ground becomes soaked. Several methods have been proposed for accurate computation of these factors, but it is questionable if these refinements are justified in practice.

GROVER, W.C. et al. 1972: "Investigation of porous pavements for urban runoff control". EPA Water Pollution Control Research Series, EPA 11034 DUY.14-12-924; 142pp. (NTIS PB-227 516).

Key words: combined sewers; urban runoff; solid wastes; overflows; waste water treatment; pollution abatement.

Laboratory and economic studies were undertaken to determine the feasibility of utilising porous pavements to alleviate combined sewer overflow pollution and reduce the design parameters of storm sewer systems by allowing storm runoff to percolate back into the ground. Laboratory studies of candidate materials revealed a porous asphaltic concrete containing 5.5 percent asphalt by weight and aggregate graded to allow a water flow of 76 in. per hour to be the optimal porous road material. Materials testing for stability, durability, and freeze-thaw susceptibility proved this material suitable for use in road construction. Asphalt Institute specifications were used to design roads with porous asphaltic concrete surfaces and gravel bases for varying traffic densities. Major design parameters considered were the load-bearing capacity and permeability of the subgrade, expected maximum precipitation and depth of frost penetration. Roads designed with porous asphaltic concrete were found to be generally more economical than conventional roads with storm sewers. The economics of porous pavement were further

enhanced by the added value of benefits from combined sewer overflow pollution relief, augmentation of municipal water supplies, improved traffic safety, preservation of vegetation, relief of flash flooding and the aesthetic benefits of a colored porous surface.

GRUNKEMEYER, G.L. 1972: "The effect of urbanisation on runoff quantity". MSc Thesis, Delaware University, Newark, Department of Civil Engineering; 84pp.

Key words: urban hydrology; urbanisation; rainfall-runoff relationships.

Red Clay Creek drainage basin, Delaware, is being developed into a populated and urbanised area. Runoff from Red Clay Creek basin showed a decreasing trend during the 1964 through 1969 period of study. This decrease was caused by an even greater decreasing trend in precipitation. The fact that runoff dropped by a lesser amount than did precipitation reflects an increasing trend in runoff. Basic land use in Red Clay Creek basin is agricultural. Ground slopes range from nearly flat to as high as 15 to 18 percent. Woodlands still cover over one quarter of the basin's land area. Slightly less than one quarter of the basin is used for pastures. Urbanisation is only in the first stages. Urban development probably will increase during the next decade because of the basin's proximity to Wilmington.

GUY, H.P. 1965: "Residential construction and sedimentation at Kensington, Maryland". Proc. Federal Inter-Agency Sediment Conference, USDA Misc. Publication No.970; p30-37.

Key words: sediment yield; water pollution sources; sediment transport; analytical techniques.

Sediment transported in storm runoff near Kensington, Md., during the transformation of part of a 58 acre area from rural to residential land use was measured for 25 storm events from July 1959 to January 1962. These data were used with the water discharge record of nearby Rock Creek in a multiple regression analysis to show the magnitude and trend of sediment movement with time. Total sediment discharge from the area was 189 tons per acre for the entire period of construction and the subsequent change to a reasonably stable residential area. The high yield of sediment is attributed to the rolling topography (3 to 25 percent slope); a very friable soil and subsoil; the construction of a street in the major drainage channel; a tendency for construction methods to expose extensive areas of the soil for a long period at a time; and a substantial amount of the 42 inches of annual rainfall occurring at a rate in excess of the infiltration capacity of unprotected soil.

GUY, H.P. 1967: "Research needs regarding sediment and urbanisation". J.

Hydraul. Divn., Proc. ASCE, Vol.93(HY6); p247-254.

Key words: urbanisation; streamflow; storm runoff; sediment yield; erosion; erosion control.

Sediment derived from construction in areas of urban growth has profound impact on downstream channels and water resources. Such sediment pollution is usually much more dynamic and intensive than sediment derived from rural areas. Research needs concerning urban derived sediment are similar to those already underway in rural areas; however, new emphasis must be given to exposed subsoils, to problems in existing stream channels, to pollution of existing and future water resources, and to more effective planning and phasing of construction. Storm drainage, that flows through existing and new channels that are later complicated by urban changes, is a foremost topic of urban hydrology, and it is discussed in this article. Some of the needed soils and stream channel research can be accomplished in laboratories, but much needs to be done on small areas at the construction sites. Although many urban research methods can be adapted from related rural programs, consideration must be given to the fact that the extent and location of the exposed subsoils in the drainage basin will change rapidly and that extremely high and variable sediment loads will be imposed upon the stream channels. Better planning and legal backing will make research findings more useful.

GUY, H.P. 1970: "Sediment problems in urban areas". U.S. Geol. Survey circular No.601-E; 8pp.

Key words: sediment yield; erosion control; water pollution sources; channel erosion.

Much of the disturbed soil in urban construction areas erodes and becomes sediment in streams; the sediment damages water control works and aquatic habitat, degrades water quality, increases flood damages, and lowers the environmental attractiveness. During the process of stabilisation of an area after construction, streams tend to erode their beds and banks as a result of increased runoff. All such sediment, whether from construction erosion or from channel erosion, is transported by streams and often deposited somewhere downstream at a location previously assigned to the movement or storage of water.

GUY, H.P. 1971: "Control of sediment in the urban environment". In, Treatise on urban water systems, Colorado State University, Fort Collins; p509-517.

Key words: urbanisation; sediment yield; erosion control; water pollution control.

If it is true that in the United States more than 4,000 acres a day are "plowed up" for real estate developments, suburban facilities, highways, and indus-

tries, then there is little doubt that we have a king-size urban sediment problem on our hands. In regard to only the sediment yield aspect, if such development lasted only one year and the yield averaged 100 tons per acre, the contribution to our streams would be 150,000 tons of sediment. Considering the time and effort now spent on pure hydrologic investigations, and the apparent effort still required, it is evident that investigations relative to urban-sediment problems must be substantially increased if really useful knowledge is to be attained in the next 2 or 3 decades.

GUY, H.P. 1974: "An overview of urban sedimentology". In, National symposium on urban rainfall and runoff and sediment control: Proceedings of a symposium held at University of Kentucky, Lexington, Ky. Report UKY BU106; p149-159.

Key words: sediment transport; urbanisation; storm runoff; erosion; channel erosion; erosion control; urban hydrology; sediment yield.

Urban sedimentology implies all theoretical, analytical, and philosophical studies on particulate matter moved, or likely to be moved, by water, wind, ice, gravity, or man in an existing or developing urban area. More commonly, however, urban sedimentology is concerned with: (1) spatial and temporal erosion of soils in construction areas, (2) the nature of the movement and impact of sediments in construction areas and in water bodies downstream, (3) methods for mitigating erosion and sediment movement, and (4) channel erosion downstream where flows have increased as a result of increased imperviousness from urbanisation. Minimising sediment problems in an urban development area begins with sound land use and structure design, then makes use of practical vegetative controls on as much of the site as possible, for as much time as possible to prevent erosion and trap sediment; and then makes use of physical controls to slow runoff and trap sediment. Such controls must be applied with specific criteria as to their needs and effectiveness; that is, the reduction in damages must exceed the cost of application.

GUY, H.P. 1974: "Remote sensing techniques for evaluation of urban erosion and sedimentation". In, Effects of man on the interface of the hydrological cycle with the physical environment. Proc. of Paris Symposium, IAHS Publication No.113; p145-149.

Key words: aerial photography; remote sensing; erosion; data collection; landuse change; erosion rates; sediment yield.

Low-altitude aerial photography was used to supplement ground based measurements for the evaluation of erosion and sedimentation conditions during the construction of a large office complex at Reston, Virginia. Ground measurements included precipitation, runoff, and sediment, as well as selected meas-

urements of sheet erosion, rill development and sediment deposition. Ground-level photographs provided additional documentation of changing basin conditions. Satellite imagery could not be used because of detail loss upon the required enlargement.

Low-altitude photography (scale 1:3600) gave good delineation of landuse changes. If used within a few hours of a rainstorm, low-altitude photography provided information on erosion and sedimentation features resulting from the storm. Ground based measurements were necessary to define the timing and magnitude of the erosion and deposition processes.

Sediment yield was 91 tonnes ha⁻¹ during the 2-year construction period beginning September 1971. The 5.5 ha forested part of the drainage area yielded little or no sediment relative to the 14.4 ha construction area. The maximum daily sediment yield of 1.19 tonnes h⁻¹ ha⁻¹ occurred during tropical storm Agnes on 21 June 1972.

GUY, H.P. 1975: "Urban sediment problems, a statement on scope, research, legislation and education". J. Hydraul. Divn., Proc. ASCE, Vol.101(HY4); p329-340.

Key words: erosion; sediment transport; sediment control.

The present system of coping with accelerated erosion and sediment movement in areas of urban development tends towards application of a large array of control techniques, mostly borrowed from rural settings. But too little is known of their control effectiveness, or whether they represent the optimum treatment, or whether they are needed in the first place. A systematic method is needed for estimating sediment movement that can be coupled with a specifically designed set of controls to minimise the adverse effects of sediment movement. This should be done in a manner that would insure that the probable reduction in damages would exceed the cost of application of such control. The report examines the need for legislative, educational, and research activities to stimulate progress in solving the many different kinds of urban sediment problems.

GUY, H.P. 1976: "Sediment-control methods in urban development: some examples and implications". Geological Society of America Special Paper No.174; p21-35.

Key words: sediment control; urbanisation; erosion; watershed management; sediment transport.

Sediment-control methods in areas of urban development must be more carefully designed temporally and spatially than methods used in rural areas. Several jurisdictions have adopted a manual for sediment-control methods that is based largely on rural sediment-control technology. The applications of these general methods too

often have adverse geomorphic implications when large quantities of sediment suddenly move into and through natural streams. An example of adverse effects of attempted sediment control is the use of small sediment-detention basins downstream from a development project when the construction phase will last for only a few months. The result is that (1) damage is done to the waterway during installation, maintenance, and, if necessary, removal of the structure; (2) little of the fine sediment is trapped and considerable coarse sediment may be lost during a storm of long recurrence interval; (3) maintenance may be neglected by the contractor, which can cause a failure of the system; and (4) the cost of the detention is passed on to the customer. The need for such a detention basin might be avoided by designing the facility so as to insure minimum disturbance of the landscape, a reduction in direct overland flow, and better timing of construction to minimize soil exposure during the rainy season.

GUY, H.P. et al. 1963: "A program for sediment control in the Washington metropolitan region". Washington, D.C., Interstate Commission Potomac River Basin; 48pp.

Key words: sediment control; erosion; erosion control; water pollution sources.

In the Washington metropolitan area, one of the fastest growing areas in the nation, rates of erosion and sediment production far exceed those in rural areas. While the consequences are numerous in the Washington area, the great concern is the effect on the quality of the water in the Potomac River. Three principal sources of sediment exist in urban areas: (1) commercial and residential development construction; (2) highway and other public construction projects; and, (3) public parks and recreation areas. In the first two instances, rapid erosion occurs during the construction period. One of the least costly and most effective means of reducing erosion is a shortening of the construction time period during which the raw soil is exposed.

GUY, H.P. and FERGUSON, G.F. 1962: "Sediment in small reservoirs due to urbanisation". J. Hydraul. Divn., Proc. ASCE, Vol.88(HY2); p27-37.

Key words: landuse change; sediment yield; urban drainage.

Expanding urbanisation activities may cause serious sediment deposition in small reservoirs. An example is that of Lake Barcroft near Washington, D.C., where 19 acre-feet or 25,000 tons of sediment have been deposited for each square mile of completed residential construction. Factors affecting the sedimentology processes in areas under urbanisation are found to be similar to, but more difficult to evaluate than, those applied to rural conditions.

GUY, H.P. and FERGUSON, G.F. 1970: "Sedimentation as an environmental problem". J. of Soil and Water Conservation, Vol.25(6); p217-221.

Key words: erosion; storm runoff; water pollution sources; sediment transport; erosion rates.

Urban erosion involves construction sites that tend to be widely dispersed. Unlike the continuing erosion on poorly managed agricultural lands, construction sites erode mainly during the brief periods between land clearing and stabilisation of the new surface. At Scott Run, a 4.54 square mile watershed near Washington, D.C., highway construction affected about 11 percent of the watershed from 1961 to 1964. Measurements of 88 storm events showed that 37 percent of the runoff and 99 percent of the sediment movement occurred in 3 percent of the time and that highway construction areas, 1 to 10 percent of the basin, contributed 85 percent of the sediment. Erosion was about 10 times that normally expected from cultivated land, 200 times that expected from grassland, and 2,000 times that expected from forest land. Sediment transport in storm runoff was measured for 25 storm events from a 58 acre watershed in Kensington, Md., between July 1959 and January 1962. During this period, 89 single dwelling houses were constructed on 20.5 acres in the upper part of the watershed. An average of 189 tons of sediment per acre was lost from the area.

GUY, H.P. and JONES, D.E. 1972: "Urban sedimentation - in perspective". J. Hydraul. Divn., Proc. ASCE, Vol.98(HY12); p2099-2116.

Key words: sediment yield; sediment control.

The perspectives on urban sedimentation contained in this report may be reduced to a few important elements: (1) urban sedimentation is apparently sufficiently costly to individuals and society to deserve a concerted effort to reduce its impact on the environment; (2) several natural and man-made aspects cause the phenomenon to be complicated in space and time; (3) sound planning and design for good land use can reduce or eliminate the problem; (4) a set of standard control measures may not be effective. Benefit evaluation of such measures is generally lacking; (5) extensive research is needed, not only to define the scope of the problem, but the cost and cost effectiveness of control methods presently used. Consideration and effective use of these elements will help to insure that disproportionate expenditures and restrictions will not be imposed on the land development industry.

HAAN, C.T. 1974: "Overview of rainfall - runoff process in urban areas". In, National Symposium on urban rainfall and runoff and sediment control proceedings, University of Kentucky, Lexington, Ky.; p1-13.

Key words: urban runoff; rainfall-runoff relationships; hydrographs; urban hydrology.

This paper covers some of the basic principles and terminology associated with urban hydrology. It was primarily intended as background or briefing material for those not already well versed in hydrology. This paper is a primer on urban hydrology which explains some basic hydrologic concepts, commonly used terminology, and currently used methods in urban hydrology.

HAAN, C.T. 1975: "Comparison of methods for developing urban runoff hydrographs". In, Proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Ky.

Key words: hydrographs; storm runoff; watershed management; flood control.

Developers of urban areas are increasingly being required to develop their property in such a fashion as to not aggravate downstream flooding. The design of storm water control facilities to meet this objective requires an estimate of runoff hydrographs. This paper compares two methods of estimating storm water runoff hydrographs for urban areas.

HAAN, C.T. 1976: "Mini-course 3: urban runoff hydrographs - basic principles". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p349-375.

Key words: urban runoff; hydrographs; storm runoff; model studies.

The treatment of hydrology here is largely limited to those parts of the hydrologic cycle of major importance in urban storm water management. This means that primary emphasis is placed on precipitation, abstractions from precipitation and the runoff process. Such things as vegetal interception of precipitation, evaporation, transpiration, soil water movement and ground water movement are mentioned but not covered in detail. These latter parts of the hydrologic cycle, although of extreme importance in areas such as agricultural hydrology or forest hydrology, are not as important in urban storm water hydrology. The intent of this treatment is to present some basic principles and general procedures applicable to urban hydrology. No specific method is advocated nor is a step-by-step cookbook procedure advocated. Rather, emphasis is placed on developing an overall understanding so that procedures most applicable to a particular problem can be selected. The treatment begins with a coverage of point rainfall data including

depth-duration-frequency curves and storm time-intensity relationships. Next, abstractions from rainfall are discussed. The treatment of runoff begins with a section on terminology and conceptual models. This is followed by hydrodynamic models and unit hydrograph procedures.

HAAN, C.T. and BARFIELD, B.J. 1972: "Rainfall and runoff in urban areas - theory and prediction". Proc. Urban Rainfall Management Problems, University of Kentucky, Lexington, Ky. Kentucky University Technical Report UKY 51-72-CE16; p9-45.

Key words: urban hydrology; peak discharge; flood forecasting; urban runoff; storm runoff; urbanisation; rainfall-runoff relationships.

It is difficult to describe the effects of urbanisation on the hydrology of an area because of the many different types and degrees of urbanisation. Spacious subdivisions with septic tanks can significantly increase water table levels and low flow of streams if the water supply is brought in from outside the basin. This type of development may have no applicable affect on storm flows. Dense residential developments which have a high fraction of the total area in streets, roads, and sidewalks may greatly increase flood flows. Urbanisation also tends to increase the frequency of floods because intense storms of short duration can produce large peak flows. The travel time of water through the basin is shortened by street gutters, storm sewers, and channel improvements. In the rational formula, increased flood flows are shown by increase of the runoff coefficient and decrease of the time of concentration. Considerable care and judgement must be used when applying the rational equation to estimating peak runoff. The location of impervious areas with respect to the design point can greatly affect runoff rates. This is a method predicting peak flows only. For some design situations, it is necessary to be able to estimate runoff volumes.

HACKETT, J.E. 1965: "Ground water contamination in an urban environment". Ground water, Vol.3(3); p27-30.

Key words: ground water resources; urban hydrology; pollution abatement; sewage disposal; water pollution sources; aquifers.

Sources of ground water and of ground water pollution in the urbanised area of northeastern Illinois are noted. Regional planning to cope with the problem of ground water contamination is advocated along with development of hydrogeologic criteria to determine whether the natural environment can adequately safeguard ground water reservoirs against contamination, and the establishment of engineering specifications to provide protection where natural safeguards are lacking.

HAGARMAN, J.A. and DRESSLER, F.R.S. 1975: "Storm water management model: dissemination and user assistance". EPA Report 670/2-75-041; 46pp.

Key words: mathematical models; waste water treatment; erosion control; water pollution; model studies; computer models.

A program of dissemination and user-assistance for the EPA Storm Water Management Model (SWMM) has been developed and implemented. Services available to SWMM users include distribution of the SWMM program itself and technical assistance in problem delineation, data preparation, execution debug, and output interpretation. Costs of this service extend only to actual computing costs. Several case studies of SWMM applications completed with UCSC assistance in the past year are included in this report. These studies include a combined sewer overflow problem in Binghamton, New York; a land use plan in the Stony Brook basin in Princeton, New Jersey; and RUNOFF/TRANSPORT calculations on the Wingohocking basin in Philadelphia, Pennsylvania. The UCSC SWMM dissemination program is now self-sustaining and continues to assist the user community.

HALL, M.J. 1973: "Synthetic unit hydrograph technique for the design of flood alleviation works in urban areas". In, International symposium on design of water resources projects with inadequate data, Madrid. IAHS Publication No.108, Vol.2; p485-500.

Key words: hydrographs; urban hydrology; analytical techniques; flood control.

The development of rural land for urban, suburban or industrial purposes can radically alter the flow regime of the catchment area within which such changes take place. The volume of surface runoff tends to increase, the lag time of the flood hydrograph to decrease and the peak rate of flow to increase. These changes should be anticipated in the design of flood alleviation works for catchment areas undergoing urbanisation, but in general, little quantitative information is available on the magnitude of the effect at different stages of urban development. If flow records are available from several catchment areas, each of which has reached a different stage of urban development, the finite period unit hydrographs derived from these data can be used as an index to the influence of urbanisation. The application of a synthetic unit hydrograph technique to flow records from both urban and rural catchment areas within the headwaters of the River Mole near Crawley, United Kingdom, has confirmed the feasibility of the approach but has shown that more thought is necessary in choosing catchment characteristics which reflect the character of the urban development.

HALL, M.J. 1974: "The hydrological consequences of urbanisation: an introductory note". In, Proceedings

CIRIA/Bristol University research colloquium on rainfall, runoff and surface water drainage of urban catchments, Bristol, April 1973; pl0-1-10-12.

Key words: urbanisation; flood control; hydrographs; urban hydrology.

Urbanisation can be cited as one of the more dramatic examples of man's interference with the hydrological cycle. While the demand for water for domestic, industrial and recreational purposes increases with the growth of an urban area, its very presence accelerates the processes by which locally stored and precipitated water is returned to the sea. Although the effect of urbanisation on the flow regime of a catchment area has been appreciated for a number of years, relatively little information has been available concerning the magnitude of the changes brought about by different degrees of development. Of principal importance in the design of flood alleviation works are: (1) the frequency distribution of peak rates of flow; and (2) the shape of the flood hydrograph (generally expressed in terms of the unit hydrograph). The effect of urban development on these aspects of flow regime is reviewed briefly in this paper.

HALL, M.J. 1977: "The effect of urbanisation on storm runoff from two catchment areas in North London". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; pl44-152.

Key words: storm runoff; hydrographs; analytical techniques.

The development of urban areas within a drainage basin may have a marked effect upon its hydrological regime. Owing to the dearth of hydrometric records from catchments undergoing urban development, the changes in flow regime which take place are often difficult to quantify. One possible approach to overcoming this problem involves firstly, the derivation of unit hydrographs from storms recorded on several catchment areas at different stages of urbanisation; and secondly, the correlation of variables describing the shape of the unit hydrograph with catchment characteristics, which include descriptions of the urban area and its growth. A study of rainfall and flow records from two adjacent catchment areas located in the northern suburbs of London has shown that simple measures of urban development, such as the proportion of impervious area, are insufficient to describe the variations in catchment response between ostensibly similar drainage areas. Greater attention should be given to both channel conditions and their modification, and the distribution of urban area within the catchment.

HAMM, D.W. et al. 1974: "Statistical analysis of hydrograph characteristics for small urban watersheds". Tracor, Inc., Austin, Texas, Completion Report No.T73-AU-9559-U; 155pp. (NTIS PB-228

131).

Key words: rainfall-runoff relationships; peak discharge; storm runoff; model studies.

The purpose was to obtain equations which predict the 30-minute unit hydrograph for small urban watersheds. Equations were derived for models of the product form that correlate basin topographical features with hydrographic parameters. The models were transformed by natural logarithms so that linear regression methods could be used to obtain estimates of the exponents in the equations. The equations were applied to a wide variety of watersheds to demonstrate their validity. Confidence intervals were derived for the estimation of each hydrographic parameter. Nomograms were supplied to provide fast and accurate solutions for each equation.

HAMMER, T.R. 1970: "Criteria for measurement of stream channels as an indication of peak flow history". RSRI discussion paper series: No.36; 56pp.

Key words: peak discharge; data collection; alluvial channels; urbanisation; analytical techniques.

The purpose of this paper is to describe the methodology of stream channel cross section measurement developed in the current Regional Science Research Institute investigation of the hydrologic effects of urbanisation. The paper relates the nature of the measurement technique to the overall objectives of the study, and presents a preliminary analysis of the data obtained. The following aspects of the hydrologic system were chosen for study: channel morphology, peak flow characteristics, and water quality at base flow. This paper is concerned with channel morphology and its relationship to peak flow characteristics.

HAMMER, T.R. 1971: "Procedures for estimating the hydrologic impact of urbanisation". Philadelphia, Pa., Regional Science Research Inst., Contract Rept. to Office of Water Resources Research; 33pp.

Key words: rainfall-runoff relationships; urban hydrology; urbanisation; storm runoff; urban runoff; peak discharge.

The results of a recent study of the hydrologic impact of urbanisation are stated in a form that may be readily applied to planning or to the estimation of current effects of urbanisation. Conversion of land to impervious surface increases storm runoff by preventing infiltration of rainwater into the soil and by eliminating surface depressions which would provide storage; consequently, the peak streamflow accompanying a storm of given magnitude is increased. This process is assisted by drainage alterations which speed runoff to the streams. Stream channel cross section area increases in response to urbanisation in the same pro-

portion as the increase in the average annual flood. An impervious area index is employed along with a basin slope factor to estimate channel enlargement and peak flow increase. The index may be estimated on the basis of the limited information which is likely to be available. The two types of information considered here are: (1) the information contained in U.S. Geological Survey 7.5 inch quadrangle maps, and (2) the number of persons per square mile in the watershed in question.

HAMMER, T.R. 1971: "The effect of urbanisation on stream channel enlargement". PhD thesis, University of Pa., Philadelphia; 330pp.

Key words: urbanisation; landuse change; channel erosion; storm runoff; rainfall-runoff relationships; mathematical models.

Increases in peak streamflow magnitudes and in stream channel cross section area are caused by impervious development in stream watersheds. Channel area was correlated with land use and other data for 78 small watersheds in the Philadelphia metropolitan region. The data consisted of measurements of amounts of land in more than a dozen basic land uses, plus information regarding sewage, topographic data, and a complete numerical description of the stream channel system. Particular attention was given to the amounts of impervious area. The object of analysis was the channel "enlargement ratio", the ratio of observed channel cross section area to "natural" channel area for the given watershed size. The final estimating equations for channel enlargement permit the estimation of the impact of any impervious development at any location in a watershed on the stream channel at all downstream points. The results are presented in equation form and also in the form of graphs and curves. For purposes of illustration, the equations are applied to a sample watershed to show how the impacts of development might be predicted. A simple, "optimal" land use plan, which would minimise the hydrologic impact of locating a given population in this watershed, is prepared and discussed.

HAMMER, T.R. 1972: "Stream channel enlargement due to urbanisation". Water Resources Research, Vol.8(6); p1530-1540.

Key words: channel erosion; landuse change; urbanisation.

Stream channel enlargement occurs in response to the change in streamflow regimen accompanying urbanisation. This empirical study relates the imputed increase in channel cross-sectional area to detailed land use data and other information for 78 small watersheds near Philadelphia. Important differences between the effects of various types of impervious land use are observed: large channel enlargement effects are found for sewered streets and areas of major impervious parcels

such as parking lots, and much smaller effects are observed for unsewered streets and impervious areas involving detached houses. Relatively low channel enlargement effects are attributed to all types of impervious development less than 4 years old and also to street and house areas more than 30 years old. The influence of impervious development on channel size is found to be significantly related to topographic characteristics of the watershed, to the location of impervious development within the watershed, and to man-made drainage alterations. Although the relative importance of these interactive factors proves difficult to establish, the most critical determinant of the amount of channel enlargement resulting from a given level of urbanisation appears to be basin slope.

HAMMER, T.R. 1972: "Stream channel enlargement due to urbanisation". RSRI discussion paper series: No.55; 41pp.

Key words: urbanisation; channel erosion; landuse change.

Stream channel enlargement occurs in response to the change in streamflow regimen which accompanies urbanisation. This empirical study relates the imputed increase in channel cross section area to detailed land use data and other information for 78 small watersheds near Philadelphia. Important differences between effects of different types of impervious land use are observed: large channel enlargement effects are found for sewered street areas and areas of major impervious parcels such as parking lots, and much smaller effects are observed for unsewered streets and for impervious areas involving detached houses. Relatively low channel enlargement effects are attributed to all types of impervious development less than 4 years old, and also to street and house areas more than 30 years old. Channel enlargement is found to be significantly related to topographic characteristics of the watershed, to the location of impervious development within the watershed, and to man-made drainage alterations; but the relative importance of these factors proves difficult to establish. The most important determinant of channel enlargement resulting from urbanisation other than the land use mix itself appears to be basin slope.

HAMMER, T.R. 1972: "Empirical estimation of flood detention capacity needed to offset effects of urbanisation on peak streamflow". RSRI discussion paper series: No.57.

Key words: landuse change; flood control; peak discharge.

A well known environmental impact of urbanisation is the increase which occurs in peak streamflows, brought about primarily by the rendering of land impervious to rainwater. Although this effect may be less critical to the ecology than a number of other impacts of urbanisation, it is likely that at

some point in the future the public will require land developers to take steps to minimise peak streamflow increase as well as other adverse effects of urban development. The purpose of this paper is to indicate the probable magnitude of this task. Given the present nature of construction materials, peak flow increase can be avoided in urbanising areas only by providing facilities for temporary storage of runoff from impervious surfaces. A wide variety of flood detention structures, designed to release the runoff slowly, might be used. In any case, these facilities should be located as far upstream as possible (i.e., close to the runoff source areas).

HAMMER, T.R. 1973: "Effects of urbanisation on stream channels and stream flow". Regional Science Research Institute; (Office of Water Resources Research, U.S. Dept. of the Interior Contract); 288pp.

Key words: landuse change; watershed management; urbanisation; streamflow; channel erosion.

The primary strength of the studies reported here is the very detailed treatment of urban land uses. Due to the use of large samples of streams, it was possible to consider the individual effects associated with a wide variety of land use variables, and thus to establish the relative importance of factors such as the size of impervious surfaces, the provision of storm sewerage, the location of impervious area within a watershed, the relative amounts of building area and pavement area, etc.

HAMMER, T.R. 1973: "Impact of urbanisation on peak streamflow". RSRI discussion paper series: No.63; 77pp.

Key words: urbanisation; peak discharge; channel erosion; flood forecasting.

Previous research of the Regional Science Research Institute has focussed upon the effect of urbanisation on stream channel cross section area. The studies reported in this paper deal directly with the influence of urbanisation on peak discharge. These studies are based on the earlier channel studies in that they employ simplified measures of urbanisation which were shown to be related to channel enlargement in the earlier studies. This paper consists of two parts. The first deals with the effect of urbanisation on average annual flood, which is the flood peak having a recurrence interval of 2.33 years. The second part investigates the influence of urbanisation on the relative sizes of flood peaks of various frequencies. That is, it deals with the ratios of the 10 year flood, 20 year flood, etc., to average annual flood. Thus, the results of the two parts can be used to predict effects of urbanisation on floods of any frequency.

HAMMER, T.R. 1974: "Water quality deterioration in a suburban basin: Brandywine Creek, Pennsylvania". RSRI discussion paper series: No.78; 55pp.

Key words: data collection; hydrologic data; water pollution.

Brandywine Creek drains a 320 square mile area located approximately 30 miles west of Philadelphia. Most of the watershed lies in Chester County, Pennsylvania, with a small portion located in New Castle County, Delaware. Brandywine Creek has been the subject of a number of major scientific studies, including an ongoing program of water quality research conducted by the Tri-County Conservancy of the Brandywine in Chadds Ford. This paper presents a brief analysis of historical water quality data for the Brandywine at Wilmington, spanning the years from 1946 through 1974. The objective of this analysis has been to determine whether water quality has deteriorated or improved in recent years, and to provide a basis for projecting future levels of water quality.

HAMPTON, B.B. 1973: "Annual compilation and analysis of hydrologic data for urban studies in the Fort Worth, Texas metropolitan area, 1971". U.S. Geol. Survey open-file report; 77pp.

Key words: urban hydrology; urban runoff; hydrologic data; flood discharge; environmental effects; data collection; rainfall-runoff relationships; sediment transport; turbidity; hydrographs.

In October 1968, the Geological Survey in cooperation with the city of Fort Worth, Texas, Department of Public Works began a program of hydrologic investigations of several small streams in Fort Worth. The investigations are designed to evaluate factors affecting floods on small streams in the metropolitan area. Studies of additional streams, one of which drains beneath the impervious area of a shopping centre, were added to the program in October 1969. The objectives are to: (1) determine, on the basis of historical data and hydrologic analyses, the magnitude and frequency of floods; (2) document and define the areal extent of floods of greater than ordinary magnitude; and, (3) determine the effect of urban development on flood peaks and volume. This report is the third in a series published annually for the Fort Worth area as part of a continuing program. The report presents the basic hydrologic data collected in four study areas during the 1971 water year (October 1, 1970 to September 30, 1971). The four study areas within the metropolitan area are Sycamore Creek, Sycamore Creek tributary, Dry Branch, and Little Fossil Creek. The Sycamore Creek tributary study area includes the highly impervious area of the Seminary South Shopping Centre as a subarea.

HAMPTON, B.B. 1974: "Hydrologic data for urban studies in the Fort Worth, Texas Metropolitan area, 1972". U.S. Geol.

Survey open-file report; 123pp.

Key words: urban hydrology; rainfall-runoff relationships; data collection; hydrologic data; storm runoff; urbanisation.

Hydrologic investigations on several small streams in Fort Worth, Texas are designed to evaluate factors affecting floods on small streams in the metropolitan area. The objectives of the program are to determine, on the basis of historical data and hydrologic analyses, the magnitude and frequency of floods; to document and define the areal extent of floods of greater than ordinary magnitude; and to determine the effect of urban development on flood peaks and volume. The four study areas within the metropolitan area are Sycamore Creek, Sycamore Creek tributary, Dry Branch, and Little Fossil Creek. The Sycamore Creek tributary study area includes the highly impervious area of the Seminary South Shopping Center as a subarea. Summaries of storm rainfall-runoff data for selected individual storms at streamflow stations and crest-stage partial-record stations are given in the tables. Detailed storm rainfall and runoff records, hydrographs, and mass curves are compiled for each station.

HAMPTON, B.B. 1975: "Hydrologic data for urban studies in the Dallas, Texas metropolitan area, 1973". U.S. Geol. Survey open-file report; 146pp.

Key words: hydrologic data; urban runoff; urban hydrology; data collection; hydrographs; urbanisation; watershed management.

This report presents the compilation and analysis of hydrologic data collected in urban or partly urban drainage basins in the Dallas, Texas, metropolitan area during the 1973 water year. The objectives of the Dallas area program are: to determine, on the basis of historical data and hydrologic analyses, the magnitude, frequency and areal extent of flooding; to document and define floods of greater than ordinary magnitude; and to determine the effect of urban development on flood peaks and volume. During the 1973 water year, storms producing the highest peak discharges occurred on March 9-10; April 23-24; May 11-12; June 3-4, 19-21; July 7-8; and September 26-27, 1973. These storms produced a variety of rainfall amounts, intensities, durations, and distribution in the drainage basins. Weighted rainfall, for these storm periods upstream from continuous-record gauging stations and selected crest-stage partial-record stations, are given. The storm analyses, hydrographs, and mass curves also are included.

HAMPTON, B.B. 1975: "Hydrologic data for urban studies in the Fort Worth, Texas metropolitan area, 1973". U.S. Geol. Survey open-file report; 129pp.

Key words: hydrologic data; urban hydrology; urbanisation; data collec-

tion; hydrographs.

In October 1968, the Geological Survey in co-operation with the city of Fort Worth Department of Public Works began a program of hydrologic investigations on several small streams in Fort Worth, Texas. The investigations are designed to evaluate factors affecting floods on small streams in the metropolitan area. Studies of additional streams, one of which drains beneath the impervious area of a shopping center, were added to the program in October 1969. The objectives of the program are: (1) to determine, on the basis of historical data and hydrologic analyses, the magnitude and frequency of floods; (2) to document and define the areal extent of floods of greater than ordinary magnitude; and (3) to determine the effect of urban development on flood peaks and volume. Basic hydrologic data collected in four study areas during the 1973 water year (October 1, 1972 to September 30, 1973) are presented. The four study areas are Sycamore Creek, Sycamore Creek tributary, Dry Branch, and Little Fossil Creek. The Sycamore Creek tributary study area includes the highly impervious area of the Seminary South Shopping Center as a subarea.

HAMPTON, B.B. 1976: "Hydrologic data for urban studies in the Dallas, Texas metropolitan area, 1974". U.S. Geol. Survey open-file report; 182pp.

Key words: hydrologic data; urban hydrology; urban runoff; urbanisation; data collection; rainfall-runoff relationships; hydrographs.

This report presents the compilation and analysis of hydrologic data collected in urban or partly urban drainage basins in the Dallas, Texas, metropolitan area during the 1974 water year. The objectives of the Dallas area program, which began in 1961, are: (1) to determine, on the basis of historical data and hydrologic analyses, the magnitude, frequency, and areal extent of flooding; (2) to document and define floods of greater than ordinary magnitude; (3) to determine the effect of urban development on flood peaks and volume. The studies involve the collection of precipitation, runoff, and flood-elevation data in 10 drainage basins within the city and 3 drainage basins outside the city in Dallas County. Two of the 10 drainage basins in Dallas have headwaters in rural areas outside the city limits, but the largest part of each drainage basin is within the city. The drainage basins within the city include Joes Creek, Bachman Branch, Turtle Creek, White Rock Creek, Elam Creek, Coombs Creek, Cedar Creek, Fivemile Creek, Newton Creek, and Whites Branch. The three drainage basins outside the city of Dallas are Tenmile Creek, Duck Creek, and South Mesquite Creek.

HANES, R.E. et al. 1970: "Effects of deicing salts on water quality and biota; literature review and recommended research". Nat. Co-op Highway Res. Prog. Report 91. Highway Res. Bd.;

70pp.

Key words: chlorides; dissolved solids.

HANSEL, N. 1977: "Horizontal division of the hydrological models for a basin with man-made influences, particularly of urbanisation". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p68-78.

Key words: mathematical models; model studies.

The problems of the horizontal division of a hydrological model for a catchment with man-made influences are shown by examples of urbanisation. A consideration of the possibilities of the horizontal division in using models for basins with man-made influences gives results for the structure of models. Data from three catchments verify the results. The influence of urbanisation and industrialisation is considerable in these catchments.

HARDT, R.A. and BURGESS, S.J. 1976: "Some consequences of area wide runoff control strategies in urban watersheds". Charles W. Harris Hydraulics Lab., Washington University, Seattle, Technical Report TR-48; 90pp.

Key words: urban runoff; rainfall-runoff relationships; peak discharge; flood control.

Consequences of 'blanket' runoff control management strategies that require all future developments in urban and suburban areas to maintain peak flow rates from their sites at the level that existed prior to urbanisation were examined. Hypothetical watersheds were studied to determine some bounds to the overall runoff management issue. Principal findings indicated that: (1) Runoff control strategies must be evaluated at the entire watershed level, not on local jurisdictional boundaries. (2) Without detailed sub-basin discharge hydrographs and main channel characteristics, the optimum drainage management scheme cannot be established. (3) Runoff volume reduction appears to be one means of achieving more effective runoff control. (4) Restricting the outflow from a retention facility to a level less than the undeveloped rate could achieve a composite peak flow rate that would equal the pre-urbanisation flow, but would run for a much greater duration at that rate. (5) Longer duration storms falling on the sub-basins under consideration produced higher peaked watershed outflow hydrographs than did shorter, more intense rainfalls. (6) For storm magnitudes greater than the control system design storm, two possibilities exist: a higher peak rate or an equal peak rate to that which would have occurred without control. Each drainage basin must be examined to determine what management options will work.

HARE, G.S. 1970: "Effects of urban development on storm runoff rates". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.2; 34pp.

Key words: urban hydrology; storm runoff; hydrographs; urban runoff; urban drainage; rainfall-runoff relationships.

Some of the developments in urban hydrology over the past 70 years are reviewed briefly, and some recent developments in the study of urban hydrology are described in more detail as they are applied to the design of such facilities as hurricane protection projects, flood control channels, stream rectification works, and flood plain management or control activities in urban areas. While it is not difficult to determine that urban development generally increases both the total runoff and the peak runoff rates, it has been extremely difficult to develop relationships which accurately define the extent of these changes. The Corps of Engineers has used the basic unit hydrograph method extensively in development of hydrology for its civil works projects. Results obtained by this method are reliable and acceptable when proper coefficients are used.

HARMS, L.L. and SOUTHERLAND, E.V. 1975: "A case study of nonpoint source pollution in Virginia". Virginia Water Resources Research Centre, Blacksburg, VPI-VWRRRC-Bulletin 88; 62pp. (NTIS PB-249 551).

Key words: agricultural pollution; urban runoff; sewage treatment; water pollution sources; organic compounds; nutrients; chemical oxygen demand; suspended solids; phosphorus compounds; algae; nonpoint pollution sources; turbidity; Kjeldahl nitrogen; nitrates.

Sources of organic matter, sediment, and nutrients were investigated for the Upper South River basin near Waynesboro, Virginia. The study period extended from the end of April until mid-September, 1974, a total of 135 days. During the study period, 156 samples were collected with the following analytical determinations being made on each sample: chemical oxygen demand, total suspended solids, turbidity, specific conductance, total kjeldahl nitrogen, and nitrate. Flow measurements were also made at the sampling stations in order that total yields of materials could be established. Sources of organic matter, sediment and nutrients were agricultural, forest and urban land drainage in addition to domestic and industrial waste water effluents. For each pound of phosphorus recorded in the river, about 10 pounds of nitrogen and 75 pounds of sediment were also present. Point sources accounted for an insignificant portion of the sediment, 2.1 percent, but were the major source of all other contaminants during the study. However, the point source contributions were overshadowed by nonpoint discharges during major storm events. Agricultural land drain-

age was a greater source of contamination than forest drainage. Urban runoff contributed substantial pollutant loads during runoff periods. The Waynesboro sewage treatment plant was the greatest source of phosphorus in the basin studied. Reduction of phosphorus in the Waynesboro sewage treatment plant effluent may reduce excessive algal production in the South River below Waynesboro.

HARO, B. 1973: "Storm drainage 'filtered' before discharge". Public Works, Vol.104(9); p124-125.

Key words: storm runoff; urban runoff; water pollution control.

The growing demand for wider streets, parking areas, and other impervious surfaces has raised the question of preservation of natural streams and drainage basins in Bellevue, Washington. With this in mind, the Department of Public Works began investigation of methods to control its urban storm runoff problem. As an experimental approach during the design of a new municipal parking lot, the city decided to install what was nicknamed an 'environmental filter system'. The purpose of the system is to delay the runoff water in reaching the storm drainage system, reduce the amount of water entering the drainage system, and filter the runoff water. The filter system consists of two primary cross sections; a trench five feet wide and another two feet wide. In both cases, their depth is five feet, determined by the depth to the ground water table. The section five feet wide receives runoff water from both sides, while the narrower section gets its water from only one side. At the catch basin where the perforated pipe meets the existing storm drainage system, the incoming invert is six inches below the outgoing invert. This forces the perforated pipe to remain partly full after the storm has passed and allows the system to redistribute the stored water back through the trench for maximum seepage into the adjacent soil.

HARPER, M.E. et al. 1975: "Degradation of urban streams from storm water runoff". In, Second Annual National Conference on Environmental Engineering Research, Development and Design; 2pp.

Key words: bioindicators; toxicity; water pollution; storm runoff.

Miller Creek and Des Moines Creek, located south of Seattle, Washington, were monitored for one year to assess the effects of storm water discharges. Organism types, organism density, and diversity indexes showed the streams to be moderately degraded. The degradation was correlated to organism habitat scour by storm water discharges. Contaminants were transported by the storm water at levels toxic to the biological community. Comparison of the biological indexes with those of a nearby stream whose drainage area is relatively undisturbed indicated Miller Creek and Des Moines Creek to be 30-40

percent below normal.

HARRIS, E.E. and RANTZ, S.E. 1964: "Effect of urban growth on streamflow regimen of Permanente Creek, Santa Clara County, California". U.S. Geol. Survey water supply paper No.1591-B; 18pp.

Key words: aerial photography; rainfall-runoff relationships; urban runoff; landuse change.

Report presents quantitative results from study of a 5.12 sq mile watershed where impervious area increased from about 4 percent to 19 percent over a 13 year period. Change in pervious area was evaluated from aerial photographs. The report contains an analysis of rainfall and runoff volume records and a double mass curve analysis of the study area and index area.

HARRIS, J.A. and SHANHOLTZ, V.O. 1975: "Application of a parametric model to simulate flows from an urban watershed". Report, Dept. of Civil Engineering, Virginia Polytechnic Institute and State University, Blacksberg; 35pp.

Key words: model studies; urbanisation; waste water disposal.

Parametric watershed models such as the Kentucky Watershed Model have been used satisfactorily for simulating the hydrology of agricultural watersheds. With the addition of a divergent flow subroutine to account for direct waste discharges and pumpages by municipal and industrial sources, these models can be used to predict the effects of urbanisation. Utilisation of the percent impervious area parameter for reflecting the degree of urban influence within the watershed has been shown to be a valid approach. Urbanisation effects on the hydrologic response of the Ottawa River watershed in Ohio were investigated with the modified parametric model.

HARTT, J.P. 1973: "A study of pollution loadings from urban runoff". In, Proceedings of the Canadian Symposium on Water Pollution Research, Vol.8; p16-25.

Key words: urban runoff; water pollution sources.

HAWKINS, R.H. 1976: "Salt storage and runoff in an urban watershed". J. Environmental Engineering Divn., Proc. ASCE, Vol.102(EE4); p737-743.

Key words: chlorides; urban runoff; low flow; ground water resources; water pollution sources.

Street salting studies in the Meadowbrook Watershed, Syracuse, N.Y., are described. Over a 3 yr study period 81.5 percent of the salts applied left the watershed in runoff waters.

Considering the suburban nature of the basin, this is in consonance with results found elsewhere. Chloride concentrations in the low flow months of April-October were found to increase with time, suggesting that salt is accumulating in the local ground water, which is a source of supply for these low flows.

HAWKINS, R.H. and JUDD, J.H. 1972: "Water pollution as affected by street salting". Water Resources Bulletin, Vol.8; p1246-1252.

Key words: water pollution; chlorides; lakes.

The authors discuss the effects of salt, used for deicing streets, on streams and lakes. In the Meadowbrook watershed in Syracuse, N.Y., it was found that the chloride content was highest in December, declining with the onset of summer, though remaining high. This suggested that salt applied the previous winter was appearing in the summer streamflow. The effect of salt runoff on a small lake was also investigated.

HEANEY, J.P. et al. 1975: "Urban storm water management modeling and decision making". University of Florida, Gainesville, Florida; 185pp. (EPA-670/2-75-022; NTIS PB-242 290).

Key words: waste water treatment; combined sewers; water pollution; computer models; storm runoff; model studies; erosion control; urban runoff.

The Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) was tested, refined, and augmented to develop decision making techniques for studying runoff problems. The refinements include incorporating a sediment prediction capability using the Universal Soil Loss Equation. Other refinements reflect recent developments such as swirl concentrators. The model was tested in Lancaster, Pennsylvania. Agreement between predicted and measured hydrographs and pollutographs was only fair, due to the very limited and somewhat questionable quantity and quality of verification data available. Quality predictions and the limited measured data available were reasonably close for the Conestoga River, the receiving waterway. The refined and augmented model showed an improved capability to describe the various processes. The decision making model examines storm water management in the general context of water resources management. It indicates that urbanisation results in significantly higher peak flows and substantially increased control costs. Interrelationships with flood control and drainage, street and parking lot design, and air pollution are included. Impervious areas associated with the automobile appear to be the most important source of storm water problems. More efficient use of paved areas appears to reduce the problem. An optimisation procedure for control strateg-

ies uses linear programming techniques and procedures from cooperative N-person game theory. The SWMM was also applied to preliminary hydraulic design of sewer systems. The runoff portion provided a more accurate inlet hydrograph. The transport portion analysed the hydraulics of flow transport through sewers, including a routine that checks for surcharging.

HEANEY, J.P. and HASAN, S.H. 1976: "Methodology for evaluating the cost of urban storm water quality management". In, Proceedings of a short course on applications of storm water management models, Florida University, Gainesville. Report EPA-600/2-77-065; p15-33.

Key words: flood forecasting; combined sewers; model studies; urban runoff; mathematical models; storm runoff; waste water treatment.

Procedures used during an EPA-sponsored study to estimate the nationwide cost of treating combined sewer overflows and storm water runoff are described. The EPA Storm Water Management Model (SWMM) was used to simulate a single storm event for a single catchment area for each of five cities in the U.S. The HEC STORM model was used to estimate hourly precipitation, runoff, and discharge rates for projections of the total volume of storm water treated for a specified size of storage unit and treatment rate. Results were used to derive storage-treatment isoquants. Mathematical derivations and procedures for adjustment according to treatment efficiency are given for the calculated isoquants. Formulas are given for the estimation of costs for storm water management based on quality control. Potential savings due to multipurpose planning and the integration of wet- and dry-weather treatment are considered.

HEANEY, J.P. and SULLIVAN, R.J. 1971: "Source control of urban water pollution". J. Water Pollution Control Federation, Vol.43; p571.

Key words: water pollution control; air pollution effects; pollution abatement.

Studies of urban water pollution have focussed on the "effluent" end of the system, i.e., given the observed pollutional load at the outfall of the sewage system, they have determined the optimal combination of pollution control facilities required to meet a specified water quality management objective. As efforts are further intensified to achieve higher levels of water quality management, the costs of additional effluent controls seem to be high. Surprisingly little is known about the origin of urban water pollution and possible control of pollution at its source. An exploratory study was undertaken to obtain a "solids budget" within a 10 acre (4.1 ha) area in Chicago, Ill. The sources investigated included air pollution, sanitary wastes, garbage, and miscellaneous sol-

ids. The source controls examined were catch basin cleaning, sewer cleaning, and street sweeping. Unit costs of street sweeping indicate that catch basins and their cleaning, along with subsequent sewer cleaning, make them undesirable. Garbage grinders are also a likely possibility for reduced use or outlawing.

HEDLEY, G. and KING, M.V. 1971: "Suggested correlation between storm sewage characteristics and storm overflow performance". Proc. Inst. of Civil Engineers, Vol.48; p399-411.

Key words: storm runoff; biochemical oxygen demand; suspended solids; overflows.

This paper describes an investigation of the quantity and quality of storm runoff from a mixed area drained half on a combined and half on a partially separate system and a possible solution to the problem of river pollution from storm sewage overflows based on the results of this and other investigations. The basis of this method of preventing pollution is the provision of sufficient storage capacity at overflows to protect watercourses, even small ones, against severe summer storms. Also described is a scheme applying these ideas to a large existing area drained on the partially separate system and various practical problems are covered.

HEDLEY, G. and LOCKLEY, J.C. 1975: "Quality of water discharged from an urban motorway". J. of Water Pollution Control, Vol.74(6); p659-674.

Key words: instrumentation; chlorides; surface runoff; urban drainage; point sources (pollution).

To determine the degree of pollution caused by a busy urban motorway, a study was carried out on a section of the A38(M), linking the centre of Birmingham with the M6 motorway; descriptions are given of the motorway and the instrumentation and methods used in the study, and results are summarised in tables and graphs. It was found that the road drainage is potentially polluting, the polluting load being significantly higher during the winter. Winter salting operations contribute directly to this pollution and also have side effects, particularly stimulation of corrosion, which further adds to this effect. Cars contribute significantly higher metallic pollution than any other sources. In view of these results, the authors point out that consideration may have to be given to the treatment of this drainage in future.

HEEPS, D.P. and MEIN, R.G. 1974: "Independent comparison of three urban runoff models". J. Hydraul. Divn., Proc. ASCE, Vol.100, (HY7); p995-1009.

Key words: mathematical models; urban

runoff; computer models; peak discharge.

Three urban runoff models (the Road Research Laboratory hydrograph method, the Storm Water Management Model, and the Cincinnati Urban Runoff Model) were applied to two urban catchments in Australia. The Road Research Laboratory method generally performed well if runoff from pervious areas was insignificant. The Storm Water Management Model was best of the three models but also required the most computer processor time. The Cincinnati Urban Runoff Model contained several deficiencies which caused poor performance. Degree of catchment sub-division was found to be an important factor in the magnitude of the peak predicted.

HEIJ, G.J. 1977: "Some effects of ground water extraction in the western part of the Netherlands on the hydrological regime". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p167-178.

Key words: ground water resources; urbanisation.

The increasing urbanisation in the western part of the Netherlands has an increasing influence on the country's ground water regime. Through this there is found to be an even stronger conflict between different parties interested in the ground water. In order to weigh one interest against another, insight is needed into the effect of different activities on the ground water head and flow and the consequences of such effects. An important activity in this area, inherent in the increasing urbanisation, is ground water extraction. Drawdown, as a result of ground water extraction, among other things influences seepage or infiltration and settlement of semipervious layers, resulting in subsidence and an increase of the hydraulic resistance. The influence of another activity on the hydrological regime, the cutting of a canal, can make a considerable call on a ground water reservoir. In view of the increasingly strong confrontation with other interests, extensive investigation is required into the most suitable locations for ground water extraction. Extracted ground water which is not consumed must be returned to the soil if possible. In addition to this, continuous attention should be given to other possibilities to satisfy the need of water.

HEINDLE, L.A. 1974: "Hydrological effects of urbanisation". Transactions AGU, Vol.55(4); p190-191.

Key words: urbanisation; urban hydrology; watershed management.

A total of 54 experts from 23 countries participated in the International Workshop on the Hydrological Effects of Urbanisation, in Warsaw, Poland, Nov. 8-10, 1973. The workshop completed its set task of reviewing a draft report,

which will be published by the time of the End-of-Decade Conference in 1974, describes the effects of urbanisation on the hydrological cycle and identified research needs for the next few years. The report is directed mainly at researchers in hydrology, but will have a special summary of interest to water managers.

HELLIWELL, P.R. et al. 1976: "Estimation of the above ground runoff hydrograph for storm design purposes". In, Proceedings National Symposium on urban hydrology, hydraulics and sediment control, University of Kentucky, Lexington, Ky.; p81-89.

Key words: flood forecasting; urban runoff; analytical techniques; model studies; surface runoff.

The problems of conversion of the rainfall hyetograph into an inlet hydrograph to the sewer system are considered using a survey of existing British data and some original observations into very small catchments at Southampton, England. The conversion of rainfall to runoff may be effectively divided into two parts. The first estimates the total volume of runoff from a given rainfall input and the second determines the distribution of this runoff in time. The first part involves the complex interaction of a large number of physical phenomena, and lends itself better to a statistical approach than a deterministic one. A regression model is postulated, relating the volume of runoff to characteristics of the catchment (e.g. catchment slope, percentage impervious, soil type) and of the storm event (e.g. rainfall volume, duration, antecedent wetness). The model is calibrated using approximately 350 storms on about 13 catchments in the United Kingdom. The second part involves the distribution of losses in time and the routing of the rainfall excess over the ground surface to the sewer inlet. This is achieved by a conceptual model, employing a non-linear reservoir model to convert excess rainfall into a sewer input hydrograph for each manhole in the sewer system.

HEM, J.D. and DURUM, W.H. 1973: "Solubility and occurrence of lead in surface waters". J. American Water Works Assoc., Vol.65(8); p562-568.

Key words: lead; water pollution sources.

This paper outlines sources of lead in surface waters, and the presented data suggest methods of reducing the lead content of drinking water at the water treatment plant.

HENDRICKS, J.R. and LIGON, J.T. 1973: "Application of a digital hydrologic simulation model to an urbanising watershed. Completion report Jul.71 - Jun.73". Clemson University, S.C. Water Resources Research Inst.,

W73-06028; 87pp.

Key words: computer models; mathematical models; landuse change.

The study examined an urbanising watershed, the Reedy River basin near Greenville, South Carolina. The objective was to determine certain hydrologic characteristics of the basin using available data and to investigate changes brought about in these characteristics by the process of urbanisation. A self-calibrating version of the Stanford Watershed Model named OPSET was applied to the Reedy River data. To investigate changes in the hydrologic characteristics, parameters were estimated for a rural watershed comparable to the Reedy River basin in size and configuration. Two applications were used to investigate the effects of precipitation and diversions on the OPSET estimated parameters.

HENGEVELD, H. et al. 1977: "Effects of urbanisation on water management in the western part of the Netherlands". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p500-513.

Key words: watershed management; urbanisation; hydrologic systems.

In this paper the quantitative effects of urbanisation on water management in the western part of the Netherlands during the last 100 years are described. Particularly the increase of paved surfaces is investigated. Moreover, the development of the water management system and more specifically the ways urban areas are related to the whole system are studied. A number of specific drainage methods are discussed. The effects of urbanisation on the water system in urban areas, on the water systems in the adjacent rural areas and on the water catch basin are indicated. This analysis and the analysis of the urbanisation plans of the Netherlands Government are used to draw conclusions with regard to the effects of future urbanisation on the water management system.

HENSON, W.R. 1970: "A unified method for computing peak discharge from ungauged urban areas for Corps of Engineers studies". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.4; 15pp.

Key words: urban hydrology; hydrographs; rainfall-runoff relationships; storm runoff; urban runoff; model studies; peak discharge; flood forecasting.

In urban hydrology, development cost, ease of use, and general applicability are the three most important characteristics that should be considered in selecting one of the methods for use in computing peak discharges from ungauged areas. Comprehensive digital simulation models will probably be limited to the major universities because of the

computer capability required, but they may prove economical where a long period of record is required for design of an urban flood control project in an area of extremely high damage potential. Synthetic unit hydrographs appear to be the method most adaptable for use in studies by the Corps of Engineers. If a sampling of basic data can be provided from urban centres over the country, the resulting method will probably have general applicability. In urban areas devoid of gauging stations, new stations would have to be set up. Although development of a method of this type would involve a large initial investment, this would be offset by the ease of use and small recurring cost.

HEPWORTH, R. 1974: "A direct approach to storm sewer design". New Civil Engineer, Vol.14, November; p44-46.

Key words: analytical techniques; storm runoff.

The Transport and Road Research Laboratory method of storm sewer design comes under periodic attack from practising engineers, who dispute either the principles or the results. So far the method's protagonists have been able to point to the correlation between predicted and recorded flows demonstrated in RRL Technical Paper No.55 as evidence of its validity, and to sidestep direct challenges by defying the opposition to produce similar evidence for alternative methods. In this article the author explains why he and others question the validity of the TRRL method, and gives a brief outline of the 'direct method'.

HERB, W.J. and YORKE, T.H. 1976: "Storm period variables affecting sediment transport from urban construction areas". p181-192. (NTIS PB-245 100/3G1).

Key words: sediment transport; urbanisation; peak discharge; storm runoff; data collection.

Eight small drainage basins, ranging in size from 0.91 to 25.2 square kilometres (0.35 to 9.73 square miles), located in the suburbs of Washington, D.C., were studied between 1963 and 1974 to determine sediment transport characteristics of streams draining urban construction areas. Annual construction ranged from less than 1 percent of basin area to more than 15 percent. Five hundred and twenty-four storms were analysed to determine the effects of 14 storm-period variables on sediment load. Factors found to be most significant were storm runoff and peak discharge. Multiple correlation coefficients for best regression equations with four independent variables ranged from 0.85 to 0.96, and standard errors ranged from 0.300 to 0.221 log units. The equations reflect the significant impact of both construction activities and summer storms on the sediment discharge of urban streams.

HERGERT, L. 1975: "Urban runoff quality and modeling study". M.S. Thesis, University of Nebraska, Dept. of Civil Engineering, Lincoln, Neb.; 141pp.

Key words: urban runoff; storm runoff; computer models; hydrologic data; hydrographs; organic compounds.

Preliminary studies on urban runoff have disproved theories about the purity of storm runoff. Urban storm runoff is a possible source of significant amounts of both organic and inorganic waste material. The question arises as to the effect of storm water on a receiving stream alone or in conjunction with other pollutional sources. Presented is a study whose purpose was to obtain data on the pollutant concentration versus duration of runoff, the relationship between concentration and flow, and the effect of land use on the amounts and types of pollutants present in runoff. The study also involved preliminary work on the development of a computer model for simulating the effects of urban runoff from various land use areas. Some conclusions reached were: (1) urban storm water may contain significant amounts of pollutants, and on some occasions these concentrations may cause serious degradation of a receiving stream; (2) the 'flush effect' of pollutants at the start of runoff was found to occur in most storms sampled in this study; (3) there are considerable concentrations, at times, of coliforms in urban runoff; (4) differences were found in pollutional loading for three sampling points - land use may prove a good indication of expected pollutional loads; and (5) the computer model was found capable of producing a flow hydrograph which gave results close to those observed in the field.

HICKS, W.I. 1944: "A method of computing urban runoff". Transactions ASCE, Vol.109, Paper No.2230; p1217-1268.

Key words: rainfall-runoff relationships; hydrographs; urban runoff.

Hydraulic investigations and rainfall-runoff gauging are presented for improved urban drainage areas of different sizes and types of development in Los Angeles, California. These results are analysed to provide data required for the development of runoff hydrographs for areas of various sizes, development, and time of concentration. Methods are presented for computing runoff for design purposes and for comparing actual values of runoff with those computed by those methods.

HINDI, W.N.A. 1976: "A computational method for the optimal design and analysis of urban sewer systems". Unpublished Ph.D. Thesis, University of Birmingham.

Key words: mathematical models.

HIRSCH, R.M. 1977: "The interaction of channel size and flood discharges for

basins undergoing urbanisation". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p83-92.

Key words: channel erosion; flood discharge; computer models.

Urbanisation brings about an increase in the frequency of flooding; therefore according to the 'bankfull frequency hypothesis', this will result in a considerable enlargement of channel cross-sectional area for alluvial streams draining urban areas. Enlargements by a factor of 2 or more have been observed and documented for many small urban streams in the United States. This change in cross-sectional area represents a positive feedback process which will further exacerbate both flooding and channel enlargement in the downstream direction, by decreasing the amount of peak attenuation by overbank storage which will occur during a flood of any given magnitude. This positive feedback relationship is demonstrated by the use of a simulation model. In the simulations described, flood discharges downstream were increased by as much as 25 percent due to channel enlargement alone. These results imply that in order to predict and manage the changes in flood frequency distributions for areas undergoing urbanisation, attention must be paid not only to the intentional modifications of the drainage system, such as paving, sewerage, and runoff detention but also to the inadvertent changes, i.e. channel enlargement.

HITTMAN ASSOCIATES, INC. 1973: "Processes, procedures, and methods to control pollution resulting from all construction activity". EPA, Office of Air and Water programs, Report EPA 430/9-73-007; 234pp.

Key words: water pollution control; sediment control; storm runoff; urbanisation; erosion control.

Methods for controlling sediment, storm water, and pollutants other than sediment which result from construction activities are described. Processes examined include site planning, preliminary site evaluation and design, use of planning tools, and structural and vegetative design. Methods examined include on-site erosion, sediment and storm water management control structures as well as soil stabilisation practices useful for achieving control of sediment, storm water runoff, and other pollutants resulting from construction activities. Storm water management practices are discussed in detail. Water pollution resulting from sediment and other pollutants generated from construction activities can be prevented by the timely application of structural and soil stabilisation measures presently available.

HOBBS, N. and BRITTON, J.D. 1974: "Computer modeling applications in urban water planning". ASCE Urban Water Resources Res. Program, New

York, Tech. Memo. No.22; 42pp.
(NTIS PB-223 673).

Key words: computer models; urban runoff; snowmelt; urbanisation.

Few cases have been publically documented where systems analysis techniques have been used in planning urban water supply systems. Indicated are applications made by a leading agency. Almost two-thirds of its metropolitan population is served by the Denver Water Department from a complex raw water collection system that extends almost 150 miles to capture mountain snowmelt and involves transfers through the Continental Divide. Not detailed are plans for large-scale reuse and automatic control. Raw water facilities-planning applications are emphasised. Descriptions, development histories, applications and costs incurred are presented for seven models: a collection system; a river-aquifer system; daily flow routing; revenue expenditure projection; large scale river basin; stream quality-quantity; and pumping power requirements for a collection system. Some of the models could be used readily elsewhere. Computer requirements and model documentation status are described. Future raw water facilities planning computer applications will include: runoff simulation and forecasting; a waste water accounting system for reuse; a data system development; urban growth pattern projection; and environmental analysis. Ultimately, raw and treated water simulation tools will be comprehensively integrated under a total system concept.

HOFFMAN, E.K. 1975: "County combats urban storm water runoff problems". Public Works, Vol.106(5); p92-93.

Key words: watershed management; storm runoff; urbanisation; flood control; sediment control.

Storm water management is being planned in Mecklenburg County, North Carolina, after a study of the effects of urbanisation on storm runoff. It was found that an increase in the amount of runoff caused by urbanised impervious areas coupled with a reduction in lag time, increases peak discharges up to 2 1/2 times, and causes an increased frequency and extent of downstream flooding. To prevent further encroachment on the existing floodplain, a floodway ordinance was passed, restricting development along any stream with a drainage area of at least one square mile. A five-year drainage capital improvement program has also been developed for stream bank sloping and stabilisation and for the control of channel widening. In addition, the planning includes erosion and sediment control to minimise stream degradation.

HOLBERGER, R.L. and TRUETT, J.B. 1976: "Sediment yield from construction sites". In, Proceedings 3rd Federal Inter-Agency Sedimentation Conference, Denver, Colorado. Water Resources Council, Washington;

pl.47-1.58.

Key words: sediment yield; model studies; erosion; sediment transport; streamflow.

Two sediment loading functions were fitted to sediment loss data from eight field studies of construction sites. Both were adaptations of the Universal Soil Loss Equation, and involved an empirically-fitted factor to account for effects of intervening terrain between construction site and point of sediment measurement in a nearby watercourse. One function used the distance from the foot of the exposed area to the nearest perennial stream, while the second function used the percent of the drainage basin undergoing construction. Comparison of predicted sediment yields (in tons/acre) with observed yields indicated that, for the first loading function, about 54 percent of the predictions fell within a range of + or - 50 percent of observed values. Approximately 30 percent of the predictions generated by the second method fell with + or - 50 percent of the observed values.

HOLBROOK, R.F. et al. 1976: "Storm water studies and alternatives in Atlanta". J. Environmental Engineering Divn., Proc. ASCE, Vol.102(EE6); p1263-1277.

Key words: combined sewers; erosion; urban runoff; computer models; nonpoint pollution sources; nutrients.

Nonpoint sources (combined sewer overflows and urban runoff) contribute about 45 percent of the BOD load and about 95 percent of the suspended solids load to metropolitan Atlanta streams. Computer simulations indicate frequent violations of proposed "Fish and Wildlife" DO standards in the receiving streams resulting from nonpoint sources. The nutrient loads in urban runoff alone to impoundments in the metropolitan area exceeded levels that result in accelerated eutrophication. Storage followed by air floatation or transmission to point surface treatment facilities during off peak periods is recommended for combined sewer overflows.

HOLEMAN, J.N. and GEIGER, A.F. 1959: "Sedimentation of Lake Barcroft, Fairfax County, Va." SCS-TP-136, Soil Conservation Service, March 1959; 12pp.

Key words: sediment yield; landuse change; lakes.

A sedimentation resurvey of Lake Barcroft, Fairfax County, Va., was made by the Soil Conservation Service, U.S. Department of Agriculture. The resurvey was made to compare the sediment yield in 1957, after two-thirds of the watershed had been urbanised, with that 20 years earlier when the watershed was predominantly in agricultural uses; to measure the loss of capacity of the lake due to this change in sediment yield; and to provide a basis for predicting the future life of the lake.

Lake Barcroft was originally constructed in January 1915 as a reserve water supply for the city of Alexandria, Va. The lake was purchased in 1950 by the Lake Barcroft Corporation for real-estate development. The greatly increased rate of sedimentation in Lake Barcroft is due primarily to the construction associated with conversion of land from agricultural to urban uses. The increase of sediment production from an average of about one-fourth acre-foot per square mile of drainage area per year before 1938 to a rate of about three-fourths acre-foot per square mile annually from 1938 to 1957 is indicative of the influence of removal of vegetation and topsoil during construction.

HOLLER, A.G. 1970: "Urban hydrology considerations in the design of interior drainage facilities for local flood protection projects". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.13; 23pp.

Key words: urban hydrology; storm runoff; rainfall-runoff relationships; urban drainage; urban runoff; peak discharge.

Usual drainage facilities whose capacities have been determined by an application of the rational method will function over a period of time long enough to include some changes in runoff relations. The runoff coefficient selected must reflect in some way future conditions expected in the drainage area. The future expected peak runoff can then be compared to the design capacity of the drainage facilities to determine their adequacy. Hydrologically significant impermeable area is related to population density. Based on a brief study of two local flood protection schemes the runoff coefficients that were selected are sufficiently conservative to allow for some degree of future urbanisation without significantly altering the degree of protection provided by the projects.

HOLLIS, G.E. 1970: "The estimation of the hydrologic impact of urbanisation: an example of the use of digital simulation in hydrology". Dept. of Geography, University College, London, Occasional Paper No.5; 24pp.

Key words: urbanisation; mathematical models; hydrologic data; environmental effects.

Changing land uses due to urbanisation have a significant effect on the hydrologic cycle of a watershed. This paper presents a study of the effect of urbanisation in a small watershed in England, Canon's Brook. Since the data from the watershed was not ideal and conventional evaluation methods such as double mass, trend analysis, and multiple regression analysis have limitations, the study developed a computer simulation model to predict runoff flows. The simulation model incorporates such factors as interception, in-

filtration, and evapotranspiration. The inputs include daily values of precipitation, monthly values of sunshine, temperature and wind speed. The output from the model is the predicted monthly runoff. Results have shown that while winter runoff has increased only slightly, summer and autumn runoff has increased five-fold. Although the simulation model is able to overcome various data problems it also has some limitations and these are evaluated in relation to the results of the study.

HOLLIS, G.E. 1974: "The effect of urbanisation on floods in the Canon's Brook, Harlow, Essex". In, Fluvial processes in instrumented watersheds, Special Publication No.6, (eds. K.J. Gregory; D.E. Walling), Inst. Br. Geographers, London; p123-139.

Key words: urbanisation; flood discharge; storm runoff; flood forecasting; analytical techniques.

The investigation of the effects of man on the hydrological cycle is one of the central concerns of hydrology and the problems of urban hydrology require urgent solution. Urbanisation, which paves over soil with impermeable surfaces and imposes a dense and efficient surface water sewer net on to a catchment, should increase both flood peaks and flood volumes, although a very large flood may be independent of land use because a saturated soil may respond to rainfall in a similar way to an impervious surface. So far, only American work has quantified these hydrological consequences of urbanisation. The 21.4 sq km clay catchment of the Canon's Brook, Harlow, Essex, has both streamflow and autographic records from October 1950. The paved area of the catchment, which is drained by surface water sewers that discharge to the natural river channel, grew to cover 16.6 percent of the catchment in the period between late 1953 and 1968. The maximum monthly flood, generalised by a long period moving average, has increased from 1.16 cubic m/sec to 2.58 cubic m/sec during the 18 year record. The frequency of winter flood peaks has changed relatively little whilst the frequency of summer floods has increased markedly. Comparison of floods with matched rainfall, soil moisture and seasonal characteristics but widely different degrees of urbanisation present in the catchment at the time of the floods, and examination of mean unit hydrographs for the rural and urbanised states of the basin reveal the magnitude of increase in flood peaks and flood volumes and the decrease in lag time, time of rise and hydrograph width, consequent on paving 16.6 percent of the catchment. More incisive analysis by regression methods reveals, however, that whilst Harlow has increased some summer flood peaks by up to 11.5 times, paving of the catchment does not seem to be a significant factor in determining the hydrograph of floods with a return period of around 20 years.

HOLLIS, G.E. 1974: "The hydrological ef-

fects of urbanisation in the Canon's Brook Catchment, Harlow, New Town, Essex". PhD Thesis, University of London, London (Unpublished).

Key words: urbanisation; urban hydrology.

HOLLIS, G.E. 1974: "River management and urban flooding". In, Conservation in practice, (eds. A. Warren; F.B. Goldsmith), John Wiley, London; p201-216.

Key words: watershed management; flood control.

Although towns usually originated on land free from the risk of flooding, urban expansion has frequently caused their spread on to more vulnerable parts. Every form of adjustment to flooding has a drawback. Engineering schemes may reduce the frequency of inundation, but provide little protection from floods in excess of the design storm. Relief, welfare work and emergency action may help flood victims, but in the longer term they simply encourage occupants to remain in the risk zone. Land use planning has been employed to prevent development in vulnerable areas, but has frequently resulted in the sterilisation of otherwise valuable land resources. The chapter concludes by drawing attention to the lack of data on river flood levels, especially before 1900, and illustrates the difficulties of floodplain planning in an urban setting by means of a case study of the lower Mole floodplain.

HOLLIS, G.E. 1975: "The effect of urbanisation on floods of different recurrence interval". Water Resources Research, Vol.11(3); p431-435.

Key words: flood discharge; storm runoff.

Studies have shown that the urbanisation of a catchment can dramatically change the flood characteristics of a river. Published results are synthesised to show the general relationship between the increase in flood flows following urbanisation and both the percentage of the basin paved and the flood recurrence interval. In general, (1) floods with a return period of a year or longer are not affected by a 5 percent paving of their catchment, (2) small floods may be increased 10 times by urbanisation, (3) floods with a return period of 100 yr may be doubled in size by a 30 percent paving of the basin, and (4) the effect of urbanisation declines, in relative terms, as flood recurrence intervals increase.

HOLLIS, G.E. 1977: "Water yield changes after the urbanisation of the Canon's Brook catchment, Harlow, England". IAHS, Hydrological Sciences Bulletin, Vol.22(1/3); p61-75.

Key words: urbanisation; rainfall-runoff relationships;

computer models.

The 21.4 sq km clay catchment of the Canon's Brook was built over during the period 1953-1968. By 1968, 16.6 percent of its area was paved and these impervious surfaces drained to the river by means of surface water sewers. Records of rainfall and runoff have been taken since 1950, i.e. before development began, and quantitative description by double mass analysis revealed an increased water yield from the catchment as urbanisation progressed. The median flow from 1950 to 1953 was around 0.057 cu m/s and this had been increased by urbanisation to about 0.142 cu m/s in 1968. The precise extent of increased water yield and its reflection in the flow regimen was derived from a computer simulation model. This was calibrated on the records for 1950-53 and then the flow from an unchanged rural catchment was simulated for the period of urban development, 1953-1968. The difference between the gauged urban water yield from a 15 percent paved catchment and its simulated rural equivalent averaged 59.4 mm per annum or about 30 percent of the runoff from the rural catchment.

HOLLIS, G.E. and LUCKETT, J.K. 1976: "The response of natural river channels to urbanisation: two case studies from southeast England". J. Hydrology, Vol.30; p351-363.

Key words: urban hydrology; urbanisation; bank erosion; erosion; channel erosion.

The hypothesis that natural channels become enlarged as a result of an increase in flood flows following urbanisation was tested in two areas of southeast England. In the West Sussex study, a regression equation was used to calculate the expected cross-sectional area of channels draining rural areas. The channel enlargement ratio, which is the actual cross-sectional area of channels draining urbanised catchments divided by the predicted cross-sectional area of the stream if its basin was rural, was then calculated for 27 urbanised catchments. The relationship between the channel enlargement ratio and the percentage of the catchment paved revealed that a 10 percent paved basin should increase channel size downstream by 1.7 times but the variance explained by the equation was not as high as that found in an American study. The second study involved a comparison of the cross-sectional morphology of the Canon's Brook, Harlow, Essex in 1956 and 1970. The 1956 survey was undertaken when little building had taken place in the catchment whilst in 1970 about 18 percent of the basin was paved. Although various measures of central tendency indicated an increase in channel size during the period, this conclusion was not confirmed by a difference of means test suited to paired observations. A possible explanation for this finding is that there is a lag time between increases in flood flows and channel enlargement. Some validity can therefore be given to the view that urbanisation leads to the

enlargement of natural channels but further work using these and other methods is needed.

HORDON, R.M. 1972: "A factor analysis of selected water quality variables in central New Jersey during 1960-1969". Paper No.H-58, presented at the 53rd Annual Meeting of the AGU, Hydrology Section, Washington, D.C.; 3pp.

Key words: urbanisation; mathematical models; dissolved oxygen; biochemical oxygen demand; turbidity; bacteria; storm runoff.

Spatio-temporal changes in water quality in central New Jersey during 1960-69 were studied by a factor analytic methodology. The period included suburbanisation with its resultant impact on watershed quality and periodic events such as the record drought of 1962-66. Eleven variables were available at each of three stations: temperature, pH, DO, turbidity, BOD, colour, alkalinity, hardness, bacteria, discharge, and percent saturation. The factor structures generally reveal the following characteristic pattern: (1) an oxygen-status factor, represented by high loadings on temperature, DO, and BOD; (2) an appearance factor based on turbidity, colour, and discharge; and (3) a third variable factor, loading occasionally on percent saturation. The oxygen-status factor tends to be the component of greatest statistical importance. Bacteria, hardness, pH, and alkalinity generally exhibit the lowest loadings of any of the 11 variables. Indeed, bacteria is the least related to any of the other variables in the data set. The cumulative degree of explanation of the rotated factors declined during the decade, suggesting an increase in independence developing among the variables. It is hypothesised that urbanisation with its associated changes in land use and runoff patterns might be intervening in the natural ecology of the stream. The effects of urbanisation, then, would be to interfere with in-stream interactions among the variables. The 30 factor structures were quantitatively compared by using a computer program called RELATE. The procedure was to compute structures based on identical sets of variables from year to year for the same station and from basin to basin for the same year. The results for the Raritan River watershed indicate that intrabasin and interbasin similarities outweigh the differences and that the factor structures evidence a high degree of stability during the decade of the 1960s.

HORDON, R.M. 1972: "Changing watersheds in metropolitan areas: a statistical analysis of selected basins in New Jersey". In, Watersheds in Transition; proceedings of a symposium, Fort Collins, Colorado. AWRA Proc. Series No.14; p394-399.

Key words: water pollution sources; landuse change; urbanisation; dissolved oxygen; biochemical oxygen demand; computer models; bacteria;

streamflow.

Some of the best water quality data sets available in New Jersey are routinely collected by large water supply agencies. Several such sets, consisting of nine variables (temperature, pH, DO, BOD, colour, alkalinity, bacteria, discharge, and percent saturation) were available in the files of the Elizabethtown Water Company, the Passaic Valley Water Commission, and the Hackensack Water Company. The data for five sites in the three major basins of northeast New Jersey - the Raritan, Passaic, and Hackensack - were grouped in calendar year sets: 1960-62 and 1967-69. Factor analysis using the Varimax rotation resulted in three factors: (1) an oxygen-related factor (high inverse loadings on temperature and DO), (2) an appearance factor (discharge and colour), and (3) a third variable factor occasionally loading on percent saturation. Intrabasin and interbasin factor structures were quantitatively compared by a statistical technique called RELATE which enables one to indicate the degree of similarity between factor structures by obtaining the cosine of the angle between component vectors. These cosine values may then be interpreted as correlation coefficients.

HORDON, R.M. 1975: "Application of factor analysis to water quality data: the Passaic River basin". In, Urbanisation and Water Quality Control. Proc. American Water Resources Assoc., No.20; p245-251.

Key words: analytical techniques; computer models; water pollution sources.

The purpose of this paper is to examine the spatio-temporal changes in water quality in the Passaic River basin in New Jersey during 1950-69 using factor analysis as a tool to extract the major sets of information from the data. The period in question included a major period of suburbanisation, and, in turn, a major impact on watershed quality, and periodic events such as the record drought of 1962-66. It was hoped that the relative effects of these trends and events could be isolated by this form of analysis.

HORKEBY, B. and MALMQUIST, P.A. 1977: "Microsubstances in urban storm water". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p252-264.

Key words: heavy metals; miscellaneous chemicals; metals; trace elements; arsenic compounds; organic compounds; pesticides.

During 1976 a catchment in Goteborg was investigated with respect to microsubstances in storm water and atmospheric fallout. The microsubstances studied were 17 heavy metals and PCB, DDT with derivatives, HCB and PAH. The concentrations of heavy metals in storm water

were not remarkably high compared with the concentrations in waste water and sometimes in drinking water. For As, Cd, Cr, Hg, Sb, V, and Pb atmospheric fallout could explain a great deal of the metal content in the storm water. For other metals only a smaller fraction could be explained by atmospheric fallout. Most of the heavy metals originate from traffic and from corrosion. The concentrations of PCB, DDT, and HCB were relatively low compared to results of earlier investigations of dustfall. The concentration of PAH in the storm water was high (10-320 micrograms of naftalene-equivalents/l unfiltered sample), on one occasion even higher than in waste water. Most of the PAH was found to be attached to particles. Applications of the different microsubstances and their effects on man, flora, and aquatic fauna are given.

HORN, D.R. 1967: "The effect of basin characteristics on the outlet hydrograph from a 9 acre impervious drainage basin". John Hopkins University, Baltimore, Md., Dept. of Environmental Engineering Science, Storm Drainage Research Project Report No. TR-6; 47pp.

Key words: mathematical models; hydrographs; peak discharge.

An analytical computer approach to the synthesis of runoff hydrographs is used to investigate the effects on the hydrographs of the variation of the physical characteristics of a nine-acre hypothetical drainage basin. The drainage density, drainage pattern, and drainage area shape are allowed to vary, and these variations are related to the change in peak flow and time to peak of the hydrograph. It is found that although each of the characteristics affects the hydrograph, the variation of the drainage density causes the greatest change in the peak flow. These results are compared to the peak flows and lag times that would be predicted by using the Rational Method on the same drainage basins. The Rational Method is shown to be almost totally insensitive to changes in drainage density. The overall results indicate that the average length of overland flow in the drainage basin can be used to predict the peak flow under conditions specified in this study.

HORN, D.R. and DEE, N. 1967: "Synthesis of the inlet hydrograph from small pervious and combined pervious - impervious drainage areas". John Hopkins University, Baltimore, Md., Dept. of Environmental Engineering Science, Report No. TR7, Storm Drainage Project; 107pp. (NTIS PB-183 010).

Key words: hydrographs; analytical techniques.

Based on the actual recorded rainfall-runoff data on two gauged areas in Baltimore (Montebello 2 - with 92 percent perviousness, and Hamilton 2 - with 30 percent perviousness), the coefficients in Horton's infiltration equation for each of these two areas were determined by using a simple line-

ar storage reservoir model of the runoff process with double routing technique suggested by Holtan and Overton (assuming these areas to be 100 percent pervious). Then by applying Schaake's runoff routing computer program together with the thus derived Horton's infiltration equations for the pervious portions of these drainage areas, the computed hydrographs can check well with the actual recorded hydrographs, if the right values of the roughness coefficient 'n' for these pervious and impervious surfaces can be used.

HORNER, W.W. and FLYNT, F.L. 1936: "Relation between rainfall and runoff from small urban areas", Trans. ASCE, Vol. 101, paper No. 1926; p140-206.

Key words: rainfall-runoff relationships; urban runoff.

The results of research into the relation between rainfall and runoff from small urban areas in St. Louis, Mo., are presented as specific studies of the runoff from parts of two different city blocks tributary to street inlets and from both roofs and ground surface of another entire city block for practically all heavy rains occurring from 1914 to 1933. Based on criteria developed at each of the locations, master frequency diagrams for both rainfall and runoff were prepared for the general region. Suggestions are offered as to how the values determined for specific blocks in St. Louis might be modified to be applicable to (a) different surface slopes; (b) other percentages of impervious area; and, (c) other typical soils.

HOSSAIN, A. et al. 1974: "Evaporation, infiltration and rainfall runoff processes in urban watersheds". Purdue University, La Fayette, Ind. Water Resources Research Centre, Technical Report No. 41.

Key words: rainfall-runoff relationships; mathematical models.

The rainfall-runoff transfer has been simulated by linear, nonlinear, time invariant and time variant deterministic models. Most of these models, particularly those based on the linear analysis concept, use the rainfall excess as the input. The weakest link in the rainfall-runoff transfer models is the proper estimation of the input, the effective rainfall. The principal objective of this study was the development and testing of methods of estimation of the rainfall excess. The other objectives of the study were the testing of the linear and nonlinear systems models in the determination of the response of watersheds at different stages of urbanisation and the development of a model of the rainfall excess-direct runoff transfer.

HOSSAIN, A. et al. 1978: "Estimation of direct runoff from urban watersheds". J. Hydraul. Divn., Proc. ASCE, Water & soil technical publication no. 15 (1979)

Vol.104(HY2); p169-188.

Key words: peak discharge; rainfall-runoff relationships; surface runoff; hydrographs.

In the present paper, a quasilinear model of the rainfall-runoff transfer is developed by means of a regional dimensionless kernel function. The instantaneous unit hydrograph (IUH) for a specific storm on a specific watershed is obtained by rescaling the regional dimensionless kernel by using the peak discharge of the IUH, the time lag of the watershed and storm characteristics. The peak discharge of the IUH and the lag time of the watershed are obtained by the given regression relationships. The model is tested by predicting the direct runoff from an urban watershed, the data from which were not used for the calibration of the model. A nonlinear deterministic model involving two kernel functions is used to compute the direct runoff from the rainfall excess. The first and second-order kernels vary with the number of storms used. The regeneration performance of the nonlinear model was not as good as that of the quasilinear model. The runoff hydrographs are sensitive to errors in the second order kernel function.

HOUGHTON, P.D. 1975: "Soil erosion within the urban environment". *J. of Soil Conservation, N.S.W.*, No.31(3/4). Part I: Recognition of urban erosion; p172-178. Part II: On-site erosion; p241-253.

Key words: sediment yield; erosion control; storm runoff; erosion.

Part I: The conservation of soil resources and the mitigation of erosion have been actively pursued for many years within the rural areas of New South Wales. This has not been the case within the rapidly expanding urban environments. Soil erosion within urban areas has not been adequately recognised to date having been allowed to occur at unprecedented rates, creating numerous problems, and resulting in heavy economic and social losses. This article describes the need to recognise urban soil erosion as an important step to legislation and research to minimise the risk of erosion in the planning and development of urban areas. Major effects of erosion are not restricted to the despoilation of the eroded area. The increased runoff from urban areas can create problems on lower land within the same catchment, in particular, problems resulting from deposition of sediment. As a consequence of erosion and siltation, social and economic effects and chemical pollution supply further evidence for the need to control and prevent erosion within the urban environment.

Part II: The lack of appreciation and need to recognise the dangers of soil erosion within urban environments have been demonstrated in part I of this article. Part II lends further evidence to this need by examining the effects of on-site soil erosion in urban areas. Construction zones, through the neces-

sity to clear vegetation for site preparation, are the areas most actively eroding at any one time. Major problems, created by natural and induced mass movements, have resulted where urban development has encroached onto areas of critical erosion hazard. These critical areas have a high erosion risk and are susceptible to erosion at any time irrespective of their stage of development. Other erosion problems associated with the urban environment and described in this article include erosion of open space areas, waste disposal areas, utility service tracts and quarry sites for building materials. Brief guidelines for the prevention and control of erosion within urban environments are presented.

HOVMAND, M.F. 1977: "Heavy metals in precipitation". In, *Diffuse vannforurensinger - tillforsel og transport*, 13th Nordic Symposium on Water Research, Roros Norway. (Preprint, in Norwegian).

Key words: heavy metals; air pollution effects.

HOWARD, W.T. and BULLER, R.D. 1975: "Unsewered development and water quality". In, *Urbanisation and water quality control*. Proc. Symposium American Water Resources Assoc., No.20; p129-139.

Key words: nonpoint pollution sources; water pollution sources; ground water resources; surface runoff.

In water resources planning, interest has been directed towards evaluating the effects of nonpoint sources of pollution on water quality. This interest is generated by the need to better understand the dynamics of nonpoint sources of pollution. Two study approaches will be reviewed that assess the impact of unsewered residential development as a potential nonpoint source of pollution. One study concentrates on ground water, while the other describes surface water quality impacts of unsewered housing. Planning considerations are presented which are based in part on findings derived from both studies. These are not recommendations, but guidelines to be considered when evaluating unsewered development.

HOWARD, W.T. and HAMMER, T.R. 1973: "Water quality impacts of unsewered housing". RSRI discussion paper series: No.66.

Key words: analytical techniques; water pollution sources.

This paper describes briefly a recent study of the impacts of unsewered residential development on stream water quality, conducted by the Regional Science Research Institute. The investigation has involved cross sectional analysis of water quality data for a carefully chosen sample of streams. Measurements of each water quality constituent have been related to land uses

and other watershed characteristics by statistical techniques. The results of the study indicate that unsewered housing has a significant effect upon some, but not all, of the water quality constituents considered. These results prove to be remarkably consistent with the findings of another water quality study, conducted by the Regional Science Research Institute in 1969.

HOWE, J.M. and WAUGH, J.R. 1972: "Urban hydrology to 1971". N.Z. Ministry of Works, Hydrol. Research Annual Report, No.24; 21pp.

Key words: urbanisation; urban hydrology; storm runoff; hydrologic data; data collection; peak discharge; watershed management.

Under the auspices of the International Hydrological Decade the Ministry of Works is establishing a network of experimental basins to study the hydrological characteristics of important soil and vegetation complexes of New Zealand. The study of the effect of cultural change on these characteristics is also included. This paper is on the Manukau City Experimental basin in which the hydrological effects of urbanisation are studied. Included are reports on related studies in urban hydrology which are carried out near the experimental basin. Research is coordinated by the National Water and Soil Conservation Organisation and is carried out in conjunction with other organisations. Ultimately it is hoped that 19 experimental basins will be established in New Zealand. The study includes the influence of urbanisation on flood peak discharges and flood volumes in particular and on the hydrological regime in general; data for developing and testing a mathematical model for the prediction of flood peak discharges for urban catchments under New Zealand conditions; data for refining existing urban storm water drainage design techniques; and design data to assist in the solution of particular storm water design problems within the catchments being studied.

HUBER, W.C. et al. 1973: "The EPA storm water management model: a current overview". In, Combined sewer overflow seminar papers, Florida University, Dept. of Environmental Engineering Sciences, Gainesville; p181-216. (EPA Report EPA-670/1-73-077).

Key words: combined sewers; overflows; storm runoff; urban runoff; mathematical models; model studies; rainfall-runoff relationships.

The problem of loading by combined and separate storm sewer overflows on streams and other receiving waters has led to the development of a comprehensive mathematical computer simulation program that models quantity (flow) and quality (concentrations) during the total urban rainfall-runoff process. The present Storm Water Management Model (SWMM) is descriptive in nature and will model most urban configura-

tions encompassing rainfall, runoff, drainage, storage-treatment, and receiving waters. It does not define nor determine any decisions for the systems or consider alternative methods for efficient economic comparisons. An overview of the SWMM is presented by illustrating its use in Lancaster, Pennsylvania. Major revisions to the Model have been made to include urban erosion prediction, modeling of new treatment devices and biological treatment facilities, monitoring of significant pollution sources, flexibility in modeling new areas, new and improved cost functions for treatment and storage options, and a modest hydraulic design capability as well as minor programming changes and slight format revisions.

HUBER, W.C. et al. 1975: "Storm water management model: user's manual, Version II". Florida University, Gainesville, Dept. of Environmental Engineering Sciences, Report EPA-670/2-75-017; 350pp.

Key words: urbanisation; mathematical models; water pollution; waste water treatment; surface runoff; combined sewers; model studies; computer models; overflows; storm water.

A comprehensive mathematical model (the EPA Storm Water Management Model, SWMM) capable of representing urban storm water runoff and combined sewer overflow phenomena was developed. SWMM portrays correctional devices in the form of user-selected options for storage and/or treatment with associated estimates of cost. Effectiveness is portrayed by computed treatment efficiencies and modeled changes in receiving water quality. The original project report published in 1971 is divided into four volumes: Volume I, 'Final Report'; Volume II, 'Verification and Testing'; Volume III, 'User's Manual'; and Volume IV, 'Program Listing' (EPA Report Nos. 11024DOC07/71, 11024DOC08/71, 11024DOC09/71, and 11024DOC10/71, respectively). (See also W71-13370). Effort on modification and improvement of the SWMM has been, and is being continued since its release. As a result, this official 'Release 2' of the SWMM includes additional program components, i.e., new runoff routine, urban erosion prediction, new treatment process performance and cost function, and new receiving water quality. This report provides a revised and improved User's Manual to accompany 'Release 2' as in the original User's Manual, Volume III.

HUBER, W.C. et al. 1975: "Overview of latest version of SWMM". In, Second Annual National Conference on Environmental Engineering Research, Development and Design; 5pp.

Key words: model studies; computer models; hydrologic data; waste water treatment; waste storage.

The EPA 1969 Storm Water Management Model (SWMM) has good documentation, is in wide use by engineers, and is continually updated. Its overall objec-

tive is facilitation of the strategy of addressing storm water quantity and quality problems. The various SWMM computational blocks are described. Input data consist of rainfall hydrographs and a physical description of the rainfall catchment, drainage, and contour system. SWMM output consists of hydrographs and pollutographs in a completely transient manner throughout all portions of the system including receiving waters. The costs associated with specified abatement facilities are computed. Originally, SWMM was used for individual storms; more recent developments include planning models utilising long time steps (typically, 1 hour) and long simulation times (several years). With these modifications SWMM may be used in the characterisation of the trade-off between storage and the treatment necessary to obtain given levels of pollution control. The advantages of SWMM include superior quality routines, the incorporation of dry weather flow for use in combined sewer areas, and the incorporation of possible treatment that occurs while runoff is being stored.

HUBER, W.C. and HEANEY, J.P. 1974: "The EPA storm water management model". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p242-246.

Key words: waste water treatment; analytical techniques; mathematical models.

A comprehensive mathematical computer simulation program was developed to model flow and quality during the total urban rainfall-runoff process. It provides an accurate representation of the physical system and an opportunity to determine the effect of proposed pollution abatement procedures. The Storm Water Management Model (SWMM) was developed, demonstrated, and verified. It has been documented and is currently in use. The SWMM is descriptive and models most urban configurations encompassing rainfall, runoff, drainage, storage/treatment, and receiving waters. Program segments correspond to physical components of the urban runoff process, and it has preliminary decision-making capabilities. Many changes have been made in details of the original program, input/output requirements, and data descriptions.

HUBER, W.C. and HEANEY, J.P. 1977: "Urban rainfall-runoff-quality data base. Report for June 1974 - April 1977". Dept. of Environmental Engineering Sciences, Florida University, Gainesville; 183pp.

Key words: data collection; hydrologic data; rainfall-runoff relationships; water pollution.

Urban rainfall-runoff-quality data gathered by others have been assembled on a storm event basis for one or more catchments in the following eight cities: San Francisco, CA; Broward County, FL; Lincoln, NB; Durham, NC;

Windsor, Ont.; Lancaster, PA; Seattle, WA; Racine, WI. Rainfall-runoff data have been assembled for one or more catchments in an additional 13 cities: Baltimore, MD; Chicago, IL; Champaign-Urbana, IL; Bucyrus, OH; Falls Church, VA; Winston-Salem, NC; Jackson, MS; Wichita, KS; Westbury, NY; Philadelphia, PA; Los Angeles, CA; Portland, OR; Houston, TX. The 21 cities contain data for a total of 41 catchments. Descriptions of the catchments, parameters and sampling procedures are provided in this report.

HUFF, D.D. et al. 1973: "Simulation of urban runoff, nutrient loading and biotic response of a shallow eutrophic lake". In, Proceedings of a workshop on modeling the eutrophication process, Water Research Laboratory, Utah State University, Logan, Utah; p33-35.

Key words: model studies; bioindicators; urban runoff; nutrients; lakes; eutrophication; phosphorus compounds; nitrogen compounds.

Research and modeling results are synthesised to simulate the behavior of the linked terrestrial and aquatic components of the Lake Wingra, Wisconsin, basin ecosystem. Runoff to the lake was simulated, ground water flows estimated, records made of lake discharge and lake stage, lake evaporation, and nutrient sources simulated. This modeling effort entails the coupling of detailed mechanistic models of the hydrology of a lake's drainage basin, prediction of nutrient loading, and biotic response. Although the model is simplified for a shallow lake, system specific regressions were utilised in the simulations sparingly, and only where mechanistic models have yet to be developed. The model represents a significant synthesis of the understanding of ecosystem functioning. The use of models as hypotheses of ecosystem behavior, therefore yields a tool for studies of management alternatives for aquatic systems. As such a tool, a model helps fill the gap between scientific insight and empirical type analyses. Simulation models may nevertheless allow for more rigorous testing of empirical models or management recommendations. This modeling effort indicates the feasibility of using detailed simulation models of lakes and their drainage basins.

HUFF, D.D. et al. 1974: "Simulation of urban runoff, nutrient loading and biotic response of a shallow eutrophic lake". Eastern Deciduous Forest Biome - IBP Contribution No.114; 53pp.

Key words: model studies; urban runoff; nutrients; eutrophication; lakes.

Through orderly progression of process model synthesis, testing, and new synthesis, a solid model structure can be built and extended for simulating whole ecosystem response to natural and man-made perturbations.

Multi-disciplinary research and team modeling efforts have provided the opportunity to conduct detailed whole ecosystem simulation studies. The lake water balance was analysed, followed by estimated nutrient loading from precipitation, dryfall, runoff, and ground water flow. Simulations of lake response, from April to September, 1970, were compared with observations. In a first attempt to link terrestrial and aquatic ecosystem models, a six month period was selected for simulating both water and nutrient loading from the terrestrial system and the associated response of the Lake Wingra, Wisconsin, ecosystem. Hydrologic simulations appear equally as accurate as field measurements, and serve as reliable means for estimating nutrient loading from storm drains in an urban watershed. The simulated response to a wide range of nutrient influx indicates that Lake Wingra is less sensitive to nutrient influx than to regeneration within the pelagic system. This implies that already productive lake systems will be less responsive to nutrient diversion than those with lower productivity.

HUFF, F.A. (ed). 1973: "Summary report of Metromex studies, 1971 - 1972". Illinois State Water Survey, Urbana, Report of Investigation 74; 169pp.

Key words: weather modification.

Metromex is an investigation of inadvertent weather modifications resulting from an urban environment. Findings are summarised from analyses of data collected during the first two years of the 5 year field operation, located in St. Louis. Primary focus is climatological-statistical analyses of surface studies, including studies of seasonal and storm rainfall, synoptic storm types, thunderstorms, hail, surface raincells, measurements of condensation nuclei and raindrop distributions, wind, temperature, humidity, and urban effects on surface and ground water quality. Results indicate that rain, thunderstorms, and hail maximise in both intensity and duration at locations 10 to 15 miles downwind of an urban-industrial region. Limited analyses of atmospheric studies are also included. One indicated effect of heat and other emissions generated by an urban area is the presence of higher cloud bases than those found in rural regions.

HUFF, F.A. 1974: "The distribution of heavy rainfall in a major urban area". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p53-58.

Key words: weather modification.

Since 1971, a network of 225 recording raingauges has been operated within a 26-mile radius of St. Louis in conjunction with an extensive 5-year investigation of urban effects on precipitation. Since improved sewer design and engineering is a current hydrologic problem of major interest, the network

data are being analysed to provide information applicable to this need. This paper summarises initial findings obtained from analyses of the 100 heaviest raincells recorded on the network during the summers of 1971-72 and the two-year pattern of storms producing one-inch or more of rainfall. Results indicate a substantial increase in rainfall yield from raincells exposed to potential urban effects compared with no-effect cells. The one-inch rainfall pattern shows a distinct maximum in a region that is frequently in the path of storms passing across the two urban-industrial areas of St. Louis and Alton-Wood River. It is concluded that if these preliminary findings are verified in the remaining years of the project that frequency relations used in the design of urban and suburban systems will need to be re-evaluated to incorporate significant urban effects upon storm runoff.

HUFF, F.A. 1976: "Relation between atmospheric pollution, precipitation and streamwater quality near a large urban industrial complex". Water Research, Vol.10(11); p945-953.

Key words: urban runoff; air pollution effects; water pollution; miscellaneous chemicals; chemical analysis.

An investigation was made of the effects of atmospheric effluents from a large urban industrial area (St. Louis) on the water quality in two small basins that are frequently downwind of the city. Analyses were made of the relative magnitude of the atmospheric contribution to streamwater pollution, and how this contribution is related to weather conditions. Field sampling was done during a 15 month period, and investigation made of atmospheric-streamwater relationships for storm, seasonal, and annual periods. Computations were made for 12 chemical constituents in the rainwater and streamwater. Results indicated that only minor changes usually occur in streamwater pollutant concentrations during and shortly following storms, and no strong relationship exists between streamwater concentration and weather conditions. For most pollutants the atmospheric deposition was small compared with the annual stream load because of major surface sources. However, evidence was also found that urban industrial sources can occasionally be important contributors to stream contamination.

HUFF, F.A. 1977: "Urban effects on storm rainfall in midwestern United States". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p12-19.

Key words: weather modification.

A comprehensive 5-year field and analysis program concerned with urban-induced effects on precipitation was recently completed at St. Louis, Missouri, USA. Data obtained from op-

eration of a network of 225 recording raingauges on 5200 sq km indicated an increase of approximately 30 percent in summer rainfall in an area which is most frequently exposed to storms crossing the urban-industrial region. This enhancement was most pronounced in heavy rainstorms that produced maxima of 25 mm or more in the network. The average water yield from individual raincells in these storms was over 70 percent greater in urban-exposed cells than in surrounding rural cells. Radar data showed a strong tendency for new raincells to form or for existing cells to intensify over the urban area. This cell enhancement was most pronounced with organised cell systems during the afternoon when solar heating is superimposed upon the man-made heat island. Hydrologically, the 5-year study indicates that the frequency distribution of heavy rainfalls of 5 min to 2 hour duration may vary significantly between urban, suburban, and rural areas in large urban-industrial regions, and this variation should be considered in the design and operation of urban hydrological systems.

HUFF, F.A. 1977: "Effects of the urban environment on heavy rainfall distribution". *Water Resources Bulletin*, Vol.13(4); p807-816.

Key words: weather modification; air pollution effects; urban hydrology; urbanisation.

A network of 225 recording raingauges was operated over an area of 5200 sq km in the St. Louis region during 1971-1975, in conjunction with an extensive investigation of urban effects on precipitation. Study of urban-induced effects on the frequency of heavy rainstorms has revealed a pronounced increase in the occurrence of storms producing 25 mm (1 inch) or more of rain. The increase is greatest in an area that is frequently in the path of storms passing across two urban-industrial regions. Analyses of raincells (rain intensity centres) within heavy convective storms shows a pronounced increase in water yield from cells exposed to potential urban effects, compared to those exposed only to the surrounding rural environment. Naturally-occurring heavy cells tend to undergo greatest enhancement from urban exposure. Other analyses indicate an above average frequency of excessive rain rates for periods of five minutes to two hours downwind of the urban-industrial complex. It is concluded that urban-induced intensification of short-duration rainstorms is sufficient to merit inclusion in the design and operation of urban-area hydrologic systems that control the flow of surplus storm water.

HUFF, F.A. and CHANGNON, S.A. 1960: "Distribution of excessive rainfall amounts over an urban area". *J. Geophys. Research*, Vol.65(11); p3759-3765.

Key words: weather modification.

Data recorded over a 10 year period from a network of 11 recording raingauges was used in a study of the distribution of excessive rainfall over the 10 square mile urban area of Champaign-Urbana, Ill. All storms were used in which one or more of the raingauges recorded an amount equalling or exceeding the 2-year rainfall for durations of 30 minutes, 1 hour, 2 hours, 3 hours, 6 hours, 12 hours, and 24 hours. Based on the 10 year sampling period, twice as many excessive rainfall amounts actually occur within the 10 square mile area compared with the number recorded at gauges; on the average, the percentage of the 10 square mile area experiencing excessive rainfall amounts increases with increasing storm duration; the majority of the excessive amounts for a duration of 30 minutes to 24 hours occur in the same storms; a point rainfall record is a satisfactory index of the areal mean rainfall frequency distribution in a 10 square mile area; and urban influences, if present, are small.

HUFF, F.A. and CHANGNON, S.A. 1973: "Precipitation modification by major urban areas". *Bulletin Amer. Met. Soc.*, Vol.54(12); p1220-1232.

Key words: weather modification; air pollution effects.

Historical weather records at eight American urban areas of varying size, type, and climate were studied for indications of inadvertent precipitation modification. The six largest cities all had experienced warm seasonal rainfall increases of 9 to 17 percent during the 1955-70 period. The increases in the midwest cities occurred largely with cold frontal systems, but in the coastal cities they were largely during air mass (non-frontal) conditions. The midwest increases also were found to occur as enhancement, not initiation, of moderate to heavy rain days. Significant increases in summer thunder-day frequencies (13 to 41 percent) and hail-day frequencies (90 to 450 percent) were found in the six large cities, and the increases occurred largely in the morning hours. The typical locations of maxima in the midwest cities were thunder over and near the city, and rain and hail 25 to 55 km downwind. The maxima of all events in coastal cities were in or near the city. Overall, the results suggest that urban precipitation enhancement is related to city size, industrial nuclei generation, and urban thermal effects. The alterations have considerable relevance to urban design, local area forecasting, local water supplies, agricultural production, hydrologic design, and to planned weather modification.

HUFSCHMIDT, M.M. 1974: "Urban water resources planning and management". In, *National Water Commission, A Review of some Issues*. Proc. of a seminar series, (ed. P.M. Ashton), Virginia Water Resources Research Centre, Blacksburg, Bulletin No.75; p9-21.

Key words: urbanisation; watershed management.

Historically, there have been two major areas of U.S. water policies, plans, and programs. One is national, which developed around concerns for interstate commerce, navigation, major flood control projects and irrigation developments. Alongside this national emphasis has been consistent local concern for domestic water supply, sewage collection, treatment and disposal, and urban storm drainage. In the past, policy recommendations implemented have been rural-resource, rather than urban oriented. With the growing urbanisation trend, national water policy for the next two decades should be urban oriented. In the report of the National Water Commission, three of the seven themes have special relationship to urban water policy: (1) urban land-use planning and the use of urban flood-plain management is emphasised as an alternative to building dams and levees, (2) water resource planning and management can best be done at the local level, placing more responsibility on local units of government, and (3) national priorities are shifted from development to environmental improvement. As a basis for analysing the Commission's findings and recommendations on planning, the author summarises 5 of his own recommendations, the aim of which is to reorient water resource planning activities at the federal and state levels to support effective planning on the urban-metropolitan scale. Serious inadequacies in urban water data are not recognised in the report, it is deficient in emphasis on urban-oriented research, but in general, it reflects well the problems and issues of urban water management and makes some very useful and constructive recommendations.

HUNTER, J.V. et al. 1975: "Measurement of urban runoff petroleum". In, Urbanisation and water quality control. Proc. American Water Resources Assoc. Symposium, Proc. No.20; p162-168.

Key words: urban runoff; storm runoff; oil wastes; organic compounds.

This is the first report of an investigation of petroleum in urban storm runoff in the Delaware Estuary. The research is part of the NSF-RANN research project, "The Petroleum Industry in the Delaware Estuary", of Rutgers University and the Philadelphia Academy of Natural Sciences. The main objective of this investigation is to quantitatively determine the relative importance of urban runoff and petroleum refinery effluents. During the past year, data were obtained as to storm water runoff for a large (13 ft diameter) storm sewer in North Philadelphia which drains a fairly well kept, mainly residential neighbourhood. In addition, data were also obtained as to the hydrocarbon contents of a secondary treated refinery effluent in the Philadelphia area to act as a point of comparison with the storm water results.

HYDROCOMP INC. 1970: "Simulation of continuous discharge and stage hydrographs in the north branch of the Chicago River". Report to the Northeastern Illinois Planning Commission, Chicago. Hydrocomp Internat. Inc., Palo Alto, Calif.; 56pp.

Key words: hydrographs; flood forecasting; mathematical models; model studies.

Streamflow simulation studies of the North Branch of the Chicago River used mathematical modeling techniques to aid the development of regional maps delimiting flooded areas for 25, 50, and 100 year frequencies and evaluation of flood control works, channel constrictions, and changes in urban development patterns. The river flows through the Chicago metropolitan area and is typical of watersheds in northeastern Illinois. It has a small channel gradient and floods a broad area at high discharge. The simulation studies showed that steps must be taken either to preserve the river's ability to flow over its flood plain or to substantially alter the channel. If flood plain storage is used for a sub-division at one point, it could be returned to the stream at another point by land purchase and excavations. Alternatively, if channel storage is not preserved, large floodways, detention basins, or underground caverns will be needed. Results of simulation studies of flood discharge and stage are presented by tables and graphs.

HYDROCOMP INC. 1975: "Evaluation of the effects of urbanisation on aquatic ecology and hydrologic systems. Completion report". Hydrocomp Inc., Palo Alto, California; 167pp.

Key words: urbanisation; hydrologic systems; environmental effects.

Three hypothetical watersheds, each 60 square miles in area with the downstream 30 square miles urbanised were simulated with, and without, urbanisation. Each watershed was assumed to have the hydrometeorologic, topographic, soil, and vegetation characteristics of a real watershed - only the size and urbanisation were assumed fixed. The conclusions as to the impact of urbanisation are discussed and the three watersheds are compared.

HYDROLOGIC ENGINEERING CENTRE. 1975: "Urban storm water runoff: STORM". Generalised Computer Program 723-S8-L2520, Davis California; 104pp.

Key words: computer models; storm runoff.

IFFT, T.H. 1969: "Solutions to urban - fringe erosion - sedimentation problems". ASAE Paper No.69; p719.

Key words: erosion; sediment yield; erosion control; sediment control.

The national emphasis on recognising environmental pollutants and their despoiling of our surroundings has focused attention on this problem since it is acknowledged that urban development causes increased erosion and sediment during construction unless a program to control this problem is developed and enforced. Urban developers, in many cases, do not have a direct incentive to apply erosion control measures. For this reason, urban erosion control is a public concern and must become the responsibility of local government through its regulatory powers. The author lists six and elaborates on basic principles in local sediment control programs.

I.H.D. SUBGROUP (UNESCO). 1974: "Hydrological effects of urbanisation". Studies and Reports in Hydrology, No.18, UNESCO, Paris; 280pp.

Key words: urbanisation; urban hydrology; urban runoff; water pollution sources.

This report represents the work of a sub-group taking part in the International Hydrological Decade, and is divided into two parts, the first consisting of case histories of urbanisation effects in five countries (West Germany, Holland, Sweden, U.S.A., and U.S.S.R.) and the second comprising eight studies to illustrate special topics within the general field of urban hydrology, including the effects of open-cast mining on the local water balance, the effect of household detergents on water quality, and the influences of urban runoff on polder regions. Each section is supported by many references to the literature, and a preface contains a long international summary.

INABA, K. 1970: "Extent of pollution by storm water overflows and measures for its control". Fifth International Water Pollution Research Conference, San Francisco, preprint paper No.HA-8; 7pp.

Key words: water pollution; storm runoff; hydrographs; waste water treatment; mathematical models; overflows; combined sewers.

A study of the quantity and quality of storm sewage from a combined sewage system in Tokyo metropolis was conducted in the period 1966-1967. Three interconnected aspects of the study are discussed: (1) the hourly variation of storm sewage and storm water quality and quantity in urban areas, (2) some considerations on the method of estimating these factors, and (3) the control of storm sewage flow and quality. It is important to estimate the hourly variation of storm sewage or storm water quality as a function of rains at

all intensities so that accurate measures can be taken for control based on a sound mathematical model. Several possibilities are investigated and it is concluded that in a combined system it is most economical and reasonable to divide the total pollution in storm sewage between the outfall sewer to the treatment works, a storage tank, and storm sewage outflows.

INSTITUTE OF HYDROLOGY. 1976: "The effect of urbanisation on flood estimates". Unpublished report - also document 76/17 of DOE/NWC working party on hydraulic design of storm sewers.

Key words: urbanisation; flood forecasting; storm runoff.

INTERNATIONAL ASSOC'N OF HYDROLOGICAL SCIENCES. 1973: "Ground water pollution". Proc. Int. Symposium on Water Pollution, Moscow, 1971. IAHS Publication No.103; 240pp.

Key words: ground water resources; aquifers; water pollution; water pollution sources; chemical wastes; organic compounds; oil wastes.

The Symposium on Ground Water Pollution was organised by the IAHS and cosponsored by the International Association of Meteorology and Atmospheric Physics and the International Association of Physical Sciences of the Ocean, during the XVth General Assembly of IUGG. All aspects of pollution were covered: natural pollution - by salts of the land, and by sea water; artificial pollution - by fertilisers, waste water, waste deposits, salts from mines, petroleum products, etc.

IOWA NATURAL RESOURCES COUNCIL. no date: "Computation of flood stages etc., urban areas". Iowa Natural Resources Council, Des Moines, Iowa.

Key words: computer models; flood forecasting.

The study outlines flood stage and water profile determinations by computer methods in urban and rural areas.

IZZARD, C.F. 1946: "Hydraulics of runoff from developed surfaces". Proceedings, Highway Research Board, Vol.26; p129-150.

Key words: rainfall-runoff relationships; storm runoff; hydrographs.

The results are given of experimental research on overland flow from paved and turf surfaces, and of analytical hydraulic studies of flow in gutters. A method is developed for computing the hydrograph of runoff resulting from given rates of rainfall, considering roughness, slope, and length of surface as variables. The hydraulics of flow in a gutter collecting runoff along the edge of a pavement as studied shows the storage effect with outflow lagging in-

flow. Empirical curves are developed with roughness, grade and length of gutter, and overland flow characteristics as variables, from which estimates can be made of the maximum rate of runoff.

IZZARD, C.F. and ARMENTROUT, C.L. 1959: "A discussion on the hydrology of urban runoff". J. Sanitary Engineering Divn., Proc. ASCE, Vol.85(SA5) Pt.1; p51.

Key words: hydrographs; rainfall-runoff relationships.

This is a discussion of "The hydrology of urban runoff" by Tholin and Keifer. The "Tholin" storage curves are generalised and two storm hydrographs are reproduced. One of these has no antecedent rainfall, the other has 0.3 in. in 2 1/2 hr. The storms are computed first for 100 percent runoff from the entire watershed and then from runoff only from the impervious area. Comparisons with the recorded hydrographs are made.

JACKSON, T.J. et al. 1976: "Flood frequency studies on ungauged urban watersheds using remote sensed data". In, Proceedings National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky; p31-39.

Key words: mathematical models; remote sensing; aerial photography.

The development of valid estimates of flood frequencies and magnitudes in ungauged urban watersheds is the subject of considerable controversy. One approach to determining the flood frequency data is to use a continuous streamflow generation model. If the model is to be useful in ungauged watersheds, its parameters must be related to measurable watershed characteristics. The present investigation was conducted to develop a technique for estimating parameter values for the STORM model using satellite multispectral remote sensing (Landsat) of watershed characteristics. Regional relationships are presented for predicting the STORM parameters, a runoff coefficient and a depression storage coefficient, from the percent of impervious area. The prediction relationship for the runoff coefficient was developed from an analysis of historical rainfall-runoff data on seven watersheds in the Baltimore-Washington area with percent of impervious areas ranging from 25 percent to 100 percent. The depression storage coefficient is estimated using 0.25 in. and 0.06 in. for pervious and impervious areas respectively.

JACKSON, T.J. et al. 1977: "Test of Landsat-based urban hydrologic modeling". J. Water Resources Planning and Management Divn., Proc. ASCE, Vol.103(WR1); p141-158.

Key words: aerial photography; remote sensing; computer models.

Many of the models designed to support the hydrologic studies associated with urban water resources planning require input parameters that are defined in terms of land cover. Estimating the land cover is a difficult and expensive task and any innovation that can reduce these problems should be of significant value to the water resources planning community. The purpose of the reported investigation was to compare conventional and Landsat-based methods for determining the land cover inputs of hydrologic planning and design models. Comparisons were based on a case study of the Fourmile Run watershed in Virginia. Results of the study indicated that for planning model studies, the Landsat-based approach is highly cost-effective. However, in the design model investigations, the errors encountered when the Landsat data are used were unacceptable.

JACKSON, T.J. and RAGAN, R.M. 1974: "Hydrology of porous pavement parking lots". J. Hydraul. Divn., Proc. ASCE, Vol.100(HY12); p1739-1752.

Key words: storm runoff; watershed management; flood control.

Numerical solutions of the Boussinesq equation were used to examine the behaviour of porous pavement systems incorporating subdrains in open graded base courses placed on impermeable membranes. A series of numerical experiments showed that substantial control of the runoff hydrograph from parking lots could be obtained through the use of porous pavements. The numerical experiments conducted with synthetic design storms were used to develop equations and graphs for use by engineers designing porous pavement systems for runoff control.

JALAL, K.F. 1977: "Water quality impacts of urbanisation - a methodology". J. Environmental Engineering Divn., Proc. ASCE, Vol.103(EE1); p49-57.

Key words: model studies; urban runoff.

The STORM (Storage Treatment Overflow Runoff Model) was used in Canada to investigate the effects of urbanisation on water quality. Three steps are involved in the application of the model for this purpose: long-term simulation of runoff quality and quantity for all planning alternatives; comparison of alternatives; and determination of the storage-treatment relationship and the optimum storage-treatment combination for the preferred alternative. Using the model can produce the optimum storage-treatment combinations for meeting a given water quality objective at minimum cost.

JAMES, I.C. 1967: "Flood runoff from partially urbanised areas, Wichita, Kansas. Report 1, analysis of initial conditions". U.S. Geol. Survey open-file report; 62pp.

Key words: storm runoff; hydrographs; peak discharge.

The effect of changes in urbanisation on flood runoff near Wichita, Kans., was studied by analysing rainfall, runoff, and urbanisation records. Data for the first three years of operation of the project include the degree of urbanisation as of September 1964, the maximum flood hydrographs and associated rainfall experienced during the three years, and the developed unit hydrographs of six study basins. Imperviousness varies from 0.86 percent to 30.48 percent in the six study basins. Variations between unit hydrographs from individual storms are probably caused by non-uniform rainfall excess. Urbanisation significantly affects flood peaks. For instance, fully urbanised Dry Creek, with a drainage area of 2.94 square miles, of which 30.48 percent is impervious, exhibited a unit hydrograph peak nearly the same as that of the far larger west branch of Chisholm Creek, with a drainage area of 16.10 square miles and an imperviousness of 1.85 percent, although the unit peak on the west branch of Chisholm Creek should be 2 to 2.5 times that

of Dry Creek.

JAMES, L.D. 1965: "Using a digital computer to estimate the effects of urban development on flood peaks". Water Resources Research, Vol.1(2); p223-234.

Key words: mathematical models; peak discharge; hydrographs; computer models; rainfall-runoff relationships.

By using the Stanford Watershed Model and varying the physical condition constants which describe the amount of urban development and channel improvement, a number of continuous hydrographs were developed for Morrison Creek in Sacramento County, California. Curves developed from these hydrographs make possible estimates of peak flow for various areas, frequencies, and degrees of urbanisation.

JAMES, L.D. 1972: "Hydrologic modeling, parameter estimation, and watershed characteristics". J. of Hydrology, Vol.17(4); p283-307.

Key words: mathematical models; rainfall-runoff relationships; urban hydrology.

A general watershed model represents the runoff phase of the hydrologic cycle by a series of moisture accounting equations. The Stanford Watershed Model uses fixed equations containing variable parameters which are calibrated for a watershed by trial and error matching of simulated to recorded flows. OPSET, a self-calibrating watershed model, was developed to estimate these parameters through a computerised least squares matching. The procedure reduces estimating scatter and provides parameter estimates which may be correlated with physical characteristics of the watershed and with watershed changes with urbanisation.

JAMES, L.D. et al. 1970: "An evaluation of relationships between streamflow patterns and watershed characteristics through the use of OPSET: a self calibrating version of the Stanford Watershed Model". Kentucky Water Resources Inst., Lexington, Research Report No.RR-36; 127pp.

Key words: streamflow; flood control; surface runoff; computer models.

More informed selection among alternative flood control measures requires better information on marginal differences in flood hazards associated with marginal differences in tributary watershed characteristics. Hydrologic modeling is the most promising approach to answering this question; however, the use of existing models is hampered by the absence of information correlating model parameters with physical characteristics of the watershed. To deal with this situation, a method was developed for estimating the parameter values for the Stanford Watershed Model which best match recorded with simulated streamflows. Physical characteris-

tics were measured for 17 rural watersheds. Correlations between the characteristics and the parameters were examined. Changes in parameter values with urbanisation were also examined. The results were used to study variations in downstream flood peaks and in annual average flood damages associated with various tributary watershed characteristics. The end product is designed to help guide urban development to minimise flood damage and storm drainage cost.

JAMES, L.D. et al. 1971: "The Peach Tree Creek watershed as a case history in urban flood plain development". Georgia Inst. of Tech., Atlanta Environmental Resources Centre. ERC-0971 W72-04127, OWRR-C-1786(3167)(4); 93pp.

Key words: storm runoff; water pollution sources; landuse change.

Historical development in the Peach Tree Creek flood plain and watershed, metropolitan Atlanta, Georgia, and the reactions of planning officials, changes in water quality and land values are analysed to ascertain the implications of historical experience for improved flood plain management policy. The report presents the historical sequences and causes and the role of governing officials in influencing development in the watershed from the time of earliest settlement, stressing flood plain development, analysis of the relative values of undeveloped lots on and off the flood plain and discusses the extent to which observed differences are caused by expected flood damages as opposed to differences in other residential choice factors, and changes in stream water quality associated with urbanisation and assesses the magnitude of the problem created by storm water washing of urban areas even if no sanitary sewer effluent is discharged directly into the stream.

JAMES, L.D. and LUMB, A.M. 1975: "UROS4: urban flood simulation model. Part 2: applications to selected DeKalb County watersheds". Georgia Inst. of Technology, Atlanta, School of Civil Engineering; 237pp. (NTIS PB-242 937).

Key words: urban drainage; urban hydrology; urbanisation; model studies; flood control.

The Urban Flood Simulation Model developed for use by DeKalb County, Georgia, to evaluate the hydrologic effects of tributary land use, culverts, detention storage, and channel conditions was applied to eight watersheds within the county. For each watershed, the basic physical characteristics, the nature of the flooding problem, the data collected for flood hydrograph simulation, and the results of the studies are described. On one 1058-acre watershed, a number of simulation runs were used to study the effects of impervious tributary area and channel improvement on flood flows. These runs show urbanisation to multiply flood peaks by a factor of about three, channelisation to multiply flood peaks by a factor that

increased from 1.06 to 1.23 as drainage area increased from 1 to 1,000 acres, and six different storms as critical in different parts of the watershed. The hydrologic analyses of the eight watersheds found that sites suitable for flood retardation dams generally were not effective except in very small watersheds, that existing culverts were causing sufficient ponding to significantly reduce downstream flooding, and that sediment and debris deposits were a major problem. The Model was very useful for quick estimation of the hydrologic effects of landuse and channel changes and for estimating flood flows for various purposes.

JAMESON, D.L. 1970: "A model relating water quality, vegetational structure and urbanisation in the San Jacinto River basin". Dept. Interior, Office of Water Resources Research; 49pp.

Key words: model studies; water pollution; urbanisation.

This study was initiated to test the hypothesis that available information was sufficient to predict the relation between amount of urbanisation and the quality of the water in the watershed of the San Jacinto River basin, Texas. Chemical water quality data are available in the published and unpublished records of the U.S. Geological Survey. Predictor variables included soil, weather, population characteristics, and estimates (from aerial photographs) of vegetation type and urbanisation. Factor analysis, discriminant analysis, and canonical correlation analysis were used for data reduction. Two models were attempted. The first used the data to construct a matrix model of the relation between predictors and water quality. The second model used a probability distribution of biomass in the vegetational community to examine the amount of reduction of the community that would not also destroy the contribution of the community to water quality. The results from both models were rejected because of the general incompleteness of the predictor data and because the available predictor data were not directly related to water quality in the areas where data were available.

JENKINS, D. et al. 1973: "Environmental impact of detergent builders in California water". Water Research, Vol.7(1/2); p265-281.

Key words: phosphorus compounds; detergents; nitrogen compounds; water pollution sources; point sources (pollution).

Most nationwide estimates in the United States place the point source phosphorus contributions to surface waters between 70-90 percent (in California this is between 80-90 percent) and the point source nitrogen input to something less than 50 percent of the total nitrogen load (in California this is about 40 percent). Detergents appear to represent somewhere on the order of 20-40 percent of the total phosphorus released to waters. The fractional

point source contribution of nitrogen and phosphorus and of detergent phosphorus is a function of population density. Detergents in California account for about 35 percent of the total phosphorus released to surface waters, but in individual hydrologic study areas this estimated contribution varies from about 10-45 percent.

JENNINGS, M.E. and KEEFER, T.N. 1977: "Routing of storm water flows through storm drains". J. of Research of the U.S. Geol. Survey, Vol.5(3); p301-306.

Key words: mathematical models; flood routing; storm runoff.

Storm-drain flow-routing methods based on kinematic-wave routing and storage-routing methods are compared with the MLSR (multiple-linearisation storm-drain routing) method for hypothetical circular pipe problems. The MLSR method, based on a diffusion-wave routing concept, is shown to give very good results without incurring the numerical solution or damping problems of other methods.

JENNINGS, M.E. and MATTRAW, H.C. 1976: "Comparison of the predictive accuracy of models of urban flow and water quality processes". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p239-243.

Key words: peak discharge; model studies; urban runoff.

Peak flow comparisons were made on four small urban catchments ranging in size from 47.8 to 613 acres using three selected storm water runoff models. Average errors varied from -5 percent to 21 percent for the models. Preliminary studies of pollutant accumulation in one basin indicated pollutant loads can be related to rainfall volume and antecedent dry days with an average correlation coefficient of 0.70. The surcharging effect of storm drains is indicated in comparisons of peak flow frequency for one of the catchments studied.

JENS, S.W. and MCPHERSON, M.B. 1964: "Hydrology of urban areas". In, Handbook of applied hydrology, (ed. V.T. Chow), Section 20, McGraw-Hill Book Co., New York.

Key words: rainfall-runoff relationships; urban hydrology; water pollution; storm runoff.

This section outlines current practices in the use of hydrologic data and methods in the solution of urban water problems and needs. Storm water drainage is given major emphasis, not only because of its considerable economic significance, but also because of the growing evidence of dissatisfaction with established methods of runoff determination and the consequent attempts to develop more realistic and accurate,

yet practical, engineering designs. In addition, brief mention is made of the utilisation of urban hydrology in connection with designs dealing with floods, water supply, pollution, airports, and expressways.

JEWELL, T.K. et al. 1974: "Application and testing of the EPA storm water management model to Greenfield, Massachusetts". In, Proceedings of National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p61-71.

Key words: mathematical models; urban runoff; model studies; computer models; suspended solids.

The Storm Water Management Model (SWMM) was used to predict quantity and suspended solids content of urban storm water runoff from a 547 acre test basin in Greenfield, Massachusetts. A sensitivity analysis of the input parameters for the runoff portion of the simulation program has been made. Initial comparison was made utilising synthetic rainfall data. An evaluation of the predictive capability of the three grids, compared with measured quantity and quality, is now in progress. Tentative guidelines have been developed that will assist potential users of this type of urban storm water runoff model. The program cannot itself design drainage systems or treatment facilities. It can perform many repetitive calculations to predict and route storm water and pollutants. If accurate input data is provided and the proper interpretation is made of the output, the SWMM can provide very accurate data upon which engineering design decisions can be made.

JEWELL, T.K. et al. 1977: "Methodology for predicting urban storm water pollutant loads". Paper presented at Annual Spring Meeting of the AGU, Washington, D.C. EOS, Vol.58(6); p389.

Key words: mathematical models; storm runoff; water pollution; suspended solids; biochemical oxygen demand; lead; zinc; phosphorus compounds.

This paper presents a rational approach to calibration of coupled quantity-quality models along with a discussion of suitable usage of the calibrated model. As an example, the U.S. Environmental Protection Agency Storm Water Management Model (SWMM) is calibrated using storm event data taken from a 1000 acre urban catchment (separate sewers) in Greenfield, Massachusetts. SWMM was chosen because of its availability to consultants and planners and because it is representative of the state of the art in storm water modeling. The calibrated model is then used to estimate annual pollutant loadings. A separate set of storm event data is used to verify the calibrated model. Quantity and quality subroutines of the SWMM Runoff Block are separated and calibrated independently. Measured rainfall and sewer flow data are used as input to the quality sub-routine and model output is calibrated

against measured pollutant concentration data. For each calibration, model parameters are adjusted until a minimum sum of squared deviations between predicted and measured outputs is obtained. Independently calibrated subroutines are then recombined and the Runoff Block is run in a continuous simulation mode, using hourly rainfall data as input, to estimate yearly pollutant loadings from storm water runoff in Greenfield, Mass. Pollutants considered are suspended solids, BOD5, total P, cadmium, lead and zinc.

JODIE, J.B. 1975: "Quality of urban free-way storm water". In, Water Quality, Conduits, and Geometrics. Transportation Research Record 556; pl-5.

Key words: urban runoff; surface runoff; water pollution; model studies; data collection; storm runoff.

The quality of storm water runoff from urban freeways was monitored during a year-long sampling and testing program in Milwaukee County, Wisconsin. Sodium chloride, calcium chloride, total solids, volatile total solids, suspended solids, volatile suspended solids, 5-day BOD, total nitrogen, pH, total phosphorus, ammonia, faecal coliforms, lead, dissolved oxygen, nitrates, and nitrites were measured for two storm water outfall locations. Analyses indicated that parameter concentrations were higher during the first hour of a rainstorm and tended to be very high during snowstorms. High salt concentrations were observed during winter and spring. No significant differences in storm water quality were observed between the two sampling stations. Total solids, suspended solids, and BOD were higher in storm water than in treatment plant effluent. Parameter concentrations for the Milwaukee study and for other cities are listed. Additional research into contamination by and treatment of urban runoff is suggested.

JOHN HOPKINS UNIVERSITY. various dates: "Progress report on the storm drainage research project". Dept. of Sanitary Engineering and Water Resources, The John Hopkins University, Baltimore, Md.

Key words: urban runoff; data collection; hydrologic data; storm runoff; instrumentation; analytical techniques.

This project represents the most extensive field measurement program of urban storm water runoff ever attempted in the U.S. Since 1948, peak flows in a large number of inlets and several main sewers draining areas up to 153 acres have been recorded simultaneously with concomitant storm rainfall. The primary objectives are: (1) development of the principles of hydraulic behaviour of storm water inlets, and the practical application of these principles to storm water inlet design practices; (2) development of instruments for measuring and recording rainfall and

storm runoff, and systematic collection of rainfall - runoff data; and (3) development of relationships between rainfall and runoff, and the application of these relationships to storm sewer design practice. The first phase was completed in 1956 with publication of the bulletin "The design of storm water inlets", the second phase in 1962 with publication of "instrumentation for measuring flows in storm water inlets" and phase 3 continues with "analysis of collected data and its relationship to the rational formula".

JOHNSON, C.J. 1966: "Urban sediment can be controlled". Proceedings, Interstate Commission on the Potomac River Basin, Washington, D.C.; 40pp.

Key words: sediment control.

JOHNSON, K.A. 1970: "An analysis of the effects of urbanisation on unit hydrograph characteristics, Antelope Creek basin - Lincoln, Nebraska". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.10; 19pp.

Key words: urban hydrology; hydrographs; rainfall-runoff relationships; storm runoff; urban runoff; peak discharge; flood forecasting.

Hydrologic design requirements and hydrologic effects of a small dam were calculated in the Antelope Creek basin, Lincoln, Nebr. The proposed dam was located in the upper portion of the basin to control runoff from a 5.4 square mile rural area. City planners forecast that the area above the dam would become a fully developed urban area. The results of this study were used in evaluating future flood probability conditions in the basin under the anticipated urban development with and without the dam in place. Unit graph characteristics were determined for the urban and rural portions of the basin. For the Antelope Creek area, the use of the generalised equations resulted in an increase in unit hydrograph peak discharge of 80 percent with the change from a rural area to one that is 60 percent impervious and fully sewered. The most important factor in determining the effects of urbanisation on peak discharges is an estimate of the sewer and channel improvement factor.

JOHNSON, S.L. 1967: "Urban hydrology of the Houston, Texas metropolitan area, compilation of basic data, 1967". U.S. Geol. Survey basic-data report; 251pp.

Key words: storm runoff; peak discharge; hydrologic data; rainfall-runoff relationships.

Basic data of the urban hydrology of Houston, Texas, October 1966 to September 1967, are compiled. Surface water records are from gauging stations, crest-stage partial-record stations, rain gauges, and miscellaneous

sites. Each gauging station record includes location, drainage area, gauge type and history, average discharge, extremes, remarks, daily discharge, total discharge, mean discharge, annual maximum and mean discharges, and peak discharges. Runoff and rainfall are computed for each drainage basin, and hydrographs and mass curves are drawn. A map of each basin shows locations of all gauges. The objectives are to provide basic runoff data for small urban drainage areas which differ in topography, soil, vegetation, tributaries, basin shape, and degree of urbanisation; to provide related rainfall data with consideration of variation in intensity and location; and to provide data showing the effects of progressive urbanisation on flood peaks and volume. Average rainfall in the Houston metropolitan area during the 1967 water year was 30.8 inches, or 15.2 inches below the 30 year (1931-60) average for the Houston airport station.

JOHNSON, S.L. 1968: "Urban hydrology, Houston metropolitan area, Texas, 1968". U.S. Geol. Survey basic-data report; 302pp.

Key words: rainfall-runoff relationships; storm runoff; hydrologic data.

Basic data of the urban hydrology of Houston, Texas, October 1967 to September 1968, are compiled. Surface water records are from gauging stations, crest-stage partial-record stations, rain gauges, and miscellaneous sites. Each gauging station record includes location, drainage area, gauge type and history, average discharge, extremes, remarks, daily discharge, total discharge, mean discharge, annual maximum and mean discharges, and peak discharges. Runoff and rainfall are computed for each drainage basin, and hydrographs and mass curves are drawn. A map of each basin shows locations of all gauges. The objectives are to provide basic runoff data for small urban drainage areas which differ in topography, soil, vegetation, tributaries, basin shape, and degree of urbanisation; to provide related rainfall data with consideration of variation in intensity and location; and to provide data showing the effects of progressive urbanisation on flood peaks and volume. Average rainfall over the Houston metropolitan area during the 1968 water year was 51 inches, or 5 inches greater than the 30 year (1931-60) average. Two area-wide storms and one localised storm of unusual magnitude occurred during the year.

JOHNSON, S.L. 1968: "Urban hydrology of the Houston, Texas metropolitan area, compilation of basic data, 1966". U.S. Geol. Survey duplicated basic-data report; 275pp.

Key words: data collection; urbanisation; hydrologic data; hydrographs.

Basic data of the urban hydrology of

Houston, Texas, 1965-1966, are compiled. Surface water records are from gauging stations, crest-stage partial-record stations, rain gauges, and miscellaneous sites. Each gauging station record includes location, drainage area, gauge type and history, average discharge, extremes, remarks, daily discharge, total discharge, mean discharges, and peak discharges. Runoff and rainfall are computed for each drainage basin and hydrographs and mass curves are drawn. A map of each basin shows locations of all gauges.

JOHNSON, S.L. 1971: "Annual compilation and analysis of hydrologic data for urban studies in the Houston, Texas metropolitan area, 1969". U.S. Geol. Survey report; 272pp.

Key words: hydrologic data; storm runoff; rainfall-runoff relationships; watershed management; streamflow; data collection; peak discharge; low flow; chemical analysis; sediment transport.

Hydrologic investigation of urban watersheds in Houston, Texas during the 1969 water year included data collections to determine the magnitude and frequency of flood peaks and flood volume, the effect of urban development on flood peaks and volume, and the variation in water quality during different flow conditions and different seasons. Runoff data are based on discharge measurements and stage records at 16 continuous-record stream-gauging stations, 16 partial-record stream-gauging stations and two reservoir-content stations. Annual records of daily discharges at continuous-record stream-gauging stations, maximum discharge at crest-stage partial-record stations, and daily contents of reservoirs are included. A comparison of runoff during the 1969 water year with the average runoff for the period of record is given. Water quality data were collected at 12 gauging stations in the Houston urban area. These gauging stations are located in watersheds in various stages of urban development.

JOHNSON, S.L. and SAYRE, D.M. 1973: "Effects of urbanisation on floods in the Houston, Texas metropolitan area". Illinois State Water Survey Lab., Urbana, Illinois, 61801; 56pp.

Key words: peak discharge; urbanisation; rainfall-runoff relationships; flood forecasting.

Rainfall and runoff data from drainage basins in the Houston metropolitan area and a 60 year rainfall record for the National Weather Service station, Houston City, were used to simulate 60 annual flood peaks at 26 sites. Selected frequency characteristics, based on these simulated annual peaks, are related to drainage area and percentage of impervious area. These relations, which may be used to estimate the flood characteristics at ungauged sites, indicate that in the Houston metropolitan area, complete urbanisation increases

the magnitude of a 2-year flood nine times and increases the magnitude of a 50-year flood five times.

JOHNSTON, W.R. et al. 1965: "Nitrogen and phosphorus in the drainage effluent". Proc. Soil Science Soc. Am., Vol.29; p287-289.

Key words: nitrogen compounds; phosphorus compounds; agricultural pollution.

Tile drainage effluent from systems on irrigated land in the San Joaquin Valley of California was analysed for nitrogen and phosphorus and the quantity of each element found was correlated with the quantity of N and P applied for four different cropping patterns. Large percentages of applied N were found to be lost in tile drainage effluent. Phosphorus losses were not significant.

JONES, B.L. et al. 1971: "Reconnaissance study of sediment transported by streams, Island of Oahu". U.S. Geol. Survey, Hawaii Division of Water and Land Development, Circular No.C33; 45pp.

Key words: sediment yield; erosion; urban hydrology; urbanisation; storm runoff; data collection; sediment transport; suspended solids.

Data collected during the first three years of a sediment measuring program were used to compute sediment yields for seven drainage basins draining the Koolau Range and central part of the island of Oahu, Hawaii. Sediment yields range from 785 to 2,200 tons per square mile annually, suspended sediment yields range from 630 to 1,400 tons per square mile, and bedload from 75 to 900 tons per square mile. Estimated mean annual discharge of sediment to Kaneohe Bay is about 37,000 tons, consisting of 19,000 tons of clay, 15,000 tons of silt, and 3,000 tons of sand, representing a deposited volume of 31 to 52 acre-feet annually. Although the investigation was island wide, most of the data collected were from streams draining the central and southern Koolau Range - the part of the island undergoing the most intensive urban development. During urbanisation, erosion and sediment transport rates are altered greatly. Construction exposes large areas of soil. Compaction of soil by heavy equipment reduces infiltration, increasing surface runoff and erosion, and the landscaping process may change slope and stream channel dimensions. Similar effects result from other urbanising processes, such as road building, drainage alterations, and paving of parking areas.

JONES, D.E. 1967: "Urban hydrology - a re-direction". Civil Engineering, ASCE, Vol.37(8); p58-62.

Key words: storm runoff; urban drainage.

Inaccuracies of present hydrology methods are outlined. An improvement is suggested wherein the fact that cities have two separate and distinct storm water drainage systems, a "minor" and a "major" system would be recognised. The minor system consists of carefully designed closed and open conduits and their appurtenances. The major system is the route followed by flood or runoff waters when the minor system is inoperable or inadequate. Cities today are overdesigning the minor systems. A reasonable design would provide that ordinary vehicular access to properties be impaired no more often than once in 2-10 years. Wiser use of natural land conditions when developing the land can obviate extensive storm sewer construction. Examples are given of some methods for this wiser use, e.g. "blue-green" land development employing ponds with open space for storm-flow detention.

JONES, D.E. 1970: "Some urban water resources management dimensions". In, Urban Water Resources Management, 3rd Conference on urban water resources research, Deerfield, Mass.; p14-31.

Key words: flood control; urban runoff.

A number of suggestions for improved urban water resources management are outlined. (1) The scope of urban and regional planning practice must be broadened to interrelate urban and natural resources planning and water resource development options. (2) Reorganisation of traditional urban water resource management is necessary. (3) Enhancement of property values and environment by optimum development of land and water resources can produce significant economic benefits. (4) Development of open spaces with ponds is consistent with enhancement objectives. (5) The adoption of the dual drainage system concept by a community can produce significant drainage construction savings, better drainage service for the populace and reduced future need for flood control expenditures. (6) Optimum water resources management will recognise benefits to both upstream and downstream lands. (7) Urban runoff management can provide benefits, especially by downstream flood peak attenuation. (8) Street layout and grade designs can be used to route urban runoff. (9) Flood proofing offers some new dimensions for floodless limitation. (10) The exposure of building sites to a uniform probability of flooding risk will not assure uniformity of relative flooding losses. (11) The economic, ecologic and social wisdom of occupying flood prone sites must be considered in establishing land use controls. (12) Municipal codes have a significant potential for reducing flooding losses in occupied flood prone areas. (13) Emphasis should continue upon definition of interrelationships between man and his water resources. (14) Today's suburb is tomorrow's city.

JONES, D.E. 1971: "Where is urban hydrolo-

gy practice today"? J. Hydraul. Divn., Proc. ASCE, Vol.97(HY2); p265-288.

Key words: landuse change; urban drainage; flood forecasting; mathematical models.

The evolution of urban street construction and its effects upon urban drainage is traced. Rational method development and inconsistencies in its application are summarised. The emphasis is on lack of absolute precipitation data with resultant inhibiting effects upon development of improved runoff prediction methods. Need for two drainage systems on each urban drainage area is defined. It indicates dual system dividends are reduced drainage costs, reduced flooding losses, and the opportunity to enhance property values, stabilise neighbourhoods, and improve urban life quality. Some basic methods for managing urban runoff are also indicated to attenuate peak flows. A low maintenance channel is identified as being more realistic than usual urban channel designs. It points out that direct losses from and expenditures for urban drainage approximate four billion dollars per year. The nation could realise disproportionately great returns from urban hydrology research. The question is, 'does the nation think it necessary'?

JONES, S.E. 1970: "Tulsa District method of urban hydrology". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.5; 13pp.

Key words: urban hydrology; hydrographs; rainfall-runoff relationships; storm runoff; urban runoff; peak discharge; flood forecasting.

In recent years the increase in urban development has been tremendous. This urban growth replaces forests and fields with paved areas and structures of residential, commercial, and industrial development. Under these circumstances the design of flood control projects by the Corps of Engineers must take into account the effects of this urban development on storm runoff rates. This is particularly true when Floodplain Information and Local Protection Studies are requested for small drainage areas which are or will be largely overbuilt by urban development. The method used by the Tulsa District Corps of Engineers to determine the effects urbanisation has on small areas, with respect to surface runoff is presented. Where recorded hydrographs are not available to permit derivation of unit hydrographs, the synthetic unit hydrograph is usually selected.

JUDD, J.H. 1970: "Lake stratification caused by runoff from street deicing". Water Research, Vol.4(8); p521-532.

Key words: lakes; salinity; snowmelt; surface runoff.

Salt is used for street deicing throughout most of the northern United

States. Much of the salt is dissolved in the melt water and flows into surrounding surface water. Salt entering First Sister Lake, Michigan, increased the density of the water in the lower lake strata. During 2 of the 3 yrs studied, the increased density prevented complete spring overturn. This can be considered a temporary monomixis. The stability of stratification of the lake was computed. Stability was from 3.5 to 8.5 times greater than when no complete overturn occurred at other times. The lake mixed completely each fall. Laboratory and field tests indicate that salt left the lake and apparently entered the ground water of the area. Dichtothermic conditions were found in the lake. Density determinations indicated that this was an unstable condition, probably of short duration.

KADOYA, M. 1973: "Predictive study on urbanising effect of drainage basin on flood runoff". In, Floods and droughts, (ed. E.F. Schulz, et al.), Water Resources Publications, State University of Colorado, Fort Collins; p436-449.

Key words: flood discharge; flood forecasting; computer models; hydrographs.

A study was undertaken to develop a suitable method for predicting the effect of urbanisation on flood runoff. A method was developed from the point of view that removing the pervious ground surface layer and replacing with pavement causes the decrease of ground water and interflow components, and that pavement and channelising of the ground surface change the roughness to accelerate and concentrate the overland flow. In applying this idea, three conceptual models are introduced. These are the kinematic wave model for overland flow and/or direct runoff, the interflow model for the flow in porous surface stratum and the recharge capacity model for ground water runoff. The Shimokari River basin (1.32 square km area) has been chosen as an objective research basin to examine the usefulness of the method. After simulating hydrographs under present conditions, the effect of urbanisation on flood runoff is discussed predictively using two methods, one of which is based on the kinematic wave model for analysing direct runoff, and the other one is the combination of the three models mentioned above. A simple method is also discussed for estimating maximum peak runoff. The method is based mainly on the estimation of the concentration time of flood runoff. Estimation of the precise effect of watershed changes on the runoff characteristics is very difficult. It seems, however, that the method proposed here is useful for predicting the effect and gives a clue for further study for the problem of floods from urban watersheds.

KAHANOVITCH, Y. and LAHAV, N. A. 1974: "Occurrence of pesticides in selected water sources in Israel". Environmental Science and Technology, Vol.8(8); p762-765.

Key words: organic compounds; pesticides; water pollution sources.

The concentration of 12 organic pesticides were determined in selected water samples in Israel during 1972-73. Where pesticides were identified, their concentrations were much lower than the permitted levels; in the great majority of the water samples studied, the pesticidal concentrations were in the order of a few nanograms per litre. The only samples that did not contain pesticides were from the Dan River and drainage water from agricultural fields. The most widespread compounds in the water samples under study were gamma-BHC and alpha-BHC. The greatest concentrations of gamma-BHC in municipal sewage indicate that this is an important source of BHC in the water bodies under study. The relatively low

and constant pesticide levels in Lake Kinneret and the other water reservoirs probably result from the buffering action of the bottom sediment.

KAO, D.T.Y. 1976: "Mini-course 2: hydraulics of urban drainage systems". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p333-347.

Key words: urban drainage; analytical techniques.

An overview of hydraulic systems for drainage of runoff water in urban areas is presented in this paper. Analyses which lead to various designs of major hydraulic components involved in urban drainage systems are also discussed with the emphasis being placed upon the basic understanding of the nature of the physical system and the characteristics of the flow behaviour. For specific applications, sources of information are provided as future references rather than duplicating numerous design tables and charts.

KAO, S.E. et al. 1973: "Effect of urbanisation on runoff from small watersheds". In, Hydrology and Water Resources in Arizona and the SW. Proc. of the 1973 meetings of the Arizona Section AWRA and the Hydrology Section, Arizona Academy of Science, Tucson, Arizona; p86-91.

Key words: urbanisation; urban runoff; rainfall-runoff relationships.

Hydrologic data obtained from three urban and one rural experimental watersheds were analysed to determine urbanisation effects on runoff. A Soil Conservation Service procedure was used to explain the relationship between rainfall amounts and runoff. A runoff curve number obtained indicated that convective storm rainfall can be related to the runoff volume from small, semiarid watersheds. A linear relationship existed between runoff volume and its corresponding peak discharge rate. Urban watersheds with a high percentage of impervious areas may not necessarily produce high peak rates for a given volume of runoff. Results show that the SCS method of relating runoff volume to rainfall is sufficiently sensitive to determine the effect of urbanisation on the volume of runoff.

KARUBIAN, J.F. 1974: "Polluted ground water: estimating the effects of man's activities". General Electric Co., Tempo, Centre for Advanced Studies, Santa Barbara, Ca. EPA, Environmental Monitoring Services. EPA-680/4-74-002; 136pp.

Key words: ground water resources; aquifers; water pollution sources.

Actual and potential ground water pollution in the U.S.A. was estimated by analysing man's activities, exemplified by pulp and paper manufacture, petrole-

um refining, steel manufacture, phosphate mining, agriculture fertiliser consumption, and beef cattle feedlots, as an alternative approach to direct sampling of ground water to monitor its quality. Estimates are based on economic growth and technological change, and hydrological analysis is used to derive the actual pollution which might be caused by these potential pollutants. The report includes statistical information and a bibliography of 29 references.

KAUFMAN, H.L. and LAI, F.H. 1976: "Joint use of SWMM and STORM models for planning urban sewer systems". In, Proceedings of the conference on environmental modeling and simulation, Cincinnati, Ohio. Report EPA 600/9-76-016; p144-150.

Key words: computer models; flood control; hydrographs; pollution abatement.

The joint use of the SWMM and STORM simulation models has been demonstrated to provide a tool for sewer system planning which effectively alleviates urban flooding and prevents pollution in the receiving waters. Techniques were developed for projection of runoff characteristics from one drainage district to others for citywide sewer planning. A concept making use of the characteristics of runoff quantity and quality and interceptor capacity for cost-effective pollution control is described. The pollutants discharged to receiving waters for various interceptor capacities have been comparatively quantified.

KAUFMANN, P. and RHAM, C.DE. 1976: "Design of large urban sewer systems with a water flow simulation program". In, Mathematical models for environmental problems. Proc. Internat. Conference, Southampton, (ed. C.A. Brebbia), Pentech Press, London; p79-86.

Key words: mathematical models; hydrographs; flood forecasting; flood routing.

The authors built a simulation model to calculate the hydrographs at every node of large sewer networks. The program (Fortran) includes elements like storm water tanks, outflow sewers, storage sewers and downward ramifications.

KAWASHIMA, T. et al. 1970: "A preliminary analysis of the effects of urbanisation on water quality". Regional Science Research Institute, Philadelphia, Pa., working paper; 44pp.

Key words: urbanisation; water pollution sources; miscellaneous chemicals.

The hydrologic effects of urbanisation were studied in the Philadelphia metropolitan area. Land uses, in combination with topographic and other natural features, affect water quality characteristics, streamflow regimen, and

channel morphology. Approximately 80 watersheds, 1 to 6 miles in area, were sampled. These watersheds vary in development from completely rural to completely urbanised. Samples were taken to represent water quality conditions at base flow. Variance in the categorisation by industrial density is unlike the variance in categorisation by residential density. For the industrial density, the null hypothesis of equality of mean concentrations for the high, medium and low densities was rejected at the 1 percent level of significance for 10 of the 21 chemicals and at the 5 percent level of significance for four additional chemicals. On the other hand, for the categorisation by residential density, the null hypothesis was rejected at the 5 percent level for only one chemical, silicon dioxide.

KEERS, J.F. 1977: "Rainfall criteria for urban drainage design". Meteorological Magazine, Vol.106(1257); p117-126.

Key words: model studies; urban drainage; rainfall-runoff relationships.

An appraisal is made of those aspects of rainfall which are important for the economic design of urban storm water drainage systems. These include the mean rainfall intensity for specified durations, the average frequency of occurrence and regional variability of heavy local falls, the relationships between rainfall intensity and time (storm profiles) and between rainfall at a point and over an area. Also discussed are other aspects of rainfall which may be important as input to models of more advanced design including statistics describing the movement of extreme rainstorms, for example once-in-two-year storms, across the catchment.

KEIFER, C.J. 1961: "Analysis of the urban runoff hydrograph". Paper presented at ASCE Hydraulics Conference, University of Illinois, Urbana, Illinois, August, 1961.

Key words: hydrographs; analytical techniques.

This paper is in part a simplification of the "Chicago Hydrograph Method" of sewer design. Runoff hydrographs calculated by the simplified method are compared with recorded hydrographs. Variations in the hydrograph are created by changing coefficients of rainfall, infiltration, depression storage, overland flow, and gutter flow.

KELLER, F.J. 1962: "Effect of urban growth on sediment discharge, N.W. Branch Anacostia River basin, Maryland". U.S. Geol. Survey prof. paper No.450-C; p129-131.

Key words: landuse change; sediment yield; erosion.

During the transition period from rural to urban land, erosion of denuded areas increases the sediment discharged by

the receiving streams. With all other factors remaining constant, sediment discharge will change with changes in land use. Land with good vegetal cover is less subject to soil erosion than land that is denuded for agricultural crops and urban development. A recent investigation provided an opportunity to measure, in a limited way, the effect of urban growth on sediment discharge.

KELLING, K.A. and PETERSON, A.E. 1975: "Urban lawn infiltration rates and fertiliser runoff losses under simulated rainfall". Proc. Soil Science Soc. of America, Vol.39(2); p348-352.

Key words: urban runoff; water pollution sources; nutrients; storm runoff; rainfall-runoff relationships; eutrophication.

Infiltration runoff measurements were made on nine urban lawns by using a sprinkling infiltrometer in conjunction with the application of a complete fertiliser at three rates. The amounts of inorganic N, P, and K removed with the runoff water were determined. Results of the infiltration measurements show that the presence of textural and compaction discontinuities within the soil profile, formed during building and lawn construction, was probably the greatest factor affecting infiltration. Where these discontinuities were distinct, water intake was reduced to about 35 percent of that for a lawn with an undisturbed profile. For lawns with similar infiltration characteristics, a first order relationship appeared to exist between amounts of fertiliser applied and amounts lost. A second order equation, however, best described the relationship between percent of applied fertiliser in the runoff and 90-min. cumulative infiltration. When the simulated storm was applied immediately after fertiliser application, fertiliser losses averaged 10.6 percent; however, when fertiliser application was followed by recommended watering before the intense storm, average losses were reduced to 1.7 percent of the amount applied.

KEMP, H.T. et al. 1973: "Water quality criteria data book, Vol.5. Effects of chemicals on aquatic life. Compilation from the literature dated 1968-1972". Office of Research and Development, U.S. EPA, Washington, D.C. 20460.

Key words: chemical wastes; environmental effects; miscellaneous chemicals; toxicity.

This report is an extensive compilation of data on the effects of chemicals on aquatic life which were extracted from literature published during the period 1968-1972. It is an update of an earlier report entitled "Water quality criteria data book, Volume 3, effects of chemicals on aquatic life" (Kemp, et al, 1971). The data are arranged alphabetically by chemical and are concisely presented in a columnar format which includes organism names, type of study, chemical effect, controlled par-

ameters, significant comments on the test, and source of the data. The data were compiled using a program prepared as part of the work.

KEMPEN, H.M.A. and TON, H. 1977: "The effects of an urban area on the water management of a rural area". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p59-62.

Key words: model studies; waste storage; storm runoff.

The discharge of a rural drainage system resulting from rainfall in built-up areas has been simulated by models of non-stationary flow. The results show that when floods are likely to occur in an existing system, the widening of the drainage channel along a few hundred metres is all that is required. This solution is much less drastic and much cheaper than the construction of storage ponds. The foundations of many buildings are on wooden piles, and it is essential that these piles stay below ground water level. In projects for rural development the water table is often lowered putting the foundations of existing buildings at risk. It is possible to remedy this by local injections of water to maintain the water level of the foundations. If the buildings are sufficiently far from the drainage channels additional measures are not necessary.

KENTUCKY UNIVERSITY. 1972: "Proceedings urban rainfall management problems (runoff, sediment, sanitary landfill)". Two-day short course on meteorology for scientists and engineers, Kentucky University, Lexington, Ky.; 176pp.

Key words: surface runoff; erosion; leachate; aquifers.

Rainfall as an important part of our environment affects our everyday life and our planning for the future. The papers included in this proceedings provide a review of the fundamentals of rainfall, runoff, erosion, and movement through soils with specific applications, the problem of managing this rainfall in urban areas and sanitary landfills. Seven papers deal specifically with sanitary landfills and discuss such topics as: potential effects on water quality, principles of water movement in sanitary landfills, pollution attenuation by soils, legal requirements for a sanitary landfill, a summary of sanitary landfill methods, technical assistance and sanitary landfills, and a case study of the Boone County field site sanitary landfill as monitored by the Environmental Protection Agency.

KENTUCKY UNIVERSITY. 1973: "Proceedings: planning and design for urban runoff and sediment management". Two-day short course, University of Kentucky, Lexington, (eds. C.T. Haan; B.J. Barfield), UKY-TR72-73-CEEDS; 29pp.

Key words: sediment control; channel erosion; urbanisation; surface runoff.

The development of agricultural, forest, or idle land for urban needs greatly increases quantities of runoff and frequency of flooding. These increased runoff flows exceed the capacity of existing channels not only to carry the water, but to resist the corrosive power of the water, resulting in stream channel erosion. During the construction phase of development, the sediment production from an area can increase by more than 100 percent. The five papers contained in this proceedings discuss available techniques for reducing these problems, including the utility of impact zoning, HUD runoff and sediment management control guidelines, basic storm drainage system design, urban storm runoff controls, and sediment control principles and methods. The papers are all directed toward preventative methods of urban runoff and sedimentation in areas undergoing development, rather than corrective procedures for already urbanised areas.

KENTUCKY UNIVERSITY. 1974: "National symposium on urban rainfall and runoff and sediment control". Proceedings Symposium held at the College of Engineering, University of Kentucky, Lexington, Ky.; 246pp.

Key words: urbanisation; storm runoff; erosion control; sediment control; erosion; urban runoff; combined sewers.

The papers of this symposium covered a variety of problems arising from runoff changes due to urbanisation. One paper reported the distribution of heavy rainfall in a major urban area, and suggested that the urban area may have an effect on the distribution. Other papers covered ways to control increased runoff due to urbanisation. Drainage systems, detention basins, and flooding were discussed. Means of controlling the increased erosion and sedimentation were described. Construction was shown to be one of the most important causes of increased erosion. The problems of separated and combined sewers were discussed.

KIBLER, D.F. 1974: "Hydrological effects of urbanisation and the factors controlling urban runoff". In, Management of urban storm runoff, Section 3. Prepared for Office of Water Resources Research; p3-1-3-17. (NTIS PB-234 316).

Key words: urbanisation; weather modification; urban runoff; landuse change.

The term 'urbanisation' refers generally to a condition in which a natural watershed has been developed for residential, commercial, and industrial purposes. The principal hydrological factor associated with urbanisation is an increase in imperviousness of the watershed surface with attendant reductions in infiltration and other ab-

stractions from storm rainfall. A summary of potential hydrological effects of urbanisation is presented. In addition to major changes in hydrology, there is evidence indicating that certain changes in the microclimate of an urban area can be expected. While urbanisation always increases the imperviousness of a natural watershed, the hydrological significance of this change is not always clearly evident in contrast to the postulated effects. For example, increases in the total runoff and peak flow may be offset by the use of building practices which provide for detention near the site where it occurs of rainfall excess on flat roofs or in small depressions or ponds. Another factor to be considered is the manner by which collected rainfall is discharged from roof tops. Other factors to be considered in analysing runoff from impervious areas are: the location of an impervious area with respect to the total watershed; and the proximity and geometry of the street gutter and underground drainage system.

KIBLER, D.F. and ROESNER, L.A. 1975: "The storm water model for computer simulation of urban runoff quantity and quality in a combined sewer system". Water Resources Engineers, Walnut Creek, California.

Key words: computer models.

KIDD, C.H.R. 1975: "A non-linear model of urban catchment response". Unpublished Ph.D. Thesis, Dept. of Civil Engineering, University of Southampton.

Key words: surface runoff; computer models.

KIDD, C.H.R. 1976: "A non-linear urban runoff model". U.K. Institute of Hydrology, NERC Report No.31; 64pp.

Key words: surface runoff; mathematical models; model studies; computer models.

The purpose of this study is to investigate the above ground phase of the urban runoff process, and a lumped-parameter non-linear model is postulated for its simulation, in addition to two simpler models (linear and time of entry) for the purposes of comparison. Two models of differing complexity for the simulation of the below ground phase are also postulated. The models are tested on two small catchments (0.6 and 0.8 ha) in the Lordshill area of Southampton. The non-linear surface routing submodel provides a better synthesis of the above ground phenomena than the linear time of entry submodels.

KING, M.V. 1967: "Storm runoff from urban areas". Proc. Inst. Civil Engineers, Vol.37; p43-56.

Key words: storm runoff;

rainfall-runoff relationships; hydrographs; urban drainage; peak discharge.

The author describes the development of a mathematical relation between rainfall and runoff in urban areas, taking into account various calculable characteristics of a drainage area and the retention action of a sewerage system as used in the Road Research Laboratory hydrographic method. It is shown that the peak flow for any particular frequency of storm depends on the time of concentration, the effective impervious area, and the total volume of water in the sewerage system at the time of peak runoff; only the last of these is difficult to determine, and for very large areas it is considered adequate to use an approximation. Having determined the retention constant for a drainage system under particular conditions, it is also possible to draw the complete runoff hydrograph. This method may be used in designing large sewers, but is not considered suitable for small ones.

KINOSITA, T. and SONDA, T. 1969: "Change in runoff due to urbanisation". In, Floods and their computation, IAHS Publication No.85, Vol.2, UNESCO; p787-796.

Key words: mathematical models; rainfall-runoff relationships.

The Public Works Research Institute of Japan set up a hydrological network on the Syakuzii River basin in the suburbs of Tokyo to determine changes of runoff due to urbanisation. This basin is composed of floodplain deposits, and its area is 48 square kilometres. Increase of total flood volume, increase of peak discharge, and decrease of travel time are caused by decrease of infiltration area, decrease of roughness of the ground surface, and decrease of inundation area due to urbanisation. Floods in 1966 were computed using a storage-runoff relation which uses data on drainage channels and the rate of infiltration. As the computation agreed well with observation, floods were estimated for the case of complete urbanisation.

KINOSITA, T. and YAMAZAKI, Y. 1974: "Increase of sediment transport due to large-scale urbanisation". In, Effects of man on the interface of the hydrological cycle with the physical environment, IAHS Publication No.113, UNESCO; p127-129.

Key words: urbanisation; sediment yield.

New towns are now under development in the suburbs of Tokyo. Sediment transport due to large scale urbanisation was measured in the flood storage ponds during the period of land development. Some data are given in this report for the design of drainage systems.

KIRSHEN, P.H. et al. 1972: "Mathematical model for screening storm water control

alternatives". Massachusetts Institute of Technology, Cambridge, Ralph M. Parsons Lab. for Water Resources and Hydrodynamics, Report No.167, R72-71; 126pp.

Key words: overflows; water pollution; combined sewers; mathematical models; sewage treatment; flood control.

The general problem of pollution from combined sewer systems is discussed and control alternatives are described. A linear programming model for screening the sizes and operating policies of storage tanks, pipes and treatment plants is formulated. The report also discusses a storm water simulation model and shows how it can be used interactively with the screening model to plan for the control of combined sewer overflow and local flooding in the Bloody Run drainage basin, Cincinnati, Ohio. The results of this case study indicate that the screening model and the planning method are reliable.

KISIEL, C.C. and DUCKSTEIN, L. 1969: "Operations research study of water resources in an urbanised arid environment". International Conference on Arid Lands in a Changing World, Arizona University, Tucson, June, 1969; 24pp.

Key words: watershed management; flood forecasting.

This paper briefly reviews the philosophy of systems analysis or operations research, presents a progress report on application of this methodology to water resources development and management in the Tucson basin, Arizona, and presents a strategy for a study of the efficiency of data collection systems. Emphasis is on an integrated systems approach with the Tucson area as a field laboratory for improvement of methodology. Details of the basin's water problems include economic growth, mining industry, agriculture and the municipal sector. Digital computer models of the physical system consider transferability of point precipitation data, time series analysis of actual stream flows and variability of natural recharge. Two different management approach models are examined for community water supply, (a) to meet projected requirements at minimum costs, (b) to maximise net benefits accruing from water use. Efficiency of data collecting systems are evaluated in terms of economic efficiency, information content and worth in terms of management schemes. The objectives of ground water management models for the Tucson basin are enumerated.

KLEIN, C.L. 1970: "Sediment pollution and water quality standards". Proc. National Conference on Sediment Control, Washington, D.C., September, 1969. U.S. Dept. Housing and Urban Development; p26-30.

Key words: water pollution control; erosion; urban runoff.

The report summarises, for the USA, aspects of urban soil erosion and control, and activities of the Federal Water Pollution Control Administration (FWPCA) in urban runoff quality.

KLEIN, D.H. 1972: "Mercury and other metals in urban soils". Environmental Science and Technology, Vol.6(6); p560-562.

Key words: mercury; metals; heavy metals; point sources (pollution).

A suite of 264 surface soil samples, selected from a 300 sq mile region which includes industrial, agricultural, and residential areas, has been analysed for mercury and Ag, Ca, Cd, Co, Cr, Cu, Fe, Ni, Pb, and Zn. All these metals are more concentrated in industrial areas than in residential and agricultural areas. All except lead are more concentrated around the airport. An asphalt plant appears to act as a point of mercury discharge.

KLEIN, L.A. et al. 1974: "Sources of metals in New York City waste water". J. Water Pollution Control Federation, Vol.46(12); p2653-2662.

Key words: metals; heavy metals; miscellaneous chemicals; industrial wastes; zinc; waste water treatment.

Sampling of New York City treatment plant influents revealed that far greater amounts of metals were being received than could be accounted for by the known discharges from metal-finishing firms. Sampling of purely residential wastes at pumping stations, of industrial wastes other than those from electroplaters, and of storm water runoff were then conducted. It was found that the nonindustrial sources, including the potable water supply, are more significant than the metal-finishing industry, and they are presently beyond control. Concentrations of metals in treatment plant effluents and sludges and in the waters of New York harbour also were determined.

KLEUSENER, J.W. 1972: "Nutrient transport and transformations in Lake Wingra". Ph.D. Thesis, water chemistry program, University of Wisconsin, Madison.

Key words: lakes; nutrients.

KLEUSENER, J.W. and LEE, G.F. 1974: "Nutrient loading from a separate storm sewer in Madison, Wisconsin". J. Water Pollution Control Federation, Vol.46(5); p920-936.

Key words: nutrients; storm runoff; suspended solids; ammonia; nitrogen compounds; phosphorus compounds; organic compounds.

Storm water runoff from a residential basin in Madison, Wisconsin, was monitored for flow and nutrient and sus-

pending solids loading from September 1970 through July 1971. Runoff samples were collected at 5 or 10 minute intervals throughout the runoff cycle. Regression analyses for the rainfall-runoff data from 35 storms indicated a nearly linear relationship between rainfall and runoff. Approximately 16 percent of the rainfall on the 123 acre basin appeared as surface runoff. This correlated closely with the area of the basin covered by streets. Ammonia nitrogen, nitrate nitrogen, and dissolved phosphorus were relatively constant throughout the runoff cycles, averaging 0.4, 0.6, and 0.6 mg/l, respectively. Organic nitrogen, total phosphorus and suspended solids concentrations were usually 3 to 10 times higher than the average concentration during the "first flush" of the basin. Annual average concentrations of organic nitrogen and total phosphorus were 3.5 and 1.0 mg/l, respectively.

KLOCK, J.W. no date: "Bacterial quality of irrigation canal waters in the agricultural-urban complex of the Salt River valley, Arizona". College of Engineering, Arizona State University, Tempe. Engineering Research Centre Publication; 34pp.

Key words: urbanisation; bacteria; storm runoff; water pollution control.

The Salt River Project derives surface water from a 13,000 square mile drainage basin and delivers it through a series of six dams on the Salt and Verde Rivers to the SRP Service Area of 250,000 acres. Recent population growth has transformed the Salt River Valley from a basically agricultural community with scattered small towns to a series of large urban centres. 30 water sampling locations were used to obtain samples of water for analysis to determine what recent changes in water quality have occurred. Attempts were then made to correlate the microbial concentrations existing at various points along the arterial canals with associated physical factors believed to be of significance. Tests showed that water from the SRP watershed at the Verde Water Treatment Plant was essentially unchanged in 18 years as measured by the coliform group analyses. Water reaching the Squaw Creek Treatment Plant via the Arizona Canal was of degraded quality, seemingly due to increased recreational uses and urbanisation. Agricultural return flow and street runoff appear to be significant factors in increased levels of coliforms and faecal streptococci organisms.

KLOET, P.VAN DER. et al. 1977: "Calculation of instantaneous unit hydrographs in an urban area". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p124-143.

Key words: hydrographs; rainfall-runoff relationships; mathematical models.

This paper deals with a parameter identification problem for the rainfall-runoff relationship in an urban area. Unit hydrographs have been calculated for areas with different percentages of impervious cover with the aid of measured rainfall and runoff. Two case studies are reported here, one a sewer district in Enschede with low quality data and the other some specially equipped catchment areas with high quality data in Lelystad, a new town in one of the IJsselmeer polders. These catchment areas include a parking lot, a residential quarter and a shopping centre. In the case study of a sewer district in Enschede one method was applied, based on Laguerre functions, to calculate unit hydrographs. Four methods were used in the second case study and the provisional results were compared. As a first method the Nash cascade was chosen as a model for the rainfall-runoff relationship. The parameters n and k were calculated by moments. Next some exercises were made with the Fourier transform method. The Nash cascade can be expanded with Laguerre functions. The last method concerns quadratic programming, which minimises the differences between computed and recorded runoff in the sense of least squares. Besides the influence of the distribution of the losses on the unit hydrograph, the different unit hydrographs have been illustrated for the catchment areas. Finally, as the last stage of modeling, a start has been made validating the identification methods by the calculation of correlation coefficients.

KNAPP, J.W. et al. 1963: "Measuring rainfall and runoff at storm water inlets". J. Hydraul. Divn., Proc. ASCE, Vol.89(HY5); p99-115.

Key words: instrumentation; urban drainage; storm runoff.

An instrument system was developed to measure rainfall and runoff in small urban drainage areas draining to storm water inlets. The system includes a rain gauge on each area, a measuring device inside the inlets, a recorder, and control providing automatic operation during storms. The installation can be completed with few alterations to existing drainage facilities.

KNAPP, G.L. and GLASBY, J.P. 1972: "Urban Hydrology - a selected bibliography with abstracts". Water Resources Investigation 3-72, U.S. Geol. Survey, Washington, D.C.; 216pp.

Key words: bibliographies; abstracts; urban hydrology; urban runoff; rainfall-runoff relationships; storm runoff; water pollution sources; urbanisation; urban drainage.

This bibliography of 650 selected references on urban hydrology is intended as a source document for scientific and water management needs. It was stimulated by increasing interest in the problems of runoff and water quality caused by increasing urbanisation. The bibliography brings together

abstracts with citations that pertain to the rainfall-runoff process, urban ground water problems, urban water pollution sources, urban climatic changes, and urban runoff modeling. Emphasis is given to technical advances of the past ten years as well as to needs for new research. This bibliography is arranged alphabetically by author and has separate geographic and subject indexes. Each abstract is followed by several added key words to relate it to other similar references.

KNAUER, D.R. 1975: "The effect of urban runoff on phytoplankton ecology". Verhandlungen International Verein Limnologie, Vol.19; p893-903.

Key words: phosphorus compounds; nitrogen compounds; nutrients; surface runoff; urban runoff; urban drainage.

Sewage treatment plants are considered to be a primary point for control of input of nutrients into lakes while little emphasis has been placed on storm water discharges via storm sewers. The physiochemical and biological changes in a lake as the result of nutrient loading via urban runoff are examined. Data collected from Mirror Lake, Wisconsin, showed that it received approximately 50 percent of its annual P loading from urban runoff. Only 28 percent of water flow to the lake came from this source. Phytoplankton productivity and biomass measurements responded to nutrient inputs. Estimated productivities increased during times of low nutrient input to higher levels during times of high nutrient input. A biomass increase of 5.5 mm³/litre was observed following the increased nutrient loading during August and September.

KNIGHT, A.L. 1976: "Urbanisation and flooding in Shades Creek basin, Jefferson County, Alabama". Alabama Geol. Survey, University, Information Series 55; 73pp.

Key words: flood control; urbanisation; flood forecasting; computer models; storm runoff; surface runoff; watershed management.

The magnitude of the 25-, 50-, 100-, and 500-year floods for drainage basins having various degrees of urban development in Jefferson County, Alabama may be estimated from graphical and mathematical relations. The basic equations utilise the relations among drainage area, lag time, a length-slope parameter, and percent imperviousness for a particular drainage basin. The relations presented in this report, and the U.S. Geological Survey step-backwater computer program, were used to compute water surface profiles along Shades Creek. Flood profiles and maps were determined on the basis of main channel conditions as surveyed prior to December 1973 but assuming complete urbanisation within the remaining part of the drainage basin. A completely urbanised area is defined as an area where curbing, guttering, and storm

sewers are complete and where more than 45 percent of the watershed has impervious cover.

KNOLL, C.G. 1969: "Preliminary determinations of sediment discharge in San Juan drainage basin, Orange and Riverside Counties, California". U.S. Geol. Survey open-file report; 28pp.

Key words: sediment yield; suspended solids.

During the 1967 and 1968 water years, the mean daily suspended sediment discharges at the gauging stations on San Juan Creek and its major tributary, Arroyo Trabuco, near San Juan Capistrano, California, were 266 tons and 124 tons, respectively. Extrapolated over the 38 years of water discharge record, 1931-68, the mean daily suspended sediment discharge at the gauging stations was 124 tons at San Juan Creek and 44 tons at Arroyo Trabuco. The mean daily coarse sediment discharge at the mouth had a mean daily value of 230 tons. Because of urbanisation, the mean daily coarse sediment discharge at the beach will be reduced by about 33 percent during the next 30 years; and, depending upon the water management practices, the reduction may be even greater.

KNOTT, J.M. 1973: "Effects of urbanisation on sedimentation and flood flows in Colma Creek basin, California". U.S. Geol. Survey open-file report; 54pp.

Key words: sediment transport; landuse change; urbanisation; sediment yield; hydrologic data; data collection; suspended solids; environmental effects; rainfall-runoff relationships.

Some of the changes are described in water and sediment discharge that occurred in the Colma Creek basin in California during a period of major urban expansion. Hydrologic data collected from 1964 to 1971 were used to evaluate trends and relations between sediment yield and land use. Total sediment yield upstream from the Colma Creek gauging stations ranged from 3,400 to 14,000 tons per square mile during 1966-70. Sediment discharge rates of Spruce Branch at South San Francisco were relatively stable in 1966-70, but increased sharply in 1968 and 1969 owing to increased construction activity and to sediment losses from a debris basin which was breached several times during large storms. Annual suspended sediment yield upstream from the Spruce Branch gauging station ranged from 2,800 to 39,000 tons per square mile during the period 1966-69. Future sediment yields of the Colma Creek basin will undoubtedly be lower than yields observed during the study period when construction activity was high. If the basin becomes completely urbanised (65 percent urban and 35 percent open space), it is probable that sediment yields for the entire basin will range from 9,700 tons in a year of average rainfall to 25,000 tons in a year of extremely high rainfall.

KOCH, C.T. 1971: "Systems description for urban water resources". In, Proceedings 16th Annual Conference on Water for Texas, urban water resource planning and management, Texas A and M University, College Station, Texas; p19-41. (NTIS PB-210 325).

Key words: hydrologic systems; watershed management.

This paper attempts to bring into proper perspective some very generalised approaches for interrelating most of the factors affecting urban water resource management. Although all the work is illustrated for the San Antonio region, such work can be transferred to other regions as well.

KOCH, E. 1970: "The effects of urbanisation on the quality of selected streams in Southern Nassau County, Long Island, New York". U.S. Geol. Survey prof. paper No.700-C; p189-192.

Key words: dissolved solids; detergents; nitrates; water pollution sources; storm runoff; surface runoff.

The water quality in the streams in southern Nassau County has diverged noticeably from natural conditions because of extensive urbanisation. The quality of two streams in sparsely populated areas in Suffolk County was compared with the quality of three streams in moderately to densely populated parts of Nassau County. The estimated load of dissolved solids of all the southern Nassau County streams presently is about 10.5 tons per day greater than the estimated load under natural conditions. Furthermore, analysis of the data for certain constituents directly affected by man shows that the detergent content of the three streams in Nassau County ranges from about 9 to 18 times the detergent content of the two Suffolk County streams; the nitrate content is 14 times that of the Suffolk County streams; and the dissolved solids content is about 3 to 4 times that of the Suffolk County streams.

KOELZER, V.A. 1972: "Urban water management". J. Amer. Water Works Assoc., Vol.64(9); p537-544.

Key words: watershed management; water pollution control; flood control.

Six areas define the functional problem of urban water management: (1) municipal water supply, (2) pollution control, (3) flood control and drainage, (4) recreation, (5) fish and wildlife, and (6) parks and open space. Out of these problems emerges the ultimate problem, the imposition of large demands for capital expenditures by all metropolitan entities. Perhaps the most effective method of coping with these problems is through integrated area-wide water management. Area-wide water management means unifying the direction of the activities of a single water function, such as water supply,

waste water treatment, parks, and open space, throughout all or several municipalities of a metropolitan area. It offers such advantages as economies of scale, improvements in efficiency and reliability, better coordination, and better overall use of water resources. Integrated water management means unifying the planning, decision making, implementation, and operation of two or more of the different water functions, and also offers such advantages as economies of scale and improved coordination. The benefits from area-wide and integrated water management appear to outweigh whatever costs are associated with such management.

KOHLHAAS, C.A. 1975: "Focus - comprehensive water resources management". Water Sewage Wks., Vol.122(6); p70-75.

Key words: watershed management; flood control; water pollution control; nonpoint pollution sources.

Concepts that are not ordinarily covered in the standard reference works on water resources and environmental science and engineering are examined, including flood retention, waste water reclamation and reuse, combined sewer overflow and urban runoff control and treatment, and other nonpoint source pollution problems. A diagram is provided, based on the natural hydrological cycle that begins with precipitation, runoff and evaporation to the atmosphere, leading to precipitation and a repetition of the cycle, and the use of water resources by man, their degradation through use and their reclamation and ultimate reuse. The purpose of the diagram is to provide general guidelines for water resources and environmental planning; to point out specific options for meeting water supply, waste disposal and waste water reclamation goals; and to provide for the evaluation of specific water resources alternatives.

KOLENBRANDER, G.J. 1972: "The eutrophication of surface waters by agriculture and the urban population". Stikstof, Vol.15; p56-67.

Key words: surface runoff; eutrophication; agricultural pollution; detergents; nitrogen compounds; phosphorus compounds.

A comparison was made between the contribution via the soil and via main drainage to the enrichment of surface water with materials containing the plant nutrients nitrogen and phosphorus. The contribution via the soil was estimated using three methods, viz. the nitrogen and phosphorus balance in the profile, lysimeter investigations and river discharge analyses. The average leaching per hectare of cropland per year for clay and sandy soils together amounts to about 32 kg N and 0.6 kg P₂O₅. Of the contribution of main drainage towards the phosphate in surface water, 50 percent emanates from the phosphate in detergents. The total contribution of phosphate (as P₂O₅) from townspeople via main drainage is

about 33 million kg/year, that of the farming community, over a cropland area of 2.2 million ha, is about 3.5 million kg/year, of which a good 1.3 million kg originates from the soil. For nitrogen the contribution from townspeople is 48 million kg/year, that from the farming community 70 million kg/year. This latter is almost entirely of soil origin.

KOPLYAY, T.M. 1976: "Urban drainage studies". Water and Pollution Control, Vol.114(1); p14-16.

Key words: urban drainage; storm runoff; water pollution sources; model studies; combined sewers.

New approaches to designing and constructing systems to convey surface waters are being examined, due to increasing land servicing costs. Loss of pervious ground due to land development results in increased storm flow velocities and higher peak flows, causing local flooding. The higher velocities also increase the pollution and sediment loads. The Canada - Ontario urban drainage program was set up to define the storm water problem in the Canadian Great Lakes region, establish priorities and schedules for studies, and develop a strategy for implementing solutions. A study is being conducted to provide an order of magnitude estimate of pollution loadings from urban runoff. Problem identification efforts also include reviewing existing municipal practices in Ontario. The Storm Water Management Model (SWMM) of the United States Environmental Protection Agency is being adapted to Canadian conditions. Several data collection projects provide site calibration data, and a sub-routine dealing with snowmelt phenomena is being added. Problems with storm sewers and combined sewers in the United States and Europe were studied. Efforts are being made to ascertain that foreign technical practices will be assessed in terms of their applicability in Canada. An ideal model for regulatory practices will be developed.

KOTHANDARAM, V. 1972: "Water quality characteristics of storm sewer discharges and combined sewer overflows". Illinois State Water Survey, Urbana. Report No. ISWS-72-CIR 109; 21pp. (NTIS PB-214 507/6).

Key words: combined sewers; overflows; water pollution; mathematical models; biochemical oxygen demand; suspended solids; water pollution control; nitrogen compounds; phosphorus compounds.

A review of pertinent case studies with emphasis on the water quality aspects rather than the quantity of storm water and combined sewer overflows is presented. Information pertaining to the quality characteristics of combined overflows and separate storm sewer discharges with the description of contributing drainage areas are presented. In addition, it summarises the storm water pollution load estimates, and ma-

thematical models; the impact of storm runoff on receiving waters; and the methods and estimated costs for pollution abatement. The case studies cited and the treatment costs tabulated should provide a reasonable basis for developing a preliminary understanding of the magnitude and scope of the storm water pollution abatement endeavours.

KRAUTH, K. 1972: "The pollution of effluents in mixed water sewage systems by rain". GWWAA, Vol.113(3); p130-131 (In German).

Key words: storm runoff; pollution abatement; sewage treatment; water pollution sources; combined sewers; overflows; biochemical oxygen demand.

Investigations on the pollution of effluents in mixed water sewage systems by storm water are described and appropriate measures to minimise such pollution are suggested. Mixed water samplings during rainfall periods contained pollutants composed of sewage water, rain water, and sludge deposits in the sewage system. Some 10 percent of the solid pollutants and 27 percent of BOD, total phosphorus, and total nitrogen were due to the sewage water, while the respective contributions by storm water and sludge deposits to the remainder of the solid load were 44 percent and 56 percent. Some 22 percent of the organic pollutants originated in the storm water. The washout of sludge deposits was found to be dependent on rainfall intensity, and flow rates above 20 inches/second caused practically complete washout. Both the BOD values and the solid contents decreased as the rainfall subsided. On a yearly average, the respective BOD and solid pollutant loads of the effluents due to storm water were equal to and ten times higher than those caused from a biological sewage treatment plant. The pollution level of effluents can be made independent of rainfall by an appropriate combination of storm water runoff and storm water basins. The excess water should be retained in a storm water basin during rain periods, and the contents of the basin transferred for biological treatment following storms. Using this method, the BOD discharge due to storm water would decrease by 60 percent.

KRAUTH, K. 1972: "The total runoff coefficient in mixed sewer systems". Gas-und Wasserfach, Wasser/Abwasser, Vol.113(7); p329-331.

Key words: storm runoff; rainfall-runoff relationships.

Results from measurements of the total runoff coefficient in the Stuttgart-Bresnau sewerage treatment facility indicates that the average quantity of storm water which fails to run off was found to be 0.52 mm (0.85 mm in dry weather and 0.46 mm in moist soil). This quantity results almost exclusively from losses due to soil wetting, and in the form of puddle water. After the total runoff coefficient is reduced accordingly with res-

pect to this loss, it becomes a constant value of about 1. Therefore it is surmised that the average storm runoff for an individual rainfall can be calculated from the quantity of the precipitation, less the losses due to wetting and puddle water.

KRAUTH, K. 1973: "Pollution of water bodies by artificial runoff of rainwater polluted by waste water of mixed sewers". Berichte der Abwassertechnischen Vereinigung e.V., No.28; p97-115.

Key words: storm runoff; combined sewers; rainfall-runoff relationships; waste storage.

In a two-year test series conducted in West Germany, runoff conditions specifically related to mixed sewer systems were determined during rainfall periods. Quantitative measurements were taken for 621 storm runoff periods with intensities greater than 7 cu ft/sec. Samples were taken of such short intervals that evaluation of the dirt load was feasible. Primary runoffs which succeeded primary rainfalls, and runoffs which partly flushed the sewers, were considered. The results indicate that only temporary storage of the storm runoff water and its subsequent purification help to reduce the dirt load. For maintaining a dirt load consistent with that occurring during dry weather, no water may pass the rain storage basin after it has been filled. Under present conditions the dry weather runoff goes directly to the purification plant and the storm runoff directly to the receiving stream without treatment.

KRAUTH, K. 1976: "The effect of various designs of rain catching basins on the pollution of the receiving water and the economy of the sewer system". Berichte der Abwassertechnischen Vereinigung e.V., No.28; p583-591.

Key words: combined sewers; water pollution control.

General considerations on the influence of rain catching basins on the pollution of recipients and on the economy of the mixed sewer system are presented. The efficiency of rainwater retention basins is apparent from the fact that the pollutant loads occurring during the initial phase of the rainwater runoff are multiples of the average load. Several basins should be linked in a by-pass system to prevent the discharge of runoff once retention in one basin reaches its capacity. Catchment basins are unable to retain the runoff during the later phase of many prolonged rain events. Basins of up to 500 cu m should be self-scavenging, and scavengers are necessary for larger units. For economic reasons, large areas should be subdivided into homogeneous zones of 20-40 ha each, with separate runoff retention basins in each.

KREMER, L.J. 1974: "Bassett Creek wat-

ershed model". Water Resources Bulletin, Vol.10(4); p789-793.

Key words: model studies; urban hydrology; hydrographs; flood control; surface runoff; storm runoff.

A synthetic hydrograph method was utilised in the development of a watershed model for a small urbanising watershed. The model was applied to the watershed and the largest flood on record was accurately reproduced. Because the model would be utilised for design of flood control plans with complete urbanisation, the method was also applied to an urbanised watershed and reproduced a measured event with good results. The method does not require extensive hydrologic data for its implementation, can be applied to watersheds in various stages of urbanisation, and permits consideration of natural or potential floodwater storage.

KROON, G.VAN DER. 1977: "Storm water characteristics of some Rotterdam sewerage districts". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p292-302.

Key words: urban drainage; storm runoff; waste water treatment.

The cost of connecting the old quarters of Rotterdam to a waste water treatment plant was estimated to be one hundred million guilders in 1971, including the costs of new high pressure mains to connect the existing pumping stations to the water treatment plant; upgrading these stations (13 stations); reconstruction of sewers, etc. This explains why urban drainage systems deserve more interest and study. To be successful this study must be done on a full technical scale. It is expected that as a result of this study many important data which may reduce the cost will be collected and will yield rational solutions to the comprehensive plan with respect to sewage treatment. The pumping station of Rotterdam needs the concept of storm water overflow pumps to the river to maintain a low storm water frequency to the surface water inland of the embankment of the river and to maintain a reasonable storm water pumping rate to the waste water treatment plant. The storm water overflow pumping system has the following advantages: (1) a reduction of the pollution of the inland surface water (i.e. canals) in the centre of the city; (2) a reduction of the total quantity of rinsewater needed for maintaining the quality of the water in the canals; (3) a reduction of the storm water pumping rate to the waste water treatment plant.

KUDRNA, F.L. 1976: "Watershed planning: a selected research bibliography". Council of Planning Librarians, Exchange Bibliography, No.1014; 57pp.

Key words: bibliographies; watershed management.

This bibliography contains over 569 selected references in the area of "Watershed Planning" produced chiefly from 1967 to 1975. The references were compiled as part of the author's doctoral studies during the years 1974 and 1975. The references listed in the bibliography are by no means definitive nor are they meant to be, but they represent many old and current publications and ongoing research which may be used as guides for further research. The bibliography is divided into three parts.

KUNKLE, S.H. 1972: "Effects of road salt on a Vermont stream". J. Amer. Water Works Assoc., Vol.64; p290-295.

Key words: snowmelt; chlorides; surface runoff.

From investigations between 1968 and 1970 into the fate of highway salt applied in the Sleepers River basin of north Vermont, the author concludes that salting of roads definitely raises the salt level of nearby streams. He recommends more scientific salting and ploughing for reducing the volume of chemicals required and keeping them closer to the road pavement, thus allowing more efficient flushing in the spring melt.

KUO, C.Y. 1976: "Evaluation of sediment yields due to urban development". Virginia Water Resources Research Centre, Blacksburg, Va. Bulletin No.98; 28pp. (NTIS PB-267 212).

Key words: sediment yield; urban runoff; storm runoff; erosion control; hydrographs; erosion rates.

This research project sought to determine sediment yields in the Cedar Hill area, Virginia Beach, Virginia. Using a Universal Soil Loss Equation, soil-erosion rates were estimated at construction, semi-construction, and well-developed sites in this area. Sediment yields were then measured at the three sites and at a downstream monitoring station and compared with the estimates. Dilution factors also were studied as a function of rainfall intensities, and are believed to correlate with the characteristics of the area undergoing construction. The dilution factor was defined as the ratio of suspended-sediment concentration on the site compared to that for an off-site specific downstream station at the peak hours of runoff hydrographs. The dilution factor was found to increase as rainfall intensity decreased, and on-site soil erosion rates varied according to the stage of construction.

KUPRIYANOV, V.V. 1973: "Hydrologic aspects of urbanisation". In, Voprosy vliyaniya khozyaystvennoy daytel'nosti na vodnyye resursy i vodnyy rezhim, (Gosudarstvenny Gidrologicheskiy Institut Trudy, 206); p122-133.

Key words: urban runoff; landuse change; urbanisation.

The impact of urbanisation on the water regime of an area and on quantitative and qualitative estimates of changes in water resources is examined. This impact can be evaluated on the basis of changes in the hydrologic regime of urban and suburban areas and on the basis of the effect of towns on the water balance of immediate urban vicinities.

KUPRIYANOV, V.V. 1977: "Urban influences on the water balance of an environment". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p41-47.

Key words: urbanisation; urban runoff.

Peculiarities of the formation of the elements of the hydrological cycle in towns are discussed. The possible quantitative changes in the hydrological elements and a town's influence upon the runoff of large river basins and regions are estimated. Specific hydrological features of urban areas are outlined.

KUPRIYANOV, V.V. and SKAKAL'SKIY, B.G. 1973: "Urbanisation and its effect on the regime and quality of surface waters". Vodnyye Resursy, Vol.2; p172-182.

Key words: urbanisation; landuse change; rainfall-runoff relationships.

Information generalised from Soviet and foreign investigations on the effect of urbanisation on the regime and quality of natural waters is presented; it can be useful for computing the hydrologic and hydrochemical effect of urbanisation and for judging the direction of the process and possible magnitude of its effect.

KURZWEIL, H.A. 1968: "The pollution of runoff from urban housing estates". Gesundheits - Ingenieur; Vol.85(6).

Key words: rainfall-runoff relationships; biochemical oxygen demand; dissolved oxygen; water pollution; sewage treatment; storm runoff; urban drainage; organic compounds.

Based on studies of rainfall and runoff in urban areas, during storms of varying intensity, results are given on the changes in the quality of water from roofs and paved areas, including data on 5-day BOD, dissolved oxygen, and organic substances. The discharge of this polluted water to the storm water sewer or sewerage system is discussed and the author recommends preliminary treatment of this runoff to reduce pollution.

LAGER, J.A. 1970: "A simulation technique for assessing storm and combined sewer systems". In, Combined sewer overflow seminar papers, Edison, N.J. November 4-5, 1969. Water Pollution Control Research Series, Report DAST-37; p151-170.

Key words: combined sewers; computer models; water pollution control.

This paper describes work in progress to develop an assessment technique for comparing alternate solutions through a comprehensive computerised program capable of "representing urban storm water runoff phenomena, both quantity and quality, from the onset of precipitation on the basin, through collection, conveyance (both combined and separate systems), storage, and treatment systems to points downstream from outfalls which are significantly affected by storm discharges". The program is intended for use by municipalities, government agencies, and consultants as a tool for evaluating the pollution potential of existing systems, present and future, and for comparing alternate courses of remedial action.

LAGER, J.A. et al. 1971: "Development of a simulation model for storm water management". J. Water Pollution Control Federation, Vol.43(12); p2424-2435.

Key words: data collection; combined sewers; analytical techniques; storm runoff.

A comprehensive simulation model (Fortran IV, 10,000+ statements) capable of representing urban storm water runoff phenomena in quality and quantity has been developed. Hydrographs and pollutographs (time varying quality concentration or mass values) were generated for real storm events and systems from points of origin in real time sequence to points of disposal with user options for intermediate storage and/or treatment facilities. Incorporated dry weather flow routines permitted the evaluation of both combined and separate sewerage systems. Internal cost routines and receiving water quality assisted in the direct cost benefit analysis of alternate programs of water quality enhancement.

LAGER, J.A. et al. 1974: "Urban storm water management and technology: an assessment". Lager, Smith, Metcalf and Eddy Inc., Palo Alto, Ca. EPA-670/2-74-040; 447pp. (NTIS PB-231 345).

Key words: water pollution; waste water treatment; sewage treatment; surface runoff; overflows; combined sewers; mathematical models.

A comprehensive investigation and assessment of promising, completed, and ongoing urban storm water projects, representative of the state-of-the-art in abatement theory and technology, has been accomplished. The results, presented in textbook format, provide a compendium of project information on management and technology alternatives

within a framework of problem identification, evaluation procedures, and program assessment and selection. Essentially every metropolitan area of the United States has a storm water problem, whether served by a combined sewer system (approximately 29 percent of the total sewered population) or a separate sewer system. However, the tools for reducing storm water pollution, in the form of demonstrated processes and devices, do exist and provide many-faceted approach techniques to individual situations. These tools are constantly being increased in number and improved upon as a part of a continuing nationwide research and development effort. The most promising approaches to date involve the integrated use of control and treatment systems with an areawide, multidisciplinary perspective.

LAGER, J.A. et al. 1977: "Catchbasin technology overview and assessment". Metcalf and Eddy, Inc., Palo Alto, Calif. Report EPA-600/2-77-051; 129pp. (NTIS PB-270 092).

Key words: urban runoff; suspended solids; combined sewers; water pollution control; urban drainage; waste water treatment.

A survey of technical and economic information on catchbasins was conducted to enable more efficient planning and decision-making for urban runoff and collection systems. The report includes: a state-of-the-art review, a review of variables affecting catchbasin efficiency, hydraulic modeling analyses, an assessment of the role of catchbasins, an economic evaluation of alternative storm and combined sewer designs, and a review of recent developments and continuing program needs. The state-of-the-art survey provides background information on catchbasin design, maintenance, and use. Hydraulic modeling analyses indicate that catchbasins could effectively remove medium to very coarse sands from storm water runoff. Removal efficiency increases with increased particle size, decreasing flow velocity, and increased basin depth. Catchbasin cleaning is recommended when solids content exceeds 40-50 percent of the storage depth. A survey on existing catchment basins indicated that mixed performance for the 1,750,000 catchment basins in the United States is probably due to underfinanced and poorly monitored programs. Major alternatives to the use of catchment basins are sewer and street cleaning, the use of inlets and flow-attenuation devices, and separate storm water storage. Recommendations from this study include further evaluation of cost effectiveness, more accurate records of catchment performance, and field scale demonstrations of catchbasin cleaning programs.

LAGERWERFF, J.V. and SPECHT, A.W. 1970: "Contamination of roadside soil and vegetation with cadmium, nickel, lead and zinc". Environmental Science and Technology, Vol.4(7); p583-586.

Key words: lead; zinc; heavy metals; oil wastes; solid wastes.

Concentrations of Cd, Ni, Pb, and Zn in roadside soil and grass samples from several locations decrease with distance from traffic. These concentrations also decrease with depth in the soil profile. The contamination has been related to the composition of gasoline, motor oil, and car tyres, and to roadside deposition of the residues of these materials.

LAMPRECHT, S.J. 1974: "Water pollution: a selected bibliography of California and U.S. Government documents". Council of Planning Librarians, Exchange Bibliography, No.604, July 1974; 30pp.

Key words: water pollution; bibliographies.

Water Pollution has been arranged into three sections: section I provides indexes in which periodical and newspaper articles as well as government documents can be found. Library of Congress call numbers have been provided in parenthesis for the user's convenience. Section II is a listing of U.S. Government documents by issuing agency. The Superintendent of Document call number is supplied at the end of each citation; most of these documents are available in federal depository libraries (i.e. those libraries which receive documents on a regular basis from the U.S. Government). The California State documents, which comprise Section III, have the issuing agency supplied in parenthesis. Although usually available only in California depository libraries, the author included them in order to make the user aware of one state's publications in the water pollution sphere.

LAND, L.F. 1971: "Annual compilation and analysis of hydrologic data for urban studies in the San Antonio, Texas metropolitan area, 1969". U.S. Geol. Survey data report; 109pp.

Key words: streamflow; rainfall-runoff relationships; urbanisation; hydrologic data; data collection; watershed management; chemical analysis; hydrographs.

This report presents a compilation and analysis of hydrologic data collected in the San Antonio, Texas urban area for the 1969 water year. The drainage basins were instrumented during the 1968 water year; therefore some data for that year are included. Precipitation data are based on 21 recording raingauges in the San Antonio metropolitan area. Runoff data are based on discharge measurements and stage records at 7 stream gauging stations, 7 crest-stage partial-record stations, 1 reservoir station, and water surface elevations at four flood-profile partial-record stations. Water quality data were collected from watersheds in various stages of urban development. This water quality program provides data on the concentration of pollutants as a result of runoff

from these watersheds. In addition, these data provide a relationship of water quality parameters to discharge and seasonal conditions. The importance of water quality in this area is unique because of the large amounts of surface water runoff recharged to the Edwards and associated limestones, which is the major aquifer supplying ground water for domestic supply, municipal supply, irrigation, and industrial use in the San Antonio area.

LAND, L.F. 1972: "Annual compilation and analysis of hydrologic data for urban studies in the San Antonio, Texas metropolitan area, 1970". U.S. Geol. Survey data report; 178pp.

Key words: rainfall-runoff relationships; urban hydrology; storm runoff; hydrologic data; data collection; peak discharge; urban drainage; hydrographs.

A compilation and analysis of hydrologic data collected in the San Antonio, Texas, urban area for the 1970 water year are presented. The objectives are: to provide data showing the effects of various stages of urbanisation on flood discharge and runoff, considering time, variation in rainfall patterns, rainfall intensity, and size of the drainage area; and to provide water quality data showing chemical constituents, nutrients, biochemical oxygen demand, pesticides, and sediment in surface water runoff from floods of various magnitudes, during all seasons of the year, from areas with different types of utilisation. Precipitation data are based on 21 recording rain-gauges in the San Antonio metropolitan area. Runoff data are based on discharge measurements and stage records at 7 stream gauging stations, 7 crest-stage partial-record stations, one reservoir station, and water surface elevations at four flood-profile partial-record stations. Water quality data have been collected from watersheds in various stages of urban development at most of the gauging stations in the San Antonio urban area. This water quality program provides data on the concentration of pollutants as a result of runoff from these watersheds.

LANDRETH, R.E. 1963: "Time lag for small urban drainage areas". MS Thesis, New Mexico State University, University Park, New Mexico.

Key words: rainfall-runoff relationships.

LANDSBERG, H.E. 1970: "Climates and urban planning". In, Urban climates, Proc. WMO Symposium, Brussels. Tech. Note 108, WMO No.254, T.P.141; p366-373.

Key words: weather modification; air pollution effects.

Urbanisation brings about several reasonably well-documented micro- and meso-climatic changes. Some of these

can be advantageous such as the heat island effect in cold climates. Others include highly undesirable consequences, principally air pollution, which is aggravated by reduction in ventilation and in some cases by insolation. Planning for new towns or for redevelopment of old cities and for their expansion should include climatic facts to minimise adverse effects. Through layout, architecture and engineering measures microclimates may be turned into assets rather than liabilities. Advance climatic studies are particularly necessary in proper siting of airports and industrial installations. Adequate provision for green spaces is always essential. Hydrometeorological studies of flood plains and drainage requirements are also mandatory, micrometeorological conditions can be mitigated or altered by judicious arrangement of street orientation, building heights and spacing, hedges, water surfaces, and suitable adaptation to orographic conditions. Regional microclimatic circumstances, such as snowfall, sunshine duration, wind regime, may dictate different countermeasures in town construction. Knowledge gained from poor adaptations to climate in established settlements can be profitably applied to new urban developments. Several case studies have been made. Noteworthy are those of Kitimat, B.C. and Columbia, Md.

LANDSBERG, H.E. 1974: "Inadvertent atmospheric modification through urbanisation". In, Weather and Climate Modification, (ed. W.H. Hess), John Wiley, New York; p726-763.

Key words: urbanisation; weather modification; air pollution effects.

This paper establishes beyond reasonable doubt that urban agglomerations cause measurable changes in the atmosphere immediately adjacent to them. Temperatures are increased, low-level lapse rates steepened, horizontal winds slowed, and updrafts induced. Turbulence and cloud formation are increased, summer rainfall is enhanced, and possibly, some winter snowfall is stimulated. Snow on the ground is diminished and so are near-surface humidities. Most apparent is the increase in pollutants from one to several orders of magnitude. They reduce solar radiation intensity, eliminate all the short-wave and a substantial portion of the long-wave ultraviolet, and shorten sunshine duration. Their effect on cloud formation and rainfall over and in the vicinity of cities is still somewhat uncertain but evidence points to occasional cases of stimulation of precipitation and perhaps some rare cases of inhibition.

LASZLOFFY, W. 1971: "Hydrological effects of urbanisation". Foldrajzi Közlemények, Vol.19(2-3); p169-178.

Key words: ground water resources; urbanisation; waste dilution; pollution abatement; oil wastes; thermal pollution; detergents.

The gathering of mankind into towns requires the continuous satisfaction of significant water demand. The first part of the article deals with the effect of water supply. The effect of sub surface water abstraction shows itself in sinking of water level in some places. The result of exaggerated continuous abstraction of water is the sinking of the ground. The increased water demand of the big towns forces us to employ and clarify the polluted water of the rivers. In congested areas, it leads to a new kind of accelerated hydrological cycle of physiological character. The concentrated water consumption goes with the production of a great quantity of waste water. The introduction of waste water into living water streams can be allowed, when its proper dilution is insured. A way of leading the polluted water back to the natural environment is the sprinkling of the waste water, but it is only possible on a loose surface. The composition of polluted waters increases the difficulties of removing them. The polluted waters contain a lot of materials hardly degradable due to the use of artificial detergents and to the increasing spread of oil as fuel. The so-called thermal pollution should not be omitted from consideration. The author deals with the effects of waste and rubbish and the effect of big towns on the water budget of the soil. This latter presents itself in water pollution, and also in the deleterious change of the runoff coefficients.

LAXEN, D.P.H. and HARRISON, R.M. 1977: "The highways as a source of water pollution: an appraisal with the heavy metal lead". Water Research, Vol.11(1); pl-11.

Key words: bibliographies; water pollution sources; heavy metals; lead; surface runoff; waste dilution.

From the literature (a bibliography of 109 references is appended), the authors discuss available information on the contamination of water resources by lead from motor traffic, dealing with dispersion of lead in runoff and receiving waters. The principle source of contamination is lead in runoff, but the extent of contamination will depend on the amount of dilution available in the receiving water. Lead dispersed to roadside soils has been shown to be effectively immobilised in the top 10 cm of soil.

LAZARO, T.R. 1976: "Nonparametric statistical analysis of annual peak flow data from a recently urbanised watershed". Water Resources Bulletin, Vol.12(1); p101-107.

Key words: landuse change; peak discharge; urbanisation; analytical techniques.

Annual maximum peak flow data for the Northeast Branch basin, a recently urbanised Washington, D.C., suburban watershed, were analysed in order to demonstrate the feasibility of a nonparametric statistical application in in-

vestigating the hydrologic impact of the rapid landuse change accompanying intense urbanisation. Annual peak flow data from the Patuxent basin above Unity, Maryland, a rural watershed in close proximity to the study area, were compared to data from the Northeast Branch for the same period utilising the Wilcoxon matched-pairs signed-ranks test. A change in central tendency of each series was noted at the 0.01 significance level: however, the change was negative in the rural basin and positive in the urbanised Northeast Branch basin. This central tendency change was considered indicative of an average decrease in the size of rainstorms producing annual maximum peak discharges. Rainstorm data from the Northeast Branch basin were divided into two equal periods (before urbanisation and after) and the Wilcoxon test was applied. It was found that rainstorms producing maximum annual peak discharges in the urbanised period were indeed smaller than those in the prior period (0.01 level of significance); however, larger annual peaks were produced. It was concluded that nonparametric statistical methods could be used readily with conventional methods to isolate and clearly analyse the various problems in an actual urban hydrologic study.

LEE, G.F. 1967: "Analytical chemistry of plant nutrients". In, Eutrophication: causes, consequences, corrections. National Academy of Science, Washington, D.C.; p646-658.

Key words: eutrophication; nutrients.

A study of the eutrophication of a particular body of water requires that the sources, types, forms, and amounts of the elements that may stimulate aquatic plant growth be determined. The investigator must ask the following questions in planning his analytical chemistry program: What elements and forms of elements should be measured? How should samples be taken? At what locations and at what frequency? What type of sample preservation will be used? What analytical methods will be used? What accuracy is desired in the analytical results? How will the data be processed and evaluated? The answer to many of these questions requires careful attention to the planning part of the study dealing with analytical chemistry. Far too often, studies are conducted without proper attention to one or more of these questions. This paper considers certain aspects of these questions and emphasises areas that require additional study. For the purposes of the paper, only nitrogen and phosphorus are considered.

LEHMANN, E.J. 1973: "Urban surface runoff. A bibliography with abstracts". U.S. NTIS, Springfield, Va. Report for 1964, May 1973; 99pp.

Key words: storm runoff; model studies; pollution abatement; waste water treatment; bibliographies; abstracts.

The NTISearch bibliography contains 95 selected abstracts of research reports retrieved using the NTIS on-line search system - NTISearch. The topics covered can be separated into three areas: urban hydrology and its modeling; storm water runoff problems and abatement; and combined sewer overflows and their control.

LEHMANN, E.J. 1974: "Water quality modeling. A bibliography with abstracts". U.S. NTIS, Springfield, Va. Report for 1964; 163pp. (COM-74-10938/0).

Key words: model studies; storm runoff; bibliographies; abstracts.

The bibliography contains 158 selected abstracts of research reports retrieved using the NTIS on-line search system - NTISearch. The abstracts contain information on models used to describe water quality. This covers models of the chemical, physical, biological, and hydrological processes important to water quality. Included are studies on the modeling of eutrophication, nutrient removal, pollutant dispersion, streamflow, heat dissipation, limnological factors, and storm water runoff.

LEHMANN, E.J. 1976: "Effects of land use and urbanisation on water resources and water quality (a bibliography with abstracts). Report for 1971 - May 1976". U.S. NTIS, Springfield, Va.; 149pp.

Key words: urbanisation; bibliographies; abstracts; storm runoff.

General studies on the effects of land use and urbanisation on water supply and water quality are presented. Reports on specific locations are included if they may be applied to another area.

LEHMANN, E.J. 1977: "Effects of land use and urbanisation on water resources and water quality (a bibliography with abstracts). Report for 1971 - May 1977". U.S. NTIS, Springfield, Va.; 231pp.

Key words: bibliographies; abstracts; storm runoff; eutrophication.

This updated bibliography contains 228 abstracts, 82 of which are new entries to the previous edition.

LEOPOLD, L.B. 1968: "Hydrology for urban land planning - a guidebook on the hydrological effects of urban land use". U.S. Geol. Survey circular No.554; 18pp.

Key words: streamflow; peak discharge; hydrographs; urban runoff; analytical techniques; flood control; sediment yield.

Using basic hydrological data of the Brandywine Creek basin of Pennsylvania, the effect of urbanisation on hydrological factors is summarised. The fol-

lowing subjects are considered: planning procedures and hydrological variables, availability of data and technique of analysis, effect of urbanisation on increasing frequency of overbank flow, local storage to compensate for peak flow increase, sediment production, effect of increased peak flows on sediment yield, and water quality. The author suggests that because the available data are not yet adequate, the report should be considered as a compilation of tentative suggestions for urban planning but by no means a definitive handbook. A list of selected references is included.

LEOPOLD, L.B. 1971: "The hydrological effects of urban land use". In, Man's impact on environment, by T.R. Detwyler, McGraw-Hill Book Co., New York; p205-216.

Key words: streamflow; urban runoff; analytical techniques; hydrographs; sediment yield; erosion.

Cities cause local but severe changes in the hydrologic cycle. The pavement and roofs of urbanisation greatly increase the percentage of the land's surface which is impervious to water. Rather than infiltrate into the ground, a high proportion of precipitation runs off into streams, causing greater flooding than in the country. Urban land use promotes erosion and produces large quantities of sediment, decreases the quality of water, and commonly causes streams to lose their attractiveness. This article attempts to summarise existing knowledge of the effects of urbanisation on hydrologic factors. It also attempts to express this knowledge in terms that the planner can use to test alternatives during the planning process. (The article is extracted from U.S. Geol. Survey circular No.554, 1958, but is updated with additional references).

LEOPOLD, L.B. 1973: "River channel change with time: an example". Bulletin Geological Soc. of America, Vol.84(6); p1845-1860.

Key words: alluvial channels; urbanisation; erosion; urban hydrology.

Channel cross sections were surveyed over a period of 20 years (1953 to 1972) to determine the amount and kind of change of channel area and position of a 3.7 square mile basin, Watts Branch, near Rockville, Maryland. For the first 12 years, the channel progressively but slowly became smaller as urbanisation of the basin gradually proceeded. After 1966, a threshold of change apparently was passed and, probably as a result of increased rate of land alteration upstream, large amounts of sediment were deposited within the channel and overbank. The number of floods exceeding channel capacity increased from two to more than ten per year. Simultaneously, the channel area began to increase. Despite the trend towards increasing cross sectional area, the net result after 20 years was

a channel smaller by 20 percent than it had been originally. Urbanisation did not alter the rate of channel migration.

LINDH, G. 1972: "Urbanisation: a hydrological headache". *Ambio*, Vol.1(6); p185-201.

Key words: urbanisation; weather modification; urban hydrology.

Urbanisation disrupts the natural hydrological cycle and creates problems concerning the quality, quantity and distribution of water. Urbanisation causes changes in the microclimate, the ground's hydrologic response, the quality and quantity of ground water, and the water balance. Urbanisation often makes it necessary to transfer water from other regions. There is presently a great need for research on urban hydrology. The use of statistical and mathematical methods, especially systems analysis, has spurred progress in certain areas of hydrology.

LINDH, G. 1976: "Urban hydrological modeling and catchment research in Sweden". ASCE, New York, Urban Water Resources Research Council, Technical Memo., TM-IHP-7; 42pp.

Key words: urban runoff; computer models; mathematical models.

Prepared in support of International Hydrological Programme Project 7. Seventh of a special ASCE Urban Water Resources Research Program technical memo series of national state-of-the-art reports. Catchment research for Swedish underground conduit drainage systems is emphasised.

LINSLEY, R.K. 1971: "A critical review of currently available hydrological models for analysis of urban storm water runoff". Hydrocomp. International, Palo Alto, California, Completion Report. W72-72-01978, OWRR-X-110 (3416)(1); 91pp.

Key words: urban runoff; mathematical models; network design.

The literature of hydrology is reviewed with respect to rainfall-runoff models. The requirements of urban hydrology and urban runoff models are defined. Existing models are described and their utility for urban applications evaluated. It is considered that several well instrumented urban experimental watersheds are needed in order to test and possibly refine existing models. Specifications for such watersheds are presented.

LINSLEY, R.K. 1973: "A manual on collection of hydrological data for urban drainage design". Office of Water Resources Research, Illinois State Water Survey Lab., Urbana, Illinois, 61807; 62pp.

Key words: data collection; hydrologic data; urban drainage.

There is very little data on urban storm flow and quality and application of modern methods to urban storm drainage management is limited by this lack. This manual is intended to indicate to city and county engineers the types of data which could be gathered by local staff as an aid in the design of future urban runoff facilities.

LINSLEY, R.K. and CRAWFORD, N. 1974: "Continuous simulation models in urban hydrology". *Geographical Research Letters*, Vol.1(1); p59-62.

Key words: mathematical models; computer models.

Continuous hydrologic simulation is defined and a simulation model is described. The information needs for urban water management systems are discussed and the use of continuous simulation of hydrologic data in meeting these information needs is reviewed. For most planning efforts data on probability of occurrence of events of various magnitudes is required and in most urban situations this can only be provided by use of a continuous simulation model.

LISPER, P. 1974: "On the composition of urban storm water and its variation". PhD Thesis, Dept. of Water Supply and Sewerage, Chalmers University of Technology. (In Swedish).

Key words: water pollution; storm runoff.

LITTLE, A.D. INC. 1971: "Inorganic pollution of freshwater". Water quality criteria data book, Vol.2, prepared for the U.S. Environmental Protection Agency; 280pp.

Key words: water pollution sources; toxicity; miscellaneous chemicals.

A survey of the literature dealing with inorganic chemical compounds was conducted to obtain and reference data relevant to the establishment of water quality criteria. More than 5,000 publications were reviewed. While nearly 300 inorganic species may exist in freshwater only 87 were identified in the literature. A wide distribution in concentrations in potable and polluted water was found. Data on acute toxicity, chronic toxicity, carcinogenicity, mutagenicity, and teratogenicity of inorganic chemicals have been tabulated. Because of the design of most of these toxicological determinations, it is difficult to extrapolate from this data to human health. This inability is furthered in that the concentrations of many materials in freshwater are reported in terms of elemental analysis alone without reference to the ionic or complex form of the material. However, toxicity varies with the complex ion and the oxidation state. Correlations have been made of minimum lethal oral

dose versus maximum concentrations reported in freshwater, and of minimum chronic toxic dose versus maximum concentration reported in drinking water. Examples of inorganic species which approach a safety limit have been observed.

LITWIN, Y.J. and SONIGIAN, A.S. 1976: "The nonpoint source pollutant loading (NPS) model". Simulation Network Newsletter, Vol.8(4); 4pp.

Key words: computer models; water pollution sources; surface runoff; urban runoff; model studies; watershed management; nonpoint pollution sources.

A computerised model for simulating nonpoint source pollutant loading is described. The model continuously simulates the hydrologic processes, including pollutant accumulation, generation, and washoff from the land surface as well as snow accumulation and melt. The model is limited in the sense that only land surface contributions to nonpoint source pollution are evaluated. Subsurface and ground water pollutants as well as channel processes are not considered. The model is concerned with the total loading of pollutant input to a stream channel or water body from the land surface; for water quality evaluations in watersheds where in-stream processes are significant, the model must be interfaced with stream water quality models. Sample results of simulating overland flow quantity and quality for an urban watershed are presented and indicate that the model provides a viable means for assessing land surface contributions of nonpoint pollutants. Calibration of certain model parameters is a necessary and critical step when applying the model to a particular watershed since the model is limited by the simplifications due to incomplete descriptions of the processes controlling nonpoint pollution.

LIU, S.K. 1974: "Stochastic analysis and control of urban estuarine water quality systems: Vol.1 - estimation and prediction". R-1622-NYC, The New York Rand Institute, New York; 110pp.

Key words: urban drainage; overflows; computer models.

Described are the interrelationships among the major components of a typical urban estuarine interactive water quality system. The nonparametric, cross-spectral method was used to analyse the responsive behavior between the rainfall and the quantity and quality of the resulting overflow, as well as the characteristics of the stochastic noise components of several drainage systems. All impulse response kernels of the resulting overflow pollutant concentration had a basic W-shaped curve, indicating the relative importance of surface washing, conduit dilution, and bottom scouring. An equation for predicting transient coliform densities in a storm/sanitary combined system overflow was derived based on

the interrelationship between the quantity and quality of the internal flow system. The prediction function from rainfall to overflow estimated by the spectral method was also compared with that obtained by direct transformation using the fast Fourier transform method. The prediction functions and coliform equations were used to develop urban drainage models for estimating the quantity and quality of discharges from the peripheral drainage systems of Jamaica Bay, New York City. These models were then used (with a two-dimensional estuarine water quality model of the day) for simulating water quality results from two summer storms occurring during 1972 and 1973. Control processes in urban estuarine water quality systems should be based upon a feed-forward scheme that uses predictive functions, since most of the parameters governing control are not measurable in real time.

LOEHR, R.C. 1974: "Characteristics and comparative magnitude of nonpoint sources". J. Water Pollution Control Federation, Vol.46(8); p1849-1872.

Key words: nitrogen compounds; nonpoint pollution sources; nutrients; phosphorus compounds.

Data from investigations reported in the literature were used in a comparison of the characteristics and relative magnitude of nonpoint sources discharged to surface waters. The comparisons were made in terms of concentration (mg/l) and potential area yield rate (kg/yr/ha). The nonpoint sources included precipitation, forest land runoff, range land runoff, cropland runoff, runoff from land receiving manure, cropland tile drainage, irrigation return flows, urban land runoff, manure seepage, and feedlot runoff. The feasibility of controlling the various nonpoint sources was discussed. Nonpoint sources of nitrogen and phosphorus were compared with point sources in a small number of watersheds.

LONG, D.T. and SALEEM, Z.A. 1974: "Hydrochemistry of carbonate ground waters of an urban area". Water Resources Research, Vol.10(6); p1229-1238.

Key words: ground water resources; model studies.

A comparison of the ground water chemical data from the shallow dolomite aquifer of Northeastern Illinois Metropolitan Area (NIMA) from August 1973 with data collected 12-40 yr earlier indicates that concentrations of all ions have increased, the greatest increase occurring in the southeastern part of the area where the overburden is thinnest. The largest increases are 843, 142, and 91 percent in Cl⁻, SO₄²⁻, and Na⁺, respectively. However, the spatial distribution of the ground water chemical types has remained the same with time. The ground water was found to be apparently supersaturated with respect to calcite and dolomite; however, the two saturation indices

were reduced by 20 and 30 percent, respectively, after considering the effect of ion pairings. The chemical character of the ground water is controlled, among other factors, by the change of carbon dioxide content of the water along the ground water flow path. A model for the solution of dolomite based on the standard equations for carbonate equilibrium is presented. The application of the model to the study area indicates that a variety of geologic conditions between the dolomite aquifer and the overlying glacial drift prevail in the area.

LONGDONG, D. 1973: "Pollution of water by storm sewerage overflows". Gewäss. Abwass. Vol.10; p65. (in German).

Key words: overflows; water pollution sources.

LOON, J.C.VAN. 1972: "The snow removal controversy: salt and heavy metals in snow and waterways". Water and Pollution Control (Can.), Vol.110(11); p16.

Key words: snowmelt; chlorides; heavy metals.

LOTT, D.L. and BEARD, L.R. 1976: "Optimisation model for the design of urban flood - control schemes". Centre for Research in Water Resources, Texas University at Austin, Technical Report CRWR-141; 228pp.

Key words: flood control; computer models.

A computer program that combines hydrologic simulation and multivariate optimisation techniques was developed to provide engineers with a useful approach to the solution of the urban flood control design problem.

LOWING, M.J. 1977: "Urban hydrological modeling and catchment research in the United Kingdom". NERC, Institute of Hydrology, Wallingford, Report No.36; 23pp.

Key words: urbanisation; mathematical models.

This report is a copy of Technical Memorandum No.IHP-4 of the American Society of Civil Engineers Urban Water Resources Research Program, published in July 1976. It is the United Kingdom contribution to the state-of-the-art reports submitted to the Subgroup on the Hydrological Effects of Urbanisation set up as part of the UNESCO-sponsored International Hydrological Decade.

LUCKETT, J.K. 1974: "The effects of urbanisation upon river channel morphology and sediment". BSc Thesis, University College London, London.

Key words: urban runoff; sediment

yield; channel erosion.

LUDWIG, H.F. et al. 1961: "Pollution - urban versus rural in Imperial Valley waters". Water and Sewage Works, Vol.108; p251-254 and p308-314.

Key words: chemical analysis; waste water treatment; water pollution.

The increasing pollution of the Salton Sea, Calif., in recent years has led to a survey of the sources of pollution of the whole of the Imperial Valley, which includes the lake and two rivers, the New and the Alamo, which run into it, and legislation by the Regional (Colorado River basin) Water Pollution Control Board of the State of California requiring treatment of all sewage before discharge to the lake or either of the two rivers. To assess the extent of any pollution and the quality of the surface waters generally in the area in order to determine what remedial measures must be taken, chemical and bacteriological analyses of the waters were carried out. The results, which are presented in tables and graphs, confirmed the necessity for at least primary treatment of sewage to remove floatable and settleable solids. Maps of the area studied are included.

LULL, H.W. and SOPPER, W.E. 1969: "Hydrologic effects from urbanisation of forested watersheds in the Northeast". U.S. Forest Service, Dept. of Agriculture, N.E. Forest Experiment Station, Research Paper NE-146; 24pp.

Key words: hydrologic data; landuse change.

Summary of data on percentage of land rendered impervious by different degrees of urbanisation.

LUMB, A.M. 1975: "UROS4: urban flood simulation model, Part 1. Documentation and user's manual". Georgia Institute of Technology, Atlanta, Ga.; 225pp. (NTIS PB-242 936).

Key words: urban runoff; urban drainage; hydrographs; urban hydrology; model studies; flood discharge.

An Urban Flood Simulation Model was developed for use by the DeKalb County, Georgia, in evaluating the hydrologic effects of tributary area land use, constricting culverts, detention storage, and channel conditions. The Model was formulated as a working tool for tributary land use planning, structural design, and flood plain management to deal with a widespread drainage problem along small urban creeks. Rainfall, streamflow, and soils data were analysed with the Stanford Watershed Model to develop an historic data file of rainfall excess or runoff for the range of land surface conditions found in DeKalb County. The Urban Flood Simulation Model simulates 25 years of annual flood peaks given the data file and prescribed physical

characteristics of as many as 100 area, channel, and storage segments in a selected drainage area. The model will calculate flood elevations and associated probabilities for specified points. Though collecting, coding, and checking the physical data may take a man-month, once the coding is complete it is relatively easy to explore the effects of changing landuse, altering the drainage system, or adding detention storage. The procedures used in developing the file of runoff data, selecting equations to incorporate within the model, the computer programming, and the recommended procedures for collecting and coding data on drainage characteristics are described in detail. The computer program is listed.

LUMB, A.M. et al. 1974: "Remedial measures for urban flood peak reduction". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p85-91.

Key words: model studies; urban runoff; flood discharge; mathematical models; computer models; hydrographs.

This study tested remedial measures for the reduction of flood peaks in urban areas through the use of a hydrologic model for the digital computer. The fact that urbanisation in a watershed generally increases peak flow rates over those in the nonurbanised watershed is well documented. However, if the urbanisation could be undertaken in a manner to minimise increases in runoff, then significant savings in drainage structures could possibly be realised and degradation of the downstream environment could be reduced. The methodology of this study included: (1) instrumentation of a small residential watershed, (2) development of a hydrologic model, (3) calibration and verification of the model, and (4) model simulation with hypothesised remedial measures for peak flow reduction. For the 11-acre residential watershed used in this study and for the assumptions that were made, the 20 percent increase in the peak flow from residential development could be reduced that amount with a combination of remedial measures including terracing, directing flow from downspouts onto lawns and the use of artificially roughened or vegetated channels. Detention storage could also achieve the 20 percent reduction in peak flows.

LUMB, A.M. et al. 1974: "Analysis of urban land treatment measures for flood peak reduction". Georgia Institute of Technology, Atlanta, Ga. (OWRR Project No.C-2064).

Key words: urban hydrology; storm runoff; computer models; watershed management; urban runoff.

Two computer models for urban hydrologic studies were developed. The Small Urban Watershed Flood Hydrograph Model is to study how flood hydrographs are affected by the arrangement of buildings and paved areas on small wat-

ersheds. Storm runoff is simulated from the physical characteristics of (1) small homogeneous land areas averaging about one quarter acre in size and (2) channel sections. The Urban Hydrograph Routing Model is to study how flood hydrographs are affected by the distribution of land uses in larger watersheds, changes in impervious area, and channel characteristics. Applications of these models showed that (1) small detention storage basins are effective in holding runoff from newly developed areas to their former peaks under natural conditions but become progressively less effective with increasing watershed size, (2) using natural instead of paved collector channels has a similar pattern of substantially reducing head-water hydrographs but diminishing effectiveness as one goes downstream, (3) draining roofs and driveways onto dense turf is effective immediately downstream and, because of volume reductions, may cumulatively have a greater effect in larger watersheds, (4) terracing is effective if dense turf is maintained but bare dirt terraces probably do not justify their costs, and (5) commercial and industrial areas accentuate flood hydrographs most when located near the middle of a watershed.

LUMB, A.M. and JAMES, L.D. 1975: "Flood hydrograph simulation for urban flood frequency analysis: the model". Paper in proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Ky.

Key words: hydrographs; flood forecasting; computer models; urban runoff; flood routing.

The Stanford Watershed Model was used to generate a runoff file, and UROS4 was programmed to route that runoff from an urban watershed subdivided into area, channel, and storage segments. UROS4 simulates an annual series of flood peaks and performs flood frequency analyses at selected study points.

LUMB, A.M. and JAMES, L.D. 1975: "Flood hydrograph simulation for urban flood frequency analysis: application to a watershed". Paper in proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Ky.

Key words: watershed management; hydrographs; computer models; urban runoff; flood forecasting.

UROS4 is used to evaluate the effects of urbanisation and drainageway channelisation on flood frequency and to analyse the hydrologic effectiveness of possible measures for dealing with flooding in the 1058-acre Warren Creek watershed in DeKalb County, Georgia. The steps to follow in applying UROS4 are outlined.

LVOVICH, M.I. and CHERNISHOV, E.P. 1977: "Experimental studies in the

water balance of an urban area". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p63-67.

Key words: rainfall-runoff relationships; landuse change.

The Institute of Geography of the USSR Academy of Sciences, Moscow, has been conducting studies on water balance changes under urban influences and industrial agglomerations, in Kursk. This is a city typical of the European part of the USSR with a population of 300,000. It is one of the economic and cultural centres of the forest-steppe zone. The results of observations on the water balance elements of the urban area are compared with data from earlier similar studies conducted near Kursk in the virgin area of the Central Chernozem Reserve and also on arable land. As a result of these studies seasonal and yearly water balances were made for the urban area and the water balance changes were estimated. The research is based on a method adopted by the Institute of Geography.

LVOVICH, M.I. and CHERNOGAEVA, G.M. 1977: "The water balance of Moscow". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p48-51.

Key words: environmental effects; urbanisation; analytical techniques.

The results of water balance estimates are given for the whole of the Moscow area and for the most built-up part within the Sadovoye ring. The technique of estimation is presented. Water balance data for the urban area are compared with those for the natural Moscow River basin to Zvenigorod. Conclusions are drawn concerning the effect of changes in the water balance of an urban area on the environment.

MacLAREN, J.F. LTD. 1975: "Review of Canadian design practice and comparison of urban hydrologic models". Research Report No.26, Training and Tech. Transfer Divn., Environmental Protection Services, Environment Canada, Ottawa; 212pp.

Key words: model studies; peak discharge; hydrographs.

A questionnaire was distributed to municipalities across Canada requesting details of their storm sewer design practice with emphasis on policies, problems with flooding and frost conditions, and attitudes towards new trends in urban drainage management. Replies from 37 municipalities from Vancouver to Halifax were received and analysed. Five urban hydrologic models were evaluated. These were: (1) The Storm Water Management Model (SWMM), (2) The University of Cincinnati Model (UCUR), (3) The Transport and Road Research Model (RRL), (4) The Queen's University Urban Runoff Model (QUURM), (5) The Proprietary Dorsch Consult Hydrograph Volume Method Model (HVM). These models were evaluated using recorded data from four residential test areas from the United States and Canada, using from 10 to 14 different storm events on each area. The accuracy and consistency of the models were assessed by means of graphical and statistical comparison of both peak runoff volumes and the complete hydrograph for the computed and recorded hydrographs. The peak flows calculated by the Rational Method were also compared with the measured flows. All models performed satisfactorily when applied to small test areas and all models gave more consistent results than the Rational Method.

MacLAREN, J.F. LTD. et al. 1976: "Storm water management model study. Volume 1". Canada-Ontario Agreement on the Great Lakes Water Quality, Research Report No.47; 295pp.

Key words: model studies; watershed management; data collection.

Objectives were: to review and modify the U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) for Canadian conditions; to select and modify a submodel for the simulation of quantity and quality of runoff resulting from snowmelt; to develop a data analysis submodel capable of extracting the SWMM meteorological data input from existing data banks; and, to select and modify a high speed model for simulation of frequency of discharges and overflows, capable of using output from the data analysis submodel as input. This study has expanded the capabilities of the original SWMM. Methods of aggregating the properties of individual subcatchments into a single equivalent catchment are described which can lead to a considerable reduction in data preparation and computer processing time. A generalised quality model was developed, based on SWMM equations and using the simplifications obtained in the aggregating techniques. Snowmelt quantity and quality models have been integrated with the SWMM. Methods of interfacing

the SWMM and STORM (U.S. Army Corps of Engineers) models have been discussed and demonstrated, and a fully operational package of models, capable of simulation of all aspects of storm water flow and quality, has been prepared for application to Canadian conditions.

MacLAREN, J.F. LTD. et al. 1976: "Storm water management model study. Volume 2". Canada-Ontario Agreement on the Great Lakes Water Quality, Research Report No.48; 148pp.

Key words: model studies; urban runoff; data collection.

Supplementary technical material used in preparing the final report is described. Six storm water routing models and four water quality models are described. Literature surveys are included for urban runoff quality and snowmelt quantity and quality. Sources of data required for storm water modeling have been assessed, and study areas in Canada and the U.S. are described. A summary of the treatment processes available in the U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) is given, and current literature and modifications to the treatment model are described.

MacLAREN, J.F. LTD. et al. 1977: "Storm water management model study. Volume 3". Canada-Ontario Agreement on the Great Lakes Water Quality, Research Report No.62; 421pp.

Key words: model studies; storm runoff; analytical techniques; computer models.

This volume, Volume 3 of a three volume report, is the User's Manual for the Canadian Storm Water Management Model developed for Fisheries and Environment Canada and the Ontario Ministry of the Environment. This Canadian study has expanded the capabilities of the original SWMM (U.S. Environmental Protection Agency). Methods of aggregating the properties of individual subcatchments into a single equivalent catchment are described. These can lead to a considerable reduction in data preparation and computer processing time. A generalised quality model was developed, based on SWMM and STORM (U.S. Army Corps of Engineers) models, and a fully operational package of models, capable of simulation of all aspects of storm water flow and quality, has been prepared for application to Canadian conditions. User information on the set up and operation of the entire model, as well as set up and use of the individual program blocks, is presented in this manual. Reference is made to the U.S. Environmental Protection Agency User's Manual, where necessary, to avoid duplication.

MAKI, T.E. and HAFLEY, W.L. 1972: "Effects of land use on municipal watersheds". North Carolina Water Resources Research Inst., Raleigh;

251pp.

Key words: landuse change; watershed management; aerial photography.

A study of the Lake Michie watershed, the source of water for the municipality of Durham, North Carolina, is reported. The study was concerned with the evaluating of the effects of land use on water quality, quantity, and timing of flow during the 43 year period since the establishment of the lake. The characteristic composition of the soils and the vegetative cover and their influence on the hydrology of the basin are discussed. Through the interpretation of aerial photographs, agricultural Census Data and other historic documents, the nature of landuse changes within the watershed have been traced. Current status of the watershed is detailed and recommendations presented for improving the quality of the water and the general hydrologic characteristics of the watershed.

MALLORY, C.W. 1973: "The beneficial use of storm water". Hittman Associates Inc., Columbia, Md., Technology Series Report, W73-06893, EPA-R2-73-139; 264pp. (NTIS PB-217 506/5).

Key words: surface runoff; flood control; water pollution; water pollution control; storm runoff.

A system study was conducted to determine the technical and economic feasibility of using small storage reservoirs throughout an urban community as a means of storm water pollution control. Facilities were provided to treat the water prior to release or to provide potable or sub-potable water for use in the community. A conventional approach to controlling storm water pollution was defined for comparative purposes. Computerised system analysis was used to select the optimal combinations of reservoir locations, type of treatment, and type of reuse on a least cost per day basis. Alternatives were ranked and the optimal practical solution determined considering the restraints.

MALLORY, C.W. and BOLAND, J.J. 1970: "A systems study of storm runoff problems in a new town". Water Resources Bulletin, Vol.6(6); p980-989.

Key words: storm runoff; urbanisation; mathematical models; computer models; water pollution control; sediment control.

A system study was conducted on the use of a large number of small reservoirs dispersed throughout an urban community as a means of storm water pollution control. The study was based on an area within the 'new city' of Columbia, Maryland. Water collected and stored in the reservoirs is treated for release or use in meeting subpotable and potable water demands in the community. Design and performance criteria were developed for such a system. A simulation model and a computerised evaluation technique were used to select the

optimal locations and system configurations. The results of this study indicated that such a system would be less expensive than a conventional engineering approach to storm water pollution control. Further, the benefits derived from the use of the storm water as a water supply can offset a portion of the cost of pollution control. Several secondary benefits also result from this concept including erosion and sediment control, storm flow damping, and recreational facilities. A program is now under way to demonstrate this concept in Columbia, Maryland.

MALMQUIST, P.A. 1978: "Atmospheric fallout and street cleaning - effects on urban storm water and snow". Prog. Wat. Tech., Vol.10(5/6); p495-505.

Key words: air pollution effects; water pollution sources; organic compounds; suspended solids; phosphorus compounds; nitrogen compounds; heavy metals; pollution abatement.

The quality of storm water and factors governing the quality have been studied by the Urban Geohydrology Research Group at Chalmers University of Technology since 1972. The atmospheric fallout was in a study in Goteborg found to contribute to the total water contents of organic matter by 20 percent, of total phosphorus by 25 percent and of total nitrogen by 70 percent. The heavy metal contributions from fallout ranged from 7 percent to 40 percent. Accordingly, the contents of pollutants in urban storm water may be considerably reduced by reduction of the local pollutant sources. Among these sources we find the corrosion of building materials and motor traffic. Urban snow was found to have significantly higher pollutant concentrations than average storm water from the same area. Urban snow, especially from areas with extensive land use, may thus be hazardous to the receiving waters and should therefore be treated as sanitary sewage. The sweeping of streets may improve the quality of storm water. The sweeping of a street in the outskirts of Goteborg removed 57 percent of the suspended solids and between 31 and 65 percent of the heavy metals on the street surfaces.

MALMQUIST, P.A. and SVENSSON, G. 1975: "Heavy metals in storm water". Vatten, Vol.3; p213 (In Swedish).

Key words: storm runoff; heavy metals.

MALMQUIST, P.A. and SVENSSON, G. 1977: "Water budget for a housing area in Goteborg". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p101-108.

Key words: model studies; storm runoff; water pollution sources.

Torslanda, a suburban area, located in

the Goteborg area on the west coast of Sweden, was investigated with respect to the functioning of the sewer systems. Both quality and quantity were taken into account. Based on measurements of rainfall, drinking water consumption, sewage and storm water flow, a water budget was calculated. A distinction was made between drainage water, sewage and storm water in the separate sewer system. In this area it was found that the drainage water flow range is 0.4-1.5 times the average sewer flow. During rainfall the sewer takes up to 30 percent of the total runoff volume, and the maximum leakage flow is 5 times the average sewage flow. Thus the separate sewer system does not perform very well with respect to quantity. The mass flows of SS, BOD, P and Pb were also calculated, and it was found that the mass flows of pollutants were less than for a combined sewer system. The mass flows of pollutants were, however, nearly of the same magnitude as those of a combined system with storage capacity.

MALMQUIST, P.A. and SVENSSON, G. 1977: "Urban storm water pollutant sources". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p31-38.

Key words: water pollution sources; storm runoff; urban runoff; heavy metals; suspended solids; metals; chemical oxygen demand; point sources (pollution).

Four urban and suburban areas in Goteborg have been investigated with respect to storm water quality and its sources of pollution. The sources studied were primarily atmospheric fallout and the corrosion of building materials, but traffic and population were also taken into account. The mass flows of zinc and copper in the storm water proved to be caused by fallout and corrosion. Lead could, as expected, be explained by the traffic. The frequency and effectiveness of street sweeping are important to the lead content in the storm water. The mass flows of suspended solids, COD, and phosphorus may be correlated to traffic and population, but phosphorus also was proved to originate from fallout. Point sources like a refuse incineration plant in one of the areas markedly increased the concentrations of pollutants in the storm water. The results of the investigation will be used to develop an entirely new type of storm water quality model, based on the pollutant sources.

MANGAN, G.F. 1971: "The role of urban water". In, Treatise on urban water systems, Colorado State University, Fort Collins; p33-47.

Key words: urban hydrology; watershed management.

The major problem areas of urban water and waterfront resource planning can be summarised as water quality management,

waterfront land use, water based recreation and open space, and metropolitan growth. In contrast, water supply alone is not really a critical interface problem - the engineering is relatively straight forward - but it gains real importance in the urban environment as a determinant of metropolitan growth rates and suburban development patterns. Sewage disposal is important as one of the several components of water quality management, though it must also be planned in areas where there is no serious pollution problem at present, and no management yet of water quality. Similarly, flood control alone is not an important interface problem, except insofar as it relates to urban land use and environmental quality. The planning of ports, harbours and navigation represents a relatively specialised area of water resources planning, and is important principally in the urban context by virtue of changing land uses around the harbour.

MANGAN, G.F. and SWENSON, H.A. (eds). 1972: "Urban water planning, a bibliography". Water Resources Scientific Information Centre, Office of Water Resources Research, U.S. Dept. of the Interior, WRSIC 72-215; 377pp. (NTIS PB-211 553).

Key words: bibliographies; abstracts; watershed management.

Urban Water Planning is another in a series of planned bibliographies in water resources to be produced wholly from the information base comprising only Selected Water Resources Abstracts (SWRA). At the time of search for this bibliography, the data base had 41,521 abstracts covering SWRA through May 15, 1972 (Volume 5, Number 10).

MANIAK, U. 1973: "Model for calculating floods in urbanised watersheds". In, Floods and droughts, (eds. E.E. Schulz. et al), Proc. 2nd Int. Symposium in Hydrology, Fort Collins. Water Resources Publications, State University of Colorado, Fort Collins; p429-435.

Key words: flood forecasting; mathematical models; rainfall-runoff relationships.

Flood protection plans should include plans for developing urban watersheds. As a consequence the development plans can add large costs to water resource planning. Since the network of stream gauges is often sparse and may be in operation for only a relatively short period of time, precipitation-runoff models can be helpful to judge changes of future runoff. A few problems of rainfall distribution are discussed followed by an example.

MANNING, M.J. 1975: "Urban storm water pollutant loadings". Paper presented at 2nd Annual National Conference on Environmental Engineering Research, Development and Design, ASCE and Univer-

sity of Florida, Gainesville, Fla.; 4pp.

Key words: combined sewers; storm runoff; water pollution sources; solid wastes; biochemical oxygen demand; organic compounds; leaves; chlorides.

Combined sewer overflows and sanitary bypasses average less than half the strength of untreated sewage, but are important because of their magnitude. Direct runoff usually has a solids concentration equal to or greater than untreated sanitary sewage. BOD5 concentrations are approximately those of secondary effluents; bacterial contamination of separate storm waste water is 2-4 orders of magnitude less than that of untreated sewage. A rainfall intensity of 2.5 cm/hour may produce flows less than or equal to 100 times normal dry weather flows. The following major sources of potential pollution are reviewed; tree litter and grass litter; transportation activities, including contributions from vehicles and from ice control, airborne contributions; soil erosion; indirect sources; street surfaces; and miscellaneous sources, including catch basins, roof drainage, animal wastes, and first flush.

MANSUE, L.J. and ANDERSON, P.W. 1974: "Effects of land use and retention practices on sediment yields in the Stony Brook basin, New Jersey". U.S. Geol. Survey water supply paper No.1798-L; 33pp.

Key words: landuse change; sediment transport; sediment yield; environmental effects; urbanisation; data collection; sediment control.

The average annual rate of suspended sediment discharge of the Stony Brook at Princeton, N.J. (44.5 square miles), is about 8,800 tons, or 200 tons per square mile. Annual yields within this basin, which is in the Piedmont Lowlands section of the Piedmont physiographic province in west-central New Jersey, range from 25 to 400 tons per square mile. Storm runoff that transports suspended materials in excess of a ton carries 90 percent of the total suspended sediment discharge from the basin. Suspended material carried during storms is 55 percent silt, 40 percent clay, and 5 percent sand. A trend analysis of sediment records collected at Princeton between 1956 and 1970 indicated an increase in suspended sediment discharge per unit of water discharge during 1956-61. From early 1962 to late 1967, sediment trends were difficult to interpret owing to complicating factors such as reservoir construction, urbanisation, and extreme drought. After 1967 yields decreased.

MARCUS, A.L. 1972: "Urban runoff and water quality problems of an urban hydrologic response". The Monadnock, Vol.46, (Worcester, Mass., Clark Univ.); p39-46.

Key words: rainfall-runoff relationships; storm runoff; water pollution

sources.

Urban development produces a unique range of hydrologic reactions of which an increase in the magnitude, duration, and frequency of storm runoff flow is a major element. This increase in volume of flow is associated with decrease in water quality. Recent studies are reviewed that show that runoff from the urban environment often becomes degraded from pollutants at the surface and in the atmosphere. Increased volumes of storm runoff produce critical problems with storage and transportation capabilities of systems designed for less frequent flows. Only recently has the need for reevaluation and implementation of an urban hydrologic cycle been realised. Urban growth is associated with the development of storm drainage systems which can alter the surface drainage pattern and reduce the lag time, or time of concentration of flow. These processes are manifested in a concentration of storm water flow with sharper, shorter, and higher peak flows than those equated with natural runoff.

MARR, G. and PIEPER, L. 1977: "Computer controlled measurements of combined waste water flow and overflow". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p277-282.

Key words: data collection; combined sewers; overflows.

Storm water runoff and overflow of combined sewer systems from urban areas cause an increasingly important pollution problem. For more detailed knowledge of the relationship between water quality and quantity three raingauges were installed in the study area and measuring and sampling devices were installed in an overflow. The study area is located in Munich and has a size of 542 ha. Data from eight continually measured parameters and from the analysed sewer samples were collected and the system was controlled by a mini-computer. A survey is presented of the average and the diurnal variations of the data collected so far.

MARSALEK, J. 1974: "A technique for flow measurements in urban runoff studies". In, Proceedings of the International Seminar and Exposition on water resources instrumentation: volume 1 - measuring and sensing methods, IWRA, Illinois; p508-516.

Key words: instrumentation; data collection; urban runoff.

A flow measuring technique combining a conventional constriction flow meter and an automated tracer-dilution method was tested in storm sewers. The application of the combined technique extends the operational range of the constriction meter without sacrificing the accuracy. A field accuracy of 5 percent can be achieved throughout the entire flow range.

MARSALEK, J. 1975: "Urban runoff modeling". Civic, Vol.27(3); p32-36.

Key words: model studies; computer models; urban runoff; storm runoff; urban drainage.

Because of the new concepts in urban drainage design, such as runoff control at source, detention, retention and storm water quality considerations, new predictive methods are needed for urban runoff. A model is needed which transforms an input rainfall into a runoff hydrograph for a particular urban area. Features of existing models are summarised. Most include the following components: catchment hydrology (precipitation, infiltration, detention, retention, and surface runoff); sewer hydraulics; and water quality aspects. A table shows whether or not 22 existing models take 16 factors in these three areas into account. There is a wide variation among models, from 1 aspect taken into account by the unit hydrograph to 14 or 16 aspects accounted for by the model called Hydrocomp. In comparison to the traditional 'rational' method of predicting runoff, the computer models are far more accurate. Calibration can improve a model for use in a particular area. With such a model an engineer can design a drainage system in an area including various runoff control schemes and estimate resulting pollution in receiving waters. A wide variety of user needs can be satisfied by available models and for many, computer programs are available. It is recommended that municipalities start collection of precipitation and runoff data for future design of urban drainage.

MARSALEK, J. 1975: "Sampling techniques in urban runoff quality studies". Water Quality Parameters, ASTM, STP 573, Amer. Soc. Testing Materials; p526-542.

Key words: urban runoff; storm runoff; model studies; water pollution; data collection.

Sampling techniques employed depend on use of data collected. If only total pollutant yields are important, then inexpensive flow proportioned composite sampling may be used. When time variation of pollutant concentration is of interest, an empirical model should be established to be used in the experimental design of data collection programs for a runoff quality study. Composite sampling techniques include; simple composite samples of water are withdrawn at regular intervals and put in a container; flow weighted composite, either a constant fraction of the flow is collected or constant volumes are collected which depend on water quality; and pollutant mass flow weighted composite sample, by monitoring a particular parameter, samples are collected for pre selected constant increments of the cumulative pollutant mass flow. In order to determine the type of sampling and minimum number of samples needed, an empirical model is needed to describe the variation of runoff quality. Several attempts at models are examined. Runoff quality is

described either by the rate at which the pollutant is washed from the drainage system or by the variation in the pollutant concentration during the runoff event. It is found in testing models that they are often only applicable to a particular site which is affected by pollutant concentrations which are non uniform over the urban area. An example is given of experimental design for sequential sampling, but practical aspects are stressed. It is important to avoid systematic sampling error by examining the depth at which the sample is taken, the capability of the sampler, sample cross contamination, and lack of synchronisation between the flow recording and sampling.

MARSALEK, J. 1975: "Instrumentation for field studies of urban runoff". Research Report No.42, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario; 82pp.

Key words: instrumentation; urban runoff; waste water treatment; water pollution sources.

Instrumentation and monitoring techniques for field studies of urban runoff were examined. In particular, the following types of instruments were studied: recording precipitation gauges; sewer flow measurement instruments; and automatic waste water samplers. After reviewing the literature and surveying equipment, some of the more promising instruments were acquired, tested in the laboratory, and operated in the field for various time periods. Individual instruments are discussed with regard to their technical data, accuracy and reliability. Recommendations for the selection, interfacing and installation of the instruments are given.

MARSALEK, J. 1976: "Urban hydrological modeling and catchment research in Canada. Urban water resources research program". Urban Water Resources Research Council, ASCE, New York, Technical Memo. TM-IHP-3; 60pp.

Key words: model studies; urban runoff; data collection; storm runoff; urbanisation; overflows; waste water treatment.

Modeling and catchment research for Canadian urban underground conduit drainage systems is emphasised. Only those models that have been tested against actual field data are discussed and applications are emphasised.

MARSALEK, J. 1976: "Malvern urban test catchment - progress report No.1". Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario; 54pp.

Key words: rainfall-runoff relationships; storm runoff; data collection.

MARSALEK, J. 1976: "Testing storm water management model of U.S. EPA". In, EPA Conference on Environmental Modeling and Simulation; p79.

Key words: storm runoff; mathematical models; model studies.

The runoff portion of the EPA Storm Water Management Model was tested on 8 watersheds in the U.S. and Canada. Model simulations are compared with field observations, and the validity and accuracy of modeling results are discussed. Model capabilities as well as limitations are discussed, and recommendations are made for model applications.

MARSALEK, J. 1977: "Runoff control on urbanising catchments". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p153-161.

Key words: flood control; computer models; rainfall-runoff relationships; peak discharge.

Recent urban drainage policies frequently stipulate the requirement of zero increase in the runoff peak flow due to the catchment development. Since runoff measurements for either of the catchment states are rarely available, urban runoff models have to be used to simulate runoff and to design runoff control measures to meet the policy requirements. A methodology for evaluation of runoff and runoff control measures is demonstrated on an urban test catchment for which extensive rainfall-runoff measurements are available for a postdevelopment stage. These measurements were used to calibrate the Storm Water Management Model of the US Environmental Protection Agency. The model was then used to simulate runoff for the predevelopment stage, the existing stage and a newly proposed low cost residential development. The simulations were made for historical and design storms of various frequencies. Runoff peaks produced by design storms were up to twice as large as those produced by historical storms of identical frequencies. The volumes of detention storage necessary to maintain the predevelopment runoff peaks were calculated for events of various frequencies of occurrence. Effects of the size and imperviousness of the urbanising catchment were detected.

MARSALEK, J. 1977: "Malvern urban test catchment, Volume 1". Canada-Ontario Agreement on the Great Lakes Water Quality, Research Report No.57, Environmental Protection Service, Fisheries and Environment Canada, Ottawa; 55pp.

Key words: rainfall-runoff relationships; surface runoff; storm runoff; data collection; hydrographs; urban runoff.

An urban test catchment (Malvern), representing a modern residential development of 58 acres, was established and instrumented in Burlington, Ontario.

The catchment topography, land use, hydrological characteristics, storm drainage and instrumentation are described and discussed. A number of precipitation-runoff events were monitored on the catchment in 1973, and some of these events were simulated with the Storm Water Management Model (SWMM) of the U.S. Environmental Protection Agency. A good fit between the simulated runoff hydrographs and the observed hydrographs was obtained.

MARSALEK, J. et al. 1974: "Comparative evaluation of three urban runoff models". 22nd Special Conference, Hydraulics Division, Proc. ASCE, Knoxville, Tenn., July-August 1974. (See also Water Resources Bulletin, Vol.11(2); p306-328, 1975).

Key words: mathematical models; urban runoff; hydrographs; computer models.

A comparison between three urban runoff models, namely, the Road Research Laboratory Model (U.K.), the Storm Water Management Model (U.S.A.) and the University of Cincinnati Urban Runoff Model (U.S.A.), is reported. Simulated hydrographs were compared with hydrographs measured on several instrumented urban catchments, both for peak points and for the entire hydrograph. The models were not specifically calibrated and used parameter values recommended by the original model designers. Of the three models studied, simulations from the Storm Water Management Model were marginally better than those of the Road Research Laboratory, but both these models were more accurate than the model developed at the University of Cincinnati.

MARTELL, J.M. et al. 1975: "PCB's in suburban watershed, Reston, Virginia." Environmental Science and Technology, Vol.9; p872-875.

Key words: organic compounds; urbanisation; water pollution sources; analytical techniques; phenols.

Polychlorinated biphenyl concentrations in Lake Anne basin, Virginia, increased from water (<0.05-0.2 ppb), to bed sediment (<2.5-105 ppb), to fish (140-700 ppb) in an average ratio of 1:500:3000. The highest concentrations were observed in the lake, which is ten years old, and receives no sewage or industrial waste discharges. Evidence indicates that the polychlorinated biphenyls (PCB's) originate from diffuse sources associated with urban development and living.

MARTENS, L.A. 1961: "Flood inundation and effects of urbanisation in metropolitan Charlotte". U.S. Geol. Survey Study on Little Sugar Creek, North Carolina, Administrative Report, Raleigh, North Carolina.

Key words: flood discharge; flood forecasting.

The mean annual flood for Little Sugar

Creek near Charlotte (37 year record, 141 sq miles), when plotted against drainage area as a primary factor, was found to be 58 percent greater than that indicated by an areal study of rural streams within a 50 mile radius. As secondary factors, slope increases this difference whereas stream length was found to have little effect. Percent of impervious areas was selected as an index to the effects of urbanisation. The impervious area of Little Sugar Creek near Charlotte was estimated to be about 15 percent of the total drainage area, compared to less than 1 percent for basins of other stations outside metropolitan Charlotte. A flood frequency plot of observed floods on Sugar Creek (37 year record) and the frequency curve to be expected for rural areas shows a tendency to converge for floods greater than a 10 year frequency. The limit of the plot is 20 years. Percent increase for Little Sugar Creek over that expected for rural areas are: mean annual flood, 58 percent increase; 10 year flood, 30 percent increase; 20 year flood, 17 percent increase.

MARTENS, L.A. 1968: "Flood inundation and effects of urbanisation in metropolitan Charlotte, North Carolina". U.S. Geol. Survey water supply paper No.1591-C; 60pp.

Key words: storm runoff; peak discharge; flood forecasting.

Investigation of floods on seven streams in metropolitan Charlotte, N.C., indicates that significant increases in flood potential accompany urban development of the basins. Urbanisation affects both the hydrology and hydraulics of drainage systems. Rainfall excess increases with the development of urban areas which are more impervious than rural areas, largely because of structures such as buildings, paved streets, and parking lots. The magnitude of the mean annual flood increases with an increase in the degree of imperviousness. The effect of impervious area diminishes with increased flood recurrence intervals becoming negligible for floods exceeding 50 years. Basin lag time for fully developed basins was found to be about one-fourth the lag time before development. The increase in impervious area and decrease in lag time associated with the urbanisation of a basin will about double the discharge of a 20-year flood. Computed flood elevations of the 20-year flood along 60 miles of stream channels reflect increases in elevation of as much as 6 feet for some areas as a direct result of extensive watershed development. In other areas, where channel and flood-plain improvements have been made, the increase in elevation of the 20-year flood is as small as 1 foot. Seventy-five percent of the channels in metropolitan Charlotte will reflect an increase of about 3 1/2 feet in the elevations of the 20-year flood as a result of the change in the basins from undeveloped to urbanised conditions. Studies to determine the feasibility of selecting cross-section properties directly from detailed topographic maps, when computing flood profiles, indicate

that about a three-tenths-foot error can be expected in profile elevations of floods at about bankful stage; a lesser error can be expected in profile elevations of floods above bankful stage.

MASSEY, B.C. 1973: "Annual compilation and analysis of hydrologic data for urban studies in the Dallas, Texas metropolitan area, 1971". U.S. Geol. Survey data report; 84pp.

Key words: urban hydrology; hydrologic data; urban runoff; data collection; rainfall-runoff relationships.

Hydrologic investigations of urban watersheds in Texas were begun by the U.S. Geological Survey in 1954. These studies are now in progress in Austin, Dallas, Dallas County, Fort Worth, Houston, and San Antonio. In August 1961, the Geological Survey in cooperation with the city of Dallas began a program of investigations designed to evaluate hydrologic factors affecting floods on several small streams in Dallas. The objectives of the Dallas area program are: to determine, on the basis of historical data and hydrologic analyses, the magnitude, frequency, and areal extent of flooding; to document and define floods of greater than ordinary magnitude; and to determine the effect of urban development on flood peaks and volume. The studies involve the collection of precipitation, runoff, and flood-evaluation data in seven drainage basins within the city of Dallas and in three drainage basins outside the city in Dallas County. Two of the seven study areas in Dallas have headwaters in rural areas outside the city limits, but the largest part of each drainage basin is within the city.

MASSEY, B.C. and WOOD, C.M. 1974: "Hydrologic data for urban studies in the Dallas, Texas metropolitan area, 1972". U.S. Geol. Survey open-file report; 135pp.

Key words: urban hydrology; data collection; streamflow; rainfall-runoff relationships; hydrologic data.

Investigations were designed to evaluate hydrologic factors affecting floods on several small streams in Dallas, Texas. The objectives of the Dallas area program were to determine the magnitude, frequency, and areal extent of flooding, on the basis of historical data and hydrologic analyses; to document and define floods of greater than ordinary magnitude; and to determine the effect of urban development on flood peaks and volume. The studies involve the collection of precipitation, runoff, and flood elevation data in seven drainage basins within the city in Dallas County. Two of the seven study areas in Dallas have headwaters outside the city limits, but the largest part of each drainage basin is within the city.

MASSING, H. 1976: "Urban hydrology studies and mathematical modeling in the Federal Republic of Germany". ASCE, New York, Urban Water Resources Research Council, Technical Memo., TM-IHP-6; 59pp.

Key words: urban runoff; computer models; mathematical models.

Prepared in support of International Hydrological Programme Project 7. The sixth of a special ASCE Urban Water Resources Research program technical memo series of national state-of-the-art reports. Modeling and catchment research for German drainage systems is emphasized and model applications are stressed.

MASTERS, H. 1973: "Using porous pavement to control runoff". News Environ. Res. Cincinnati, August; p1-3.

Key words: pollution abatement; flood control.

A study is being made of the feasibility of using porous pavements to alleviate pollution from combined sewer overflows and storm water discharge, by allowing the water to percolate into the soil, rather than to fill the sewer system. The results so far indicate that porous pavements could provide a practical solution to such problems as relief from flash flooding, partial elimination of combined sewer overflows and storm water discharges, ground water recharge and preservation of vegetation.

MATSUBARA, SHIGEAKI. and YOKOO, MASAI. 1971: "Examination of rain water loss mechanism in an urban area". In, Proceedings of the 7th Conference on Sanitary Engineering Research, Japan Soc. of Civil Engineering, Cttee. on Sanitary Engineering; 157pp.

Key words: rainfall-runoff relationships; data collection; mathematical models.

In an urban area, surface conditions characterized by infiltration and non-infiltration areas are considered to be the significant factors that control the outflow phenomena. Weak rainfall in an urban area results in outflow from the non-infiltration area, and strong rainfall in the combination of outflows of both infiltration and non-infiltration areas. Based on the data obtained during an investigation on the rainwater outfall in an urban area, outflow coefficients and water losses are calculated. Furthermore, through quantitative analysis various mathematical formulations are examined. It is concluded that although mathematical tools such as the peakflow quantity formula will continue to be used in the future, further improvements are necessary to allow more accurate forecasting and to obtain more precisely the loss mechanism in an urban area.

MATSUMOTO, J. et al. 1971: "Study of ra-

inwater runoff characteristics in urban districts". Preprint, Japan Society of Civil Engineers 26th Annual Science Lecture Meeting, Tokyo; 2pp.

Key words: storm runoff; rainfall-runoff relationships; sewage treatment; water pollution sources.

During heavy rainfalls, sewage in drain pipes is diluted by inflowing storm water and subsequently discharged into a river. Water pollution caused from such final effluents is rapidly becoming a problem. The quality and quantity of the drainage water at a pumping plant in the city of Sendai has been determined by the examination of the storm runoff as well as the change in water quality. Storm runoff was plotted against rainfall omitting values of less than 0.05 inches/hour intensity. Results indicate that storm runoff related in a linear fashion to rainfall and was unaffected by rainfall intensity. The quality of diluted drainage sewage was analysed and compared with the water quality calculated from discharged sewage sampled on a clear day. The quantity of effluent doubled and the BOD was approximately half.

MATTHIAS, C.D. 1970: "Urban hydrology in connection with channel improvement project at Newmarket Creek, Virginia". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.8; 17pp.

Key words: urban hydrology; hydrographs; rainfall-runoff relationships; storm runoff; urban runoff; peak discharge; flood discharge.

Flood frequencies were determined for a proposed channel improvement in Newmarket Creek, Va. The drainage area contributing to the channel ranged from 2.33 square miles to 8.54 square miles with various conditions of watershed development and various portions of channel improved. A large shopping centre, similar to the thousands of such centres being constructed throughout the country, was constructed directly on the flood plain. A channel, which proved to be inadequate, was provided around the end of the shopping centre to carry the flow of the stream. Slopes in the main study area are relatively flat, about 0.5 feet per 1000 feet. Also, the cross section of the flood plain on either side is flat so that, under natural conditions, considerable water is stored along the stream and the runoff is slow. Unit hydrographs were derived for a drainage area of one square mile for a number of different times of concentration covering the required range expected in the study. The 2-, 10-, and 100-year flood peak discharges were obtained by application of appropriate storm rainfall to the unit hydrograph.

MATRAW, H.C. and SHERWOOD, C.B. 1977: "Quality of storm water runoff from a residential area, Broward County, Florida". J. Research, U.S. Geol. Survey, Vol.5(6); p823-834.

Key words: rainfall-runoff relationships; flood control; chemical oxygen demand; nitrogen compounds; phosphorus compounds.

Rainfall, runoff, and water quality information were collected in a 19.2 hectare single-family residential area in Broward County, Fla., between April 1974 and September 1975. During this period, 231 rainfall periods were recorded; 106 were large enough to produce runoff, and 30 were sampled for chemical analyses. The fraction of rainfall that runs off is low, usually 5 to 10 percent. Several factors which combine to reduce runoff are the large areas of pervious lawns (61 percent), the gentle slope of the area, and the use of grassy swales for routing storm water. Bulk precipitation (rainfall plus dry fallout) quality is good by comparison to that of other metropolitan areas. As a consequence of the low runoff and the low concentrations of the bulk precipitation, loads for this residential area are small. Estimated annual load for chemical oxygen demand was 22.5 kilograms per hectare; total residue, 82.3 kg/ha; total nitrogen, 1.48 kg/ha; and total phosphorus, 0.21 kg/ha.

MCBOYLE, G.R. 1968: "A review of urban climatology". Earth Science Journal, Vol.2(1); p88-95.

Key words: weather modification.

The review attempts to elucidate the history and the developing research work done in the field of urban climatology, with special emphasis on temperature. References are made to the works of certain researchers whose publications have not been translated into the English language. The reference list is by no means complete but contains most of the important works in this field.

MCBRIDE, J.R. 1976: "Impact of urbanisation on water yield, flood peak sediment yield, and water quality in the Berkeley Hills, California". Technical completion report, California Univ., Davis; 20pp. (NTIS PB-262 077/1ST).

Key words: urbanisation; nutrients; dissolved oxygen; nitrogen compounds; sediment yield; peak discharge; flood discharge; watershed management.

The objective of this project was to determine the impact of urbanisation on the hydrologic characteristics of watersheds in the Berkeley Hills of central California. The initial approach was to calibrate three stream gauging stations prior to the development of one watershed above one of these stations and to follow changes in hydrologic characteristics during and subsequent to development. A summary of data on annual water yield, characteristics of flood peaks, sediment yield, and water quality for the three non-urban watersheds is presented.

McCOY, R. 1972: "The urban climate". In, Proceedings symposium on urban rainfall management problems, University of Kentucky, Lexington, Ky.; Technical Report UKY 51-72-CE16; p1-7.

Key words: urbanisation; urban hydrology; air pollution effects; weather modification.

Three factors associated with cities account for most of the observed climatic differences compared with nearby rural areas. These factors are: alteration of natural surfaces, internal heat production of cities, and change of composition of the urban atmosphere. Alteration of natural surfaces includes the obvious physical change from relatively smooth surface to a surface that is aerodynamically rough. The main effects of increased roughness are reduction of wind turbulence. The added turbulence may contribute to an increase of precipitation in cities. The natural surface is also altered in terms of the composition of materials. The change from vegetated surface to one of concrete and asphalt produces changes in specific heats present at the location, increases heat storage capacity, and provides fewer evaporative surfaces for cooling. Activities within a city are frequently heat producing. Furnaces, both residential and industrial, internal combustion engines, and thermal-electric power plants each contribute to a high concentration of heat in a city from sources that are not usually present in rural areas. A wide variety of gases, including sulfur oxides, nitrogen oxides, carbon dioxide, and water vapour are added to the atmosphere. Particles may affect temperature by blocking incoming solar radiation. Particles, by acting as condensation nuclei, are the major factor contributing to increases in cloudiness, fog, haze, and precipitation in urban areas.

McCUEEN, R.H. 1974: "A regional approach to urban storm water detention". Geographical Research Letters, Vol.1(7); p321-322.

Key words: waste storage; flood control.

To control the increase in storm water runoff due to urban development many states require some form of storm water detention. However, existing laws use an individual site approach to storm water management rather than the more efficient regional approach. An individual site approach to storm water detention may actually increase the potential for localised flooding.

McCUEEN, R.H. 1975: "Flood runoff from urban areas". Maryland Water Resources Research Centre, College Park, Tech. Rept. No.33; 78pp. (NTIS PB-244 504).

Key words: urban hydrology; urbanisation; peak discharge; model studies.

This study examined several important aspects of urban water resources management and resulted in the following: (1) a set of prediction equations that can be used to estimate different land use characteristics from selected demographic characteristics; (2) a set of design curves relating peak discharge and the land use intensity rating, as a function of the exceedence probability (i.e. return period); (3) a set of design curves showing the effect of rooftop detention on peak discharge for various land use intensity ratings and exceedence probabilities; (4) a computer model of a storm water detention facility; (5) a model study comparing the effect of the individual site approach to the regional approach of storm water detention; (6) a set of design curves that can be used in the design of storm water detention facilities for areas characterised by high concentrations of impervious areas (e.g. streets and parking lots); (7) a water quality simulation model that can predict the level of eight pollutants in runoff from urban and suburban streets; (8) a set of prediction equations that can be used to predict water use of selected commercial establishments.

McCUEEN, R.H. and JAMES, L.D. 1972: "Nonparametric statistical methods in urban hydrologic research". Water Resources Bulletin, Vol.8(5); p965-975.

Key words: landuse change; peak discharge; streamflow; analytical techniques.

In urban hydrologic studies, it is often necessary to determine the effect of changes in urban land use patterns on such runoff characteristics as flood peaks and flow volumes. Nonparametric statistical methods have properties that make them valuable tools for detecting hydrologic change caused by a treatment, such as urbanisation, that changes a watershed over a period of time. Several techniques are used for illustrative purposes to analyse the effect of urbanisation on 24 years of annual flood peaks for a Louisville, Kentucky, watershed. Urbanisation increases the central tendency of peaks, but not their dispersion. Peak flows modelled by holding watershed parameters constant also increase because of an upward trend in precipitation. By following the numerical examples and looking up test statistics in referenced sources, these methods can be applied to other situations.

McCUEEN, R.H. and PIPER, H.W. 1975: "Hydrologic impact of planned unit developments". J. Urban Planning and Development Divn., ASCE, Vol.101(UP1); p93-102.

Key words: storm runoff; urban hydrology; urban runoff; model studies; urbanisation; hydrographs.

The hydrologic impact of planned unit developments (PUD) is examined. A linked-process hydrologic model was

formulated to estimate the hydrologic impact of various land use configurations and examine the potential of various storm water management practices. Components are included to simulate the various hydrologic processes such as interception, infiltration, evapotranspiration, surface retention and detention, subsurface flow, rooftop storage and runoff, overland flow on impervious surfaces, gutter flow and storm sewer routing, which are involved in transforming rainfall to storm water runoff. Peak discharges from a planned unit development have been computed to be as much as three times those of a single family detached dwelling unit and five times those of undeveloped land use. This fact makes it imperative that storm water management alternatives for PUD be investigated. The linked-process hydrologic model employed in this study appears to be a valid means for estimating the hydrologic impact of PUD and the effect of various storm water management alternatives. The use of rooftop detention may reduce peak discharge by approximately 4 percent. However, parking lot detention appears to be a more practical detention alternative.

McELROY, A.D. et al. 1975: "Analysis of nonpoint source pollutants in the Missouri basin region". Midwest Research Inst., Kansas City, Mo.; 176pp. (EPA/600/5-75-004; PB-245 896/6WP).

Key words: nonpoint pollution sources; computer models; hydrologic data; nitrates; turbidity; biochemical oxygen demand; dissolved oxygen; dissolved solids; phosphorus compounds.

A study was conducted of nonurban, nonpoint sources of pollution in Missouri basin utilizing a unique, computer-based data system. The Data Bank contains extensive information on land use, soil, climate, water quality, and other parameters in the Missouri basin. The current study was concerned with the adequacy of the Data Bank relative to development of nonpoint pollution models. Evaluation of information in the Data Bank yielded detailed land use and water quality profiles in the basin. The results show that the Data Bank is a useful base to depict the basinwide relations between various land uses and water quality. Regression equations of these relationships were developed for individual subbasins as well as for the entire basin. The regression equations, and the accompanying statistical analysis of significance, indicated that the water quality parameters NO₃, BOD, and turbidity correlate well with land use on a basinwide basis. Other parameters, namely phosphorus, dissolved oxygen, and dissolved solids, did not correlate well with land use.

McELROY, A.D. et al. 1975: "Water pollution from nonpoint sources". Water Research, Vol.9(7); p675-682.

Key words: nonpoint pollution sources; agricultural pollution; industrial

wastes; sediment yield; nutrients; pesticides; organic compounds; thermal pollution; salinity; bacteria; heavy metals.

The nature and extent of nonpoint pollution sources in the United States were assessed for four major industrial activities: agriculture, silviculture, mining and construction. Nonpoint pollutants exert a significant influence on water quality in the United States. Based on land use data, more than 97 percent of the land area in the U.S. is a potential source of nonpoint pollution. Among the pollutants identified from agriculture, silviculture, mining and construction, important pollutants are sediment, nutrients, pesticides, organic wastes, thermal discharges, acid mine drainage, salinity, radioactivity, microbial pollutants, and heavy metals. Agriculture, especially cropland, is responsible for the release of large quantities of sediment, nutrients, and pesticides. Because of the production of large quantities of organic wastes from livestock operations, these wastes can be potential sources of water quality degradation, if not handled properly. Silviculture is a source of sediment. Other pollutants originating from silvicultural operations include very limited quantities of nutrients, pesticides, and thermal discharges. Surface mining is a major source of erosion sediment. Acid mine drainage, salinity, and heavy metals are other important pollutants from mining. Sediment is a major pollutant from construction industry.

McELROY, A.D. et al. 1975: "A systematic review of methodologies for quantification of pollutants from nonpoint sources". In, Second Annual National Conference on Environmental Engineering Research, Development and Design; 4pp.

Key words: sediment yield; phosphorus compounds; model studies; nonpoint pollution sources; leachate; solid wastes; nitrogen compounds; biochemical oxygen demand.

An extensive data base exists for estimation of sediment load generation in both rural and urban areas, and on this basis the effects of changes in land use or land practices on sediment yields can be estimated. Phosphorus is transported principally on sediment; and P emissions can be calculated from a knowledge of the P content of eroding soils. Emissions of the insoluble forms of N can be calculated in a like manner, but the transport of soluble forms of N into subsurface waters is more uncertain. BOD is a relatively simple function of estimated loads of sediment for sources which erode mainly by erosion of sediment; BOD sources from animal wastes and solid waste leachates are much more variable. The mechanisms of sediment generation from soil surfaces are capsulised in the Universal Soil Loss Equation dealing with on-site erosion, which lacks a delivery term. A delivery term is a factor relating the quantity of on-site eroded sediment to the quantity delivered to surface streams. The EPA has developed

a storm water management model for assessment of urban runoff and loads of pollutants in the runoff.

McELROY, A.D. et al. 1976: "Loading functions for assessment of water pollution from nonpoint sources". Midwest Research Inst., Kansas City, Mo; 468pp. (EPA/600/2-76/151; PB-253 325/5WP).

Key words: model studies; analytical techniques; nonpoint pollution sources.

Methods for evaluating the quantity of water pollutants generated from nonpoint sources including agriculture, silviculture, construction, mining, runoff from urban areas and rural roads, and terrestrial disposal are developed and compiled for use in water quality planning. The loading functions, plus in some instances emission values, permit calculation of nonpoint source pollutants from available data and information. Natural background was considered to be a source and loading functions were presented to estimate natural or background loads of pollutants. Loading functions/values are presented for average conditions, i.e., annual average loads expressed as metric tons/hectare/year (tons/acre/year). Procedures for estimating seasonal or 30 day maximum and minimum loads are also presented. In addition, a wide variety of required data inputs to loading functions, and delineation of sources of additional information are included in the report. The report also presents an evaluation of limitations and constraints of various methodologies which will enable the user to employ the functions realistically.

McELROY, F.T.R. et al. 1976: "Sampling and analysis of storm water runoff from urban and semi-urban watersheds - systematic development of methodologies in planning urban water resources for medium size communities". Purdue University Water Resources Research Centre, Technical Report No.64; 102pp. (partial completion report).

Key words: storm runoff; urban runoff; suspended solids; biochemical oxygen demand; bacteria; water pollution sources.

Storm water runoff samples were collected and analysed from urban and semi-urban/rural watersheds located in West Lafayette, Ind. Preliminary sampling was performed in order to develop sampling methodology; i.e. to determine the importance of sampling frequency, duration on the resultant storm water pollutographs, etc. The effects of total rainfall, rainfall intensity, and antecedent dry period on the runoff quality were also determined. The data clearly showed a significant difference in the pollutional concentration of BOD and suspended solids between the urban and semi-urban/rural watersheds. The peak concentration was almost always higher in the urban watershed, being 1-2 times higher in suspended solids and 8-9 times higher in BOD. The mass emission pollutographs were affected by

both concentration and flow. However, the flow hydrograph had a much more significant effect on the shape and magnitude of the pollutograph than did concentration. There were indications that the antecedent dry period prior to the storm event had an effect on the magnitude of the mass emission pollutograph. This will receive more study in future research.

McELROY, F.T.R. and BELL, J.M. 1974: "Storm water runoff quality for urban and semi-urban watersheds". Water Research Centre, Purdue University. Tech. Report No.43; 156pp. (NTIS PB-231 482).

Key words: urban runoff; storm runoff; urban drainage; faecal coliforms; biochemical oxygen demand; suspended solids; hydrographs.

Samples of storm water runoff from an urban and a semi-urban/rural watershed were collected at established gauging-sampling stations. The pollutional characteristics of the runoff for the two watersheds were different. The peak BOD, suspended solids, total coliform and faecal coliform tended to be higher from the urban watershed, but there was considerable range in concentration. A 'first flush' of suspended solids and BOD was exhibited at the urban sampling station while this was not so evident at the semi-urban/rural station. Mass emission pollutographs of BOD and suspended solids showed that the concentration and flow both affected the shape of the pollutograph. The flow hydrograph had a very dramatic effect on the shape and magnitude of the pollutograph. Comparing the two watersheds as to unit 'pounds per day per acre-MGD', the storm water runoff from the semi-urban/rural watershed had suspended solid and BOD values ranging from .14 to 4.3 lb/day/acre-MGD and from .07 to .14 lb/day/acre-MGD, respectively. The urban watershed had BOD values ranging from 7 to 25 lb/day/acre-MGD and suspended solids ranging from 2 to 8 lb/day/acre-MGD.

McGILL, G.L. and AUSTIN, L.B. 1974: "the use of radar in urban hydrology". J. Hydrology, Vol.22(1/2); p131-142.

Key words: urban hydrology; remote sensing.

The radar and raingauge records of summer storms occurring over the city of Ottawa between 1969 and 1972 were used to study seven events which lead to the flooding of house basements. It was found that these tended to occur as a result of slow moving storms and on one occasion due to a storm elongated in its direction of travel. These features of storm dynamics appeared to be more important than either the intensity of the storm (maximum instantaneous rainfall rate) or the total accumulation. A brief discussion of the match between the scale of resolution of the radar and the watershed scale size in urban areas is included.

McGRIFF, E.C. 1972: "The effects of urbanisation on water quality". J. Environmental Quality, Vol.1(1); p86-88.

Key words: urbanisation; water pollution sources; water pollution; peak discharge; storm runoff; eutrophication; sediment yield.

Urbanisation increases the sediment load carried by streams, decreases ground water recharge, promotes eutrophication, and causes temperature variation in streams, all of which tend to alter water quality. Urbanisation increases the volume of runoff and the size of the flood peak, and decreases the lag time. Ground water recharge is minimised, which reduces low flow augmentation and its dilution potential. The quality of urban runoff is a major factor in promoting the copious growth of plankton and algae. Stream temperatures increase during the summer and decrease during the winter, with reference to streams flowing through natural settings. Dissolved oxygen content tends to be critical during the low flow conditions found in the summer, and, since the solubility of oxygen decreases with an increase in the temperature, the effect of urban runoff on a stream is adverse. Urbanisation can also have a pronounced affect on the quality of ground water.

MCKENZIE, S.W. and MILLER, T.L. 1976: "Basic data on urban storm water quality, Portland, Oregon". U.S. Geol. Survey open-file report 77-594; 71pp.

Key words: urban runoff; storm runoff; water pollution sources; streamflow; chemical analysis; data collection; analytical techniques.

To assess urban storm water quality characteristics in the metropolitan area of Portland, Oregon, seven drainage basins were selected with varying drainage areas, basin slopes, impervious areas, land uses, and active construction areas. Automatic water quality samplers, raingauges and stream gauges were installed in each basin. From September 1, 1975, to May 1, 1976, data were collected to determine rainfall intensities and stream discharge. Almost 500 samples from the seven basins were analysed to describe pollutants for at least four complete storms on each of the basins. In addition to the storm samples, several base flow samples were collected and analysed for each site. Stream discharge and water quality data are tabulated.

McMANIS, G. 1972: "The application of binary tree structures to hydrologic network simulations". MS Thesis, Nebraska University, Lincoln, Dept. of Computer Science; 94pp. (NTIS PB-228 698).

Key words: computer models; hydrographs; mathematical models; urban drainage.

Dynamic simulation techniques can provide urban water planners with needed

hydrologic response information. Such techniques for modeling the interactions between (1) a storm bounded by a generalised polygon, and (2) any arbitrarily distributed network over which the storm passes are described and demonstrated. A simulator for the hydrologic response of any encoded channel network has been designed and implemented in FORTRAN. The network is represented by a binary tree structure within which the topologic connections, geometric and other attributes of its segments can be introduced, altered, and retrieved by a set of programmed functions. The comprehensive computer package can model either the behavior of existing drainage systems or the expected performance changes from modification of a drainage system. The simple, yet detailed distributed model has the potential of revealing worst-case velocities or patterns for moving storms. The model has been applied to an existing drainage system, simulating both the runoff at any point and the cumulative behavior in relation to a given storm description.

McPHERSON, M.B. 1969: "The nature of changes in urban watersheds and their importance in the decades ahead". In, Effects of watershed changes on streamflows (eds. W.L. Moore; C.W. Morgan), Water Resources Symposium, No.2, Centre for Research in Water Resources, University of Texas; pl57-164.

Key words: watershed management; urban hydrology.

The consequences of urban development and intensification of use on the water resource are examined. Water quality will be of increasing importance and the supply of good quality water must be subjected to more rigorous economic evaluation. In view of the often conflicting demands of economic and social factors, there is a need for comprehensive planning.

McPHERSON, M.B. 1970: "A framework for urban water resources research". In, Report on the 5th Annual Water Resources Conference, sponsored by the Office of Water Resources Research, Dept. of the Interior, Washington, D.C.; pl43-148.

Key words: urbanisation.

The evolution of the United States from an agrarian to an urban society has seemingly outpaced the capacity for adjustment of our prevailing institutions of government. The greatest task of local governments in the future will be in providing new services. To meet needs of water services in urban America, government and academic cooperation is urged in research, and centralised direction in operation. Recent studies of research needs on urban water resources have found a preponderance of critical needs at the interfaces, linkages and interrelationships with all other urban system elements. Research needs focus on providing the basis for devising new policies, creating new

programs and establishing new institutions. The broad objective of all research should be to clarify the interactions that take place through linkages of 5 major areas. The immediate objective of individual research would be reinforcement of knowledge on one of the major categories. In the past, water resource development has been essentially land-orientated; future planning must be people-orientated. Scientists must be consequence-conscious in water resource planning and attempt to make their technological data understandable to citizens who make judgements.

McPHERSON, M.B. 1972: "Hydrologic effects of urbanisation in the U.S." ASCE Urban Water Resources Research Program, Tech. Memo. No.17, June 1972; 45pp. (NTIS PB-212 579).

Key words: urbanisation; weather modification; water pollution.

Distributed for the information of U.S. researchers, this is one of seven national case studies of the IHD/Unesco Subgroup on the Effects of Urbanisation on the Hydrological Environment. Consistent with the format of the other Subgroup case studies, the topics treated include; urbanisation indicators; character of precipitation; microscale climatic effects; major effects resulting from urban water resources facilities; projected impact of community scale urban water conservation measures; water supply impact; flooding effects; pollution effects; effects of mining activities; effects of other water body uses; and water balance inventories. Emphasis is on effects, to the extent that national and regional generalisations can be drawn. As for nearly all developed countries, a scarcity of information on urban hydrologic phenomena delimits quantification of urbanisation effects. On the other hand, sufficient indications are available to make qualitative judgments on a broad range of such effects.

McPHERSON, M.B. 1972: "Urban runoff". ASCE Urban Water Resources Research Program, Tech. Memo. No.18, August 1972; 53pp. (NTIS PB-212 580).

Key words: urbanisation; surface runoff; water pollution; flood control; watershed management.

The report is a review of the effects of urbanisation on hydrology. Topics discussed include the following: urban storm water disposal; landuse changes; morphological changes in drainage; changes in flood characteristics; flood mitigation versus the amenities of drainage; some management possibilities; research status and needs.

McPHERSON, M.B. 1973: "Need for metropolitan water balance inventories". J. Hydraul. Divn., Proc. ASCE, Vol.99(HY10); p1837-1848.

Key words: environmental effects;

urbanisation; hydrologic systems.

More water balance inventories, determining the quantity and quality aspects of the fate of water as it cycles through a metropolitan area, are needed for evaluation of the hydrological effects of urbanisation and related development of strategies for resource management and environmental protection. A general accounting for the overall movement of water and pollutants can be ascertained by comparing such complete inventories over successive time intervals. The status of metropolitan comprehensive water resource systems is outlined, system complexities are described, and the need for inventories is explained. Serious obstacles have impeded advances, but progress is being made in a few notable instances. Investments in such research worldwide are well below levels that could be justified by the economic and environmental importance of urban water resources.

McPHERSON, M.B. 1974: "Environmental impact of urban storm water runoff". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p11-82.

Key words: analytical techniques; urban runoff; peak discharge.

Urban storm water runoff and mathematical models describing it are discussed. Peak drainage runoff rates can be reduced by means of proper land development design. The bulk of storm drainage systems convey very modest flow rates, substantiating the surmise that the majority of catchments replace mainly fringe tributary natural channels. The most dramatic hydrologic impact of urban development is that on peak flows, where the basin lag time is reduced as an area becomes urbanised. Structural means for mitigating flood plain inundation are designed to provide a much higher level of protection than that for storm drainage systems. Pollution from storm sewer discharges can be almost as severe as that from combined sewer overflows. Substantial departures from traditional underground systems that remove storm water as rapidly as possible are required for enhancement of urban environment, conservation of water resources, and reducing water pollution. The rational method of sewer design involves numerous artificialities. For preliminary analysis and design of specific projects, the use of the simplest models is recommended. Ad hoc temporary rainfall-runoff-quality measurements to calibrate and verify the crude models used are recommended. Opportunities for design application of more detailed modeling techniques may arise if actual field data is available. Use of more detailed models is mainly justified to give a better insight into the underlying processes and develop more rational understanding of the simpler models. Exploration of metropolitan-wide pollution-control alternatives should employ the simplest mass-balance and mass-routing techniques. Most models require a computer for efficient calcu-

lation.

McPHERSON, M.B. 1975: "Special characteristics of urban hydrology". In, Prediction in catchment hydrology, (eds. T.G. Chapman; F.X. Dunin), Australian Academy of Science, Canberra; p239-255.

Key words: computer models; urban hydrology.

The field of urban hydrology is distinguished from classical hydrology both in terms of subject matter and in the organisation and support of research. A review is provided of current activity and expected directions in the field in the USA. The more widely used models are classified into planning, design/analysis, and operation types, and recent developments in the formulation and use of each type are reviewed, together with recent attempts to evaluate and compare them. Considerations affecting the selection of input precipitation data for a chosen model are discussed.

McPHERSON, M.B. 1975: "Urban hydrological modeling and catchment research in the U.S.A.". Urban Water Resources Research Program Technical Memorandum No.IHP-1, ASCE; 56pp.

Key words: urban drainage; mathematical models; instrumentation; analytical techniques.

Modeling and catchment research for urban underground conduit drainage systems is emphasised. Only those models that have been tested against actual field data are discussed and the more than 100 test entries are restricted to cases where a report describing the tests is available to the public, resulting in a concentration on 16 models. In describing the latest advances in catchment research, instrumentation, telemetry, and data reduction are emphasised; and difficulties encountered in attainment of metropolitan water balance inventories are noted.

McPHERSON, M.B. 1976: "Urban water resources". EOS (Trans. American Geophys. Union), Vol.57(11); p798-806.

Key words: urban hydrology.

Urban water resource research around the world commonly has suffered from inadequate attention and support and from discontinuous and erratic efforts. More than a decade ago it was possible to say that there was a need for research to establish the nature of the effects of urbanisation on basic hydrological processes. Today, the broad nature of these effects is only beginning to be understood. The paper outlines relevant features of local government, indicates the economic and social significance of urban water resources, and attempts to define progress that has been made and areas of neglect.

McPHERSON, M.B. (ed). 1977: "Research on urban hydrology, Vol.1". UNESCO Technical Papers in Hydrology, No.15 (a contribution to the IHP); 185pp.

Key words: urban hydrology; model studies; computer models.

This volume has been prepared under International Hydrological Programme sub-project 7.1, 'Research on Urban Hydrology'. It contains the first five of the national state-of-the-art reports foreseen within the general framework of project 7, 'Effects of Urbanisation on the Hydrological Regime and on Water Quality', adopted by the Intergovernmental Council of the International Hydrological Programme at its 1975 session. The project includes also sub-project 7.2, 'Development of Mathematical Models applied to Urban Areas considering both Water Quality and Quantitative Aspects'. The report for the U.S.A. served as the prototype for the series of national reports, and was circulated in other countries for the purpose of obtaining analogous contributions.

McPHERSON, M.B. (ed). 1978: "Research on urban hydrology, Vol.2". UNESCO Technical Papers in Hydrology, No.16 (a contribution to the IHP); 265pp.

Key words: urban hydrology; urban runoff; computer models; mathematical models.

This is the second volume prepared under International Hydrological Program sub-project 7.1 entitled 'Research on Urban Hydrology'. It contains seven national state-of-the-art reports foreseen within the general framework of project 7, 'Effects of Urbanisation on the Hydrological Regime and on Quality of Water', adopted by the Intergovernmental Council of the International Hydrological Program at its 1975 session. The project includes also sub-project 7.2, 'Development of Mathematical Models applied to Urban Areas considering both Water Quality and Quantitative Aspects'. The state-of-the-art reports are from France, Federal Republic of Germany, India, Netherlands, Norway, Poland, and Sweden.

McPHERSON, M.B. et al. 1969: "An analysis of national basic information needs in urban hydrology". ASCE Basic Information Report; 112pp.

Key words: rainfall-runoff relationships; urbanisation; instrumentation; hydrologic data; urban hydrology.

The article focuses on data needs, data devices and data networks. Primarily aimed at improvement in design of storm drainage, an intensive study was made of the data requirements for analysing rainfall-runoff-quality relationships and of suitable data collection instrumentation, with consideration of the types of networks required for the collection of adequate data. Suitable data collected with properly coordinated instrumentation in networks representing a variety of climatic, geo-

graphic, and land use conditions, are virtually non-existent. There are very meagre amounts of performance data with which existing or proposed storm drainage facilities can be checked or designed. Transfer of data findings between metropolitan regions is a central and primary objective. Recommendations centred on hydrologic information needs are related to storm sewers. The replacement value of existing storm sewerage systems in the United States is at least \$22 billion, and it is estimated that an average of about \$3.5 billion per year will be spent on construction of new storm sewerage systems over the next several years. The plan recommended for a minimum national program of urban storm drainage research would cost on the order of 1/3 percent of this average annual construction cost.

McPHERSON, M.B. et al. 1974: "Management of urban storm runoff". ASCE Urban Water Resources Research Program Technical Memo. No.24; 92pp. (NTIS PB-234 316).

Key words: urbanisation; pollution abatement; rainfall-runoff relationships; water pollution sources; hydrographs; erosion control; computer models; urban runoff; storm runoff; urban drainage.

The Hydrologic Engineering Centre, Corps of Engineers, U.S. Army, sponsored a training course on 'management of urban storm water, quantity and quality' at its facilities in Davis, California, in February 1973. Water Resources Engineers of Walnut Creek, California, conducted the course for the Centre. This report contains eight of the fifteen course lectures, on the following topics: an overview of urban storm drainage, by G.T. Orlob; hydrologic effects of urbanisation and the factors controlling urban runoff, D.F. Kibler; effects of urban runoff on receiving waters, by C.W. Chen; concepts of urban storm runoff control, by R.P. Shubinski; storm water treatment process, by J.A. Lager; storage of urban runoff, by J.A. Lager; storm water treatment versus storage, by R.P. Shubinski; and, design of storm water drainage systems, by M.B. McPherson. Much of the content has not appeared elsewhere or is from limited distribution project reports. Aside from its value as a unique information source, this project is suitable for use as a text or manual. Three other lectures are subsumed in a companion report that documents a computer model for preliminary evaluation of runoff quality in metropolitan master planning.

McPHERSON, M.B. and MANGAN, G.P. 1975: "ASCE urban water resources research program". J. Hydraul. Divn., Proc. ASCE, Vol.101(HY7); p847-855.

Key words: urban runoff; urban hydrology.

Since 1967 the ASCE Urban Water Resources Research Council has carried out a program to help establish coordi-

nated long-range research on urban water resources on a national scale. Progress made through mid-1974 on research needs assessment, urban water management, translation of research findings into practice, facilitation of urban runoff research, and collaboration and participation in research of local governments and other organisations is summarised.

McPHERSON, M.B. and SCHNEIDER, W.J. 1974: "Problems in modeling urban watersheds". Water Resources Research, Vol.10(3); p434-440.

Key words: mathematical models.

Modeling of urban watersheds is complicated by the complexities of the hydrologic system brought about by urbanisation, model scale, and client diffusion. Modeling objectives vary widely, from storm sewer design to management of local runoff to river basin planning. Each objective requires a different approach in modeling. Current difficulties in modeling involve inherent nonlinearities in most methods of processing inputs for linear models, problems of storm definition, interconnection of urban catchment areas, and shortage of detailed rainfall-runoff water quality data for calibration. Despite handicaps, progress has been made in modeling urban watersheds and will continue to be made.

MEDINA, M.A. 1975: "A continuous model to study the relative importance of storm, combined, and DWF sewer runoff". In, Second annual National Conference on Environmental Engineering Research, Development and Design; 5pp.

Key words: computer models; biochemical oxygen demand; dissolved oxygen; urban runoff.

Data for the study area are used to simulate the response of the receiving water to the combined effects of BOD from upstream sources, dry weather urban sources, and wet weather urban sources. An equation for initial conditions of BOD in the receiving water is developed, and the hypothetical impact on the receiving stream is estimated using simplified mathematical modeling procedures. The total hours of runoff-producing rainfall throughout the year are separated into storm events (ranging from 1 to several hours duration) according to the number of dry weather hours preceding each hourly occurrence. For a given point, the runoff and pollutant loads are summed and the critical DO deficit is estimated as a function of river temperatures and BOD concentration. The minimum DO is calculated subsequently. The time and distance to each critical deficit point and the stream velocity are computed for each event. The impact of urban runoff may be summarised by the number of times predicted DO levels fall below a specified value.

MEHN, A. 1962: "The determination of resi-

dential area runoff coefficients and a study of rainfall frequency for the New Orleans area". MSCE Thesis, Tulane University, New Orleans, Louisiana.

Key words: rainfall-runoff relationships.

The chief purpose of the work was the development of 'Test Values' of a typical residential area runoff coefficient for the New Orleans area from rainfall and discharge measurements. The paper includes the methods used in detail as well as study of rainfall frequencies for the New Orleans area.

MEINHOLZ, T.L. et al. 1974: "An application of the storm water management model". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p109-113.

Key words: model studies; urban runoff; combined sewers; mathematical models; storm runoff; water pollution control.

The Environmental Protection Agency Storm Water Management Model (SWMM) uses a high speed digital computer to predict the quantity and quality of storm water runoff for a given rainfall event. This paper discusses the application of the SWMM to a combined sewer area of 832 acres which has its wet weather discharges treated by two satellite screening/dissolved air floatation units totalling 93 cfs in capacity. It was concluded that SWMM is an accurate tool for predicting the quantity and quality of urban runoff. Naturally, the results of the SWMM are only as accurate as the input data.

MEINHOLZ, T.L. et al. 1975: "Problems and policy alternatives: urban areas". In, Proceedings of a workshop on nonpoint sources of water pollution, Illinois University at Urbana-Champaign, Agricultural Experiment Station and Illinois Institute for Environmental Quality; p20-24.

Key words: water pollution sources; storm runoff; urban runoff; waste water treatment; nonpoint pollution sources; faecal coliforms; waste water disposal.

Storm generated flows and runoff, sewer overflows, and other aspects of urban nonpoint water pollution are discussed, using examples from case histories at Kenosha and Racine, Wisconsin. Storm water often contains high faecal coliform counts (up to 76,000 per 100ml). Separation of sanitary sewage from storm water does not necessarily provide a solution to the problem of storm water disposal. Moreover, sewers are usually combined in a single system in the central city where all the land is totally developed. Reference is made to an investigation of combined sewage characteristics made of discharges in 15 cities, with data given for BOD values, COD, suspended solids, nitrogen, phosphorus, and coliform counts. Before further technology and dollars

are expended in the areas of advanced and tertiary treatment of municipal waste waters for the betterment of water quality, an in-depth analysis of the health hazards and water quality degradation resulting from the continued discharge of untreated storm water should be performed. Areas of further development include better drainage area housekeeping practices such as street cleaning, construction site runoff control and prudent application of chemicals to land, as well as improvements in conveyance systems and the treatment of discharges emanating from these systems.

METCALF and EDDY, INC. 1971: "Storm water problems and control in sanitary sewers, Oakland and Berkeley, California." Metcalf and Eddy Inc., Paper SN 5501-0095; 311pp. (NTIS PB-208 815).

Key words: surface runoff; flood control; water pollution.

An engineering investigation was conducted on storm water infiltration into sanitary sewers and associated problems in the East Bay Municipal Utility District, Special District No.1, with assistance from the cities of Oakland and Berkeley, California. Rainfall and sewer flow data were obtained in selected study sub areas that characterized the land use patterns predominant in the study area. Results obtained were extrapolated over larger drainage areas. A computerised flow routing program for the sewer system was used in this analysis. Ratios of infiltration to rainfall in the study sub areas range from 0.01 to 0.14. Ratios of peak wet weather flow to average dry weather flow range from 2.1 to 9.1.

METCALF and EDDY, INC. 1971: "Storm water management model, Volume 1 - final report". Metcalf and Eddy Inc., Palo Alto, California, Water Pollution Control Research Series; 365pp. (NTIS PB-203 289).

Key words: surface runoff; water pollution; combined sewers; overflows; mathematical models.

A comprehensive mathematical model, capable of representing urban storm water runoff, has been developed to assist administrators and engineers in the planning, evaluation, and management of overflow abatement alternatives. Hydrographs and pollutographs (time varying quality concentrations or mass values) were generated for real storm events and systems from points of origin in real time sequence to points of disposal (including travel in receiving waters) with user options for intermediate storage and/or treatment facilities. Both combined and separate sewerage systems may be evaluated. Internal cost routines and receiving water quality output assisted in direct cost-benefit analysis of alternative programs of water quality enhancement. Demonstration and verification runs on selected catchments, varying in size from 100 to 5,400 acres, in four U.S. cities (approximately 20 storm events,

total) were used to test and debug the model. The amount of pollutants released varied significantly with the real time occurrence, runoff intensity, duration, pre-storm history, land use, and maintenance. Storage-retreatment combinations offered best cost effectiveness ratios.

METCALF and EDDY, INC. 1971: "Storm water management model: Volume II. Verification and testing". Metcalf and Eddy Inc., Palo Alto, California, Water Pollution Control Research Series; 185pp. (NTIS PB-203 290).

Key words: storm runoff; mathematical models; combined sewers; water pollution; surface runoff.

The report represents the verification and testing of a comprehensive mathematical model, capable of representing urban storm water runoff to assist administrators and engineers in the planning, evaluation, and management of overflow abatement alternatives. Hydrographs and pollutographs (time varying quality concentrations or mass values) were generated for real storm events and systems from points of origin in real time sequence to points of disposal (including travel in receiving waters) with user options for intermediate storage and/or treatment facilities. Both combined and separate sewerage systems may be evaluated. Internal cost routines and receiving water quality output assisted in direct cost-benefit analysis of alternate programs of water quality enhancement. Demonstration and verification runs on selected catchments, varying in size from 180 to 5,400 acres, in four U.S. cities (approximately 20 storm events, total) were used to test and debug the model.

METCALF and EDDY, INC. 1971: "Storm water management model: Volume III. User's manual". Metcalf and Eddy Inc., Palo Alto, California, Water Pollution Control Research Series; 375pp. (NTIS PB-203 291).

Key words: surface runoff; combined sewers; water pollution; overflows; mathematical models; storm runoff.

The report is a user's manual for a comprehensive mathematical model, capable of representing urban storm water runoff, to assist administrators and engineers in the planning, evaluation, and management of overflow abatement alternatives. Hydrographs and pollutographs (time varying quality concentrations or mass values) were generated for real storm events and systems from points of origin in real time sequence to points of disposal (including travel in receiving waters) with user options for intermediate storage and/or treatment facilities. Both combined and separate sewerage systems may be evaluated. Internal cost routines and receiving water quality output assisted in direct cost-benefit analysis of alternative programs of water quality enhancement.

METCALF and EDDY, INC. 1971: "Storm water management model: Volume IV. Program listing". Metcalf and Eddy Inc., Palo Alto, California, Water Pollution Control Research Series; 256pp. (NTIS PB-203 292).

Key words: surface runoff; mathematical models; combined sewers; water pollution; overflows; storm runoff.

The report presents the program listing for a comprehensive mathematical model, capable of representing urban storm water runoff to assist administrators and engineers in the planning, evaluation, and management of overflow abatement alternatives. Hydrographs and pollutographs (time varying quality concentrations or mass values) were generated for real storm events and systems from points of origin in real time sequence to points of disposal (including travel in receiving waters) with user options for intermediate storage and/or treatment facilities. Both combined and separate sewerage systems may be evaluated. Internal cost routines and receiving water quality output assisted in direct cost-benefit analysis of alternate programs of water quality enhancement.

MEYER, C.F. 1973: "Polluted ground water: some causes, effects, controls and monitoring". Environmental monitoring series, General Electric Co., Santa Barbara, California; 283pp. (EPA-600/4-73-0016, W74-07615; NTIS PB-232 117-2).

Key words: ground water resources; aquifers; water pollution; waste water disposal; water pollution control.

Ground water pollution aspects of the following topics are discussed: institutional and legal constraints; injection wells into saline and fresh water aquifers; lagoons, basins, and pits; septic systems; sewer leakage; spraying; landfills; surface-ground water relationships; salt water intrusion; land subsidence and collapse; effects of urbanisation and of flow diversion, including wells and surface structures; spills of liquid pollutants; tank and pipeline leakage; and ground water basin management, including related surface activities.

MEYER, L.D. 1974: "Overview of the urban erosion and sedimentation processes". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p15-23.

Key words: erosion; urban runoff; channel erosion; erosion rates; urban drainage; urban hydrology.

Public concern and legislation are forcing responsible officials to face urban erosion problems. Results of agricultural research, especially the Universal Soil Loss Equation and simulated rainfall studies of erosion control practices for denuded land, are

major sources of applicable information. Disseminating and adapting available knowledge promises to hasten the development of effective solutions to these major urban environmental problems.

MEYER, L.D. et al. 1971: "Erosion, runoff and vegetation of denuded construction sites". Transactions ASCE, Vol.14(1); p138-141.

Key words: erosion; storm runoff; erosion control.

Six typical construction site conditions were subjected to intense simulated rain storms. Soil and water losses were generally very large. Subsequent revegetation of these conditions was also studied. Straw mulch and applied topsoil were the best treatment tested for both erosion control and revegetation.

MEYER, L.D. and KRAMER, L.A. 1969: "Erosion equations predict landscape development". Agricultural Engineering, Vol.50(9); p522-523.

Key words: analytical techniques; sediment control.

The effect of slope shape on the sediment load from several land slopes is discussed. A procedure is described for determining the slope shape which will minimise sediment movement and slope shape changes. An example is presented which applies the technique to a hillside construction site. This article will be of special interest to highway planners and land developers.

MEYER, L.D. and PORTS, M.A. 1976: "Mini-course 1: prediction and control of urban erosion and sedimentation". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p323-331.

Key words: sediment yield; erosion rates; analytical techniques; erosion control.

Since soil erosion and sedimentation by water are complex processes, a better understanding of them provides a sound basis for developing improved prediction and control methods for urban areas. The Universal Soil Loss Equation is an important technique for evaluating urban erosion rates, and various conservation practices are effective for controlling urban erosion and sedimentation. Design of control plans requires the selection of appropriate control practices. These topics are discussed and illustrated as they relate to solving urban problems in erosion and sedimentation.

MILASZEWSKI, R. and OSUCH-PAJZDZINSKA, E. 1972: "Features of rainfall generated runoff pollution". GWSTA, Vol.46(4); p112-116 (In Polish).

Key words: rainfall-runoff relationships; water pollution sources; industrial wastes; air pollution effects; pesticides; organic compounds; nutrients; ammonia.

Problems related to runoff pollution are reviewed. Industrial development and urbanisation during the past years have led to a considerable degree of air pollution affecting the purity of the rain water. Precipitation generated runoff may carry aerosols from industrial smoke, dusts or other pollutants, radioactive fallout, synthetic fertilisers and pesticides, domestic pollutants, or other impurities. Nitrogen, phosphorus, and organochloric compounds ranging from 0.5 to 2.8 mg/litre, 0 to 0.9 mg/litre, and 0.08 to 0.41 mg/litre concentrations, respectively, in rain water were found while 0.7 to 2.9 mg/litre of ammonia were analysed from roof runoff. Included in this article are graphs describing the diurnal variation of ammonia concentrations in domestic sewage systems and discussions on the sewage systems as affected by the runoff. The intensity of road traffic and ground conditions constitute additional factors in the contamination of the runoff.

MILLER, C.R. and VIESSMAN, W. 1972: "Runoff volumes from small urban watersheds". Water Resources Research, Vol.8(2); p429-434.

Key words: rainfall-runoff relationships; surface runoff; storm runoff.

An empirical equation estimates the runoff volume from rainfall on small urban watersheds. If the rainfall is less than 1.5 inches, the runoff is predicted by the relationship between the percent impervious area in the watershed and the percent excess rainfall. An adjustment is made for the initial abstraction combined with the initial surface depression storage. For rainfall amounts greater than 1.5 inches, an additional increment of runoff is added for the pervious areas by using the hydrologic soil class, the vegetative cover, and the controlling parameters. Detailed 1 or 5 minute rainfall and runoff records from four small urban watersheds for 77 storms were used to develop the procedure. The method was tested on 17 additional storms on these watersheds. The maximum prediction error was 37 percent for over 80 percent of the test events. The median error was 17 percent of the actual runoff.

MILLER, E.G. 1966: "Effect of urbanisation on low flow". U.S. Geol. Survey prof. paper No.550-A; p166.

Key words: low flow; urbanisation.

Although the most commonly accepted hydrologic effect of urbanisation is an increase in peak flows, urbanisation sometimes affects low flow also. Contrary to what might be expected to result from a decrease in pervious area, the low flows on two streams were

found to be increased by urbanisation. In one instance the increase was due to return flow from domestic and industrial use, and in the other instance it was due to return flow from irrigation. Under extreme low flow conditions, as much as 2/3 of the flow of Assunpink Creek, in central New Jersey, originates at a sewage treatment plant servicing an area that obtains its water from outside the basin drained by the creek. In addition, the author found that the return flow from 15 individual plants along the creek totalled 2 cubic feet per second more than the 38 cfs withdrawn. These findings indicate that the natural flow of this creek has been increased considerably by urbanisation.

MILLER, J.F. 1969: "Generalised charts of hydrologic factors useful in urban planning". Paper presented at the AGU 1969 National Fall Meeting.

Key words: hydrologic data; urban hydrology.

The Environmental Science Services Administration prepares maps and tables of average and extreme values for various climatic and hydrologic factors. Many of these products are useful to the urban planner. A brief description is given of the meteorological or climatological basis for some of these products and examples are shown of possible applications to urban hydrology.

MILLER, R.A. et al. 1971: "Hydrology of two small river basins in Pennsylvania before urbanisation". U.S. Geol. Survey prof. paper No.701-A; 57pp.

Key words: hydrologic data; landuse change; suspended solids; water pollution sources.

Basic data on water quality, chemical quality, and suspended sediment are tabulated to record the conditions existing in two basins near Philadelphia, each about 32 square miles in area. The basins in 1970 are agricultural land for the most part, but urban and industrial development is imminent as the Philadelphia metropolitan area expands. Hopefully, as changes caused by urbanisation occur in future years, data published herein will be useful as a base for comparison. Pickering Creek basin has a higher population than the upper East Branch Brandywine Creek basin. The two are comparable in discharge characteristics and in shapes and sizes of channels, but the Pickering Creek basin is producing a considerably larger suspended sediment load. Also the effects of urbanisation are discernible in some chemical parameters. During the study, a small sub-basin was converted from agricultural use to an industrial park. This change resulted in a marked increase in sulphates, nitrates, chlorides, and dissolved solids in the streamflow.

MILLS, W.C. et al. 1976: "Use of a piecewise linear model with spatial struc-

ture and input for evaluating agricultural to urban hydrologic impact". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p215-223.

Key words: landuse change; mathematical models; hydrographs.

A distributed watershed model that provides a framework for evaluating the hydrologic impact of change from agricultural to urban land use is described. The model incorporates a grid system for obtaining and structuring input of spatially distributed watershed and rainfall information. The SCS curve number system is used to quantify watershed soil-cover complexes and is linked to a retention function for determining effective rain and runoff. Routing of overland and channel flow is done by convolution with the impulse response of a linear reservoir. The reservoir time constant is related to Manning's flow equation and a feedback mechanism is incorporated to give piecewise linearisation of the watershed response. The watershed model is tested on three instrumented watersheds by simulating runoff hydrographs and comparing them with measured hydrographs. Use of the model for evaluating hydrologic effects of urbanisation is demonstrated by simulating and comparing hydrographs for several different land use patterns.

MISCHE, E.F. and DHARMADHIKARI, V.V. 1971: "Runoff - a potential resource". Water and Wastes Engineering, Vol.8(2); p28-31.

Key words: storm runoff; urbanisation; water pollution sources; waste water treatment; urban hydrology; suspended solids; pesticides; bacteria; nutrients.

The authors suggest that urban runoff is a potential water resource, but little consideration has been given to its treatment and reuse. Experiments have been carried out on the runoff from 3 urban areas in Arizona, with different degrees of development, to determine the composition of the runoff and possible methods of treatment. The suspended solids content was found to decrease as the area became more developed and paved, and simple coagulation with alum removed most of the solids. The concentrations of nitrate and phosphate were low, and 67-80 percent of the COD was removed by removal of suspended solids. The highest concentrations of bacterial contamination were found in the more developed areas, but pesticide concentrations were low. It was concluded that urban runoff was amenable to treatment by coagulation, although the sludge produced could present a disposal problem, but further treatment would depend on the use to which the water was to be put.

MITCHELL, R.N. 1976: "Hydrologic data for urban studies in the Austin, Texas metropolitan area, 1974". U.S. Geol. Survey open-file report; 60pp.

Key words: hydrologic data; rainfall-runoff relationships; urban runoff; data collection; peak discharge; hydrographs.

Rainfall and runoff data are presented for Waller Creek and Wilbarger Creek, Texas, for the 1974 water year (October 1, 1973 to September 30, 1974). The Waller Creek drainage area lies entirely within the city of Austin, with the headwaters originating in the northern part of the city. The creek flows south for 6.6 miles to the Colorado River. Storm sewers and street gutters divert runoff both into and out of the natural drainage area. The headwaters of Wilbarger Creek originate in Travis County near the Williamson County line. The creek flows southeasterly about 40 miles to the Colorado River. The Wilbarger Creek study area is about 15 miles north of the city of Austin. A summary of rainfall-runoff data for each storm is shown. Computations with hydrograph and mass curves for each storm are included.

MITCI, C. 1974: "Determine urban runoff the simple way". *Water and Wastes Engineering*, Vol.11(1); p24,26,35-36.

Key words: flood forecasting; flood routing; analytical techniques; hydrographs.

The Montreal Urban Community wanted runoff hydrographs based on storm patterns for its runoff system designs. A simplified method, based on precipitation statistics and updated intensity-duration curves, permits mathematical simulation of design storms of various frequencies. Data from a flow measurement program and the inflow from each sub-basin are used to route the design storm flow through sewage collectors to obtain the total system outflow hydrograph. For each given storm frequency and various percentages of impervious surface, the hydrograph peaks, concentrated through the sewer system, give a chart to determine sewer facility size.

MIYATA, M. 1969: "Variation in runoff and flood drainage caused by urbanisation in the Shakuji River basin, Tokyo". *Geographical Review of Japan*, Vol.42(10); p667-680. (In Japanese).

Key words: rainfall-runoff relationships; peak discharge; landuse change.

The changes in runoff brought about by urbanisation are examined in the Shakuji River basin (47.98 square km). A hydrological analysis was made of two comparable storms (typhoon no.22 in 1958 and typhoon no.4 in 1966) using the impermeable area as an urbanisation index, runoff ratio, peak flow and other indices. In 1958, the urbanisation ratio was 0.26 and the runoff ratio, 0.50; in 1966 the respective values were 0.42 and 0.52. The data are compared with a similar study made in the Meguro River basin where in 1966, the urbanisation ratio was 0.82 and the runoff ratio, 0.55. It is es-

timated that an increase in the urbanisation ratio from 0.60 to 1.00 gives an increase in runoff ratio from 0.56 to 0.59; peak flow increases from 126.5 cubic metres/sec to 179.6 cubic metres/sec.

MONITION, L. 1977: "Effects of urbanisation on ground water". In, *Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality*. IAHS Publication No.123; p162-166.

Key words: ground water resources; urbanisation.

The new law promulgated in July 1976 concerning the protection of the natural environment states that the ground water and the subsoil are resources that must be protected from all forms of degradation. The effects of urbanisation on ground water are characterised by changes in recharge, runoff, piezometric level, flow and physical and chemical properties. The quantitative evaluation of these impacts is now possible by means of simulation techniques which allow one to analyse and predict the detrimental changes. Some examples of the effects of urbanisation on ground water (aquifers) are mentioned: galleries, tunnels, metros, underground parking, canalisation of water courses, water supply, gravel pits.

MOORE, B.E. et al. 1975: "Viral association with suspended solids". *Water Research*, Vol.9; p197-203.

Key words: suspended solids; viral factors.

Laboratory models and field sewage samples were used to study viral association with particulates in suspension. Poliovirus and coliphages T2, T7 and f2 were tested for their adsorption and elution from both organic and inorganic suspended solids at a variety of pH values and in both the presence and absence of a divalent cation. The results indicate that no one of the viruses tested can be used to describe a general pattern of adsorption. T2 and f2 readily associated with the clays used in the presence of divalent cation, while T7 and poliovirus adsorbed equally well to both organic and inorganic particulates. All viruses varied in the degree to which they associated with naturally-occurring suspended solids in primary and final sewage effluents; maximal association occurred at the pH extremes of 4.0 and 10.0 for all systems. Regardless of the conditions used to effect adsorption, all viruses tested, with the exception of f2, were infective by plaque assay in their adsorbed form. These data suggest that no one coliphage system can acceptably model for behavior of poliovirus in laboratory or field conditions. Furthermore, the results reaffirm and broaden the findings that viruses associated with suspended particulates are infective. Therefore, any system used to monitor virus levels in the environment must adequately account not only

for free virus, but also for those which are solids-associated.

MOORE, W.L. and MORGAN, C.W. (eds). 1969: "Effects of watershed changes on streamflow". Section 3, Urban Watersheds, Water Resources Symposium No.2, University of Texas, Austin. Texas Univ. Press; p183-254.

Key words: urbanisation; rainfall-runoff relationships; hydrographs; flood control; watershed management; peak discharge; model studies; mathematical models; computer models; analog models.

This special lecture series was arranged to present the most advanced approaches to evaluating the effects of watershed changes on streamflow. To an increasing degree man's activities are altering the hydrologic characteristics of watersheds, both rural and urban, and it is urgent to know the character and extent of the changes and how they affect plans for development. Numerous field studies designed to evaluate the effect of specific watershed changes by comparisons between watersheds have been in operation for sufficient time to build up a significant length of record. New methods of computer simulation of watersheds have reached a stage of development to offer an attractive tool for attacking the problem in new ways. The effects of the changes can best be evaluated when the entire performance of the watershed is understood in detail. Then all of the physical processes can be followed and the performance of the watershed can be simulated by numerical or analog techniques which correspond to the physical processes. Watershed changes produce effects in both the amount and the quality of streamflow. The topics discussed include model studies, land treatment in rural watersheds, flood control structures, rural pollution, the effects of urbanisation on peak flow, the effects of urbanisation on water yield, and urban water quality changes.

MOREAU, D.H. et al. 1973: "Regional water resource planning for urban needs: part II (appendices)". North Carolina Water Resources Research Institute, Raleigh, Report No.77, (UNC-WRRI73-77); 88pp.

Key words: water pollution control; model studies.

Appendices including methodology used in employment projections, water resource simulation model, optimal control of multi-unit inter-basin water resource systems, statistics and models of streamflow, and water quality model.

MORI, Y. 1974: "An analysis of runoff in an urban area". Research Report of Chiba Institute of Technology, No.19; p133-137. (In Japanese).

Key words: sewage treatment; urban runoff; analytical techniques.

Amounts of effective rainfall entering a sewage channel in the Tokyo area were calculated and compared with observed values. The sewage channel selected is 4300 m long and its surrounding area is considered to be 6.2 sq km. Market and residential areas are located at the up-stream portion of the channel; industrial and business areas are located at the downstream end. Types of rainfall are divided into eleven categories based on the rainfall intensity and rainfall period. No clear relationship between effective rainfall and rainfall type was observed. In all cases, the rainfall runoff to the sewage channel was completed within one hour after the precipitation stopped. The effective rainfall increased with an increase in the rainfall intensity. The calculation used basic equations for the runoff curve, assuming Manning's law.

MORRISON, K. et al. 1971: "Storm water runoff from an urban highway drainage system". District of Columbia, Dept. of Highways and Traffic, Washington. Materials Development and Research Divn., Final Report; 141pp. (NTIS PB-207 275).

Key words: surface runoff; mathematical models; storm runoff.

The purpose of this study is to develop a better method for estimating urban runoff in designing urban highway drainage systems in the district of Columbia. An underpass pumping station for depressed highways was gauged from 1964 to 1969 to record the urban storm runoff into this station. 18 observed storm records were compared to the computed results by 3 currently used methods of prediction: the rational method, the unit hydrograph method, and the modified area-time method.

MORROW, N.L. and BRIEF, R.S. 1971: "Elemental composition of suspended particulate matter in metropolitan New York". Environmental Science and Technology, Vol.5(9); p786-789.

Key words: suspended solids; chemical analysis; metals.

Suspended particulate matter was collected every sixth day at five stations in the New York metropolitan area for one year using high-volume samplers and Whatman no.41 filters. These samples were analysed by emission spectrography for calcium, lead, iron, copper, aluminium, silicon, nickel, vanadium, sodium, and magnesium. This sampling and analysis procedure has the advantage of eliminating the acid extraction step common to methods in which glass-fibre collection media are employed, and of permitting Si, Al, and other elements present in glass to be determined without high blank corrections. In general, trends in the concentrations of the elements are not obvious, though most of the elements seem to follow approximately the same pattern over the year.

MUELLER, R.F and LAHN, F.M. 1970: "The Anacostia River, ecological imbalance of an urban valley". National Aeronautics and Space Admin., Tech. Memorandum X-65549; 28pp.

Key words: urbanisation; water pollution sources; sediment transport; industrial wastes.

The Anacostia River, a branch of the Potomac, flows in the eastern part of the district of Columbia, and in adjacent suburban Prince George's and Montgomery Counties. It is in many ways a prototype of the urban stream showing severe ecological imbalances resulting from intensive and unplanned land use and the general impact of technology. The Anacostia River valley is out of balance with respect to stresses placed upon it by uncontrolled technological expansion. Symptoms of this imbalance are widespread biological, chemical and physical pollution as well as destructive land use and hydrologic practices. As a result the potential as an environmental asset is being lost to the nearly one million inhabitants of the basin. Instead it has become an enormous burden and threat to the health and well-being of these inhabitants. The environmental deterioration will lead to high tax burdens for years to come.

MULLER, R.A. 1967: "Some effects of urbanisation on runoff as evaluated by Thornthwaite water balance models". Proc. 3rd Annual American Water Resources Conference, November 1967, San Francisco, California; p127-136.

Key words: rainfall-runoff relationships; urbanisation; flood control.

Water balance methodology (including the Thornthwaite potential evapotranspiration) and water balance models are applied to the Raritan River basin in New Jersey, in order to gain some understanding of hydroclimatological processes and interrelationships associated with urbanisation of drainage basins. The precise objectives are: to compare and contrast selected Thornthwaite water balance components as calculated by several more or less 'standard' techniques; to demonstrate that potential evapotranspiration and water balance models can be utilised as hydroclimatological controls to obtain first approximations of the consequences of land cover type change, or urbanisation within a river basin; and, to explore generated water balance data based on the assumption of the transformation of a watershed from rural to urban. Calculated runoff takes into account the monthly and seasonal variation of precipitation and soil moisture storage as well as energy availability for evapotranspiration loss. Measured runoff not only includes the climatic variation but in addition the effects of landuse change. Hence, the differences between calculated and measured runoff over time should be a measure of the effects of landuse change on runoff.

MULLER, R.A. 1969: "Water balance evaluation of effects of subdivisions on water yields in Middlesex County, New Jersey". Proc. Assoc. of American Geographers, 1; p121-126.

Key words: rainfall-runoff relationships.

This paper considers the role of impervious surfaces associated with urban subdivisions within the hydrological cycle. Thornthwaite's potential evapotranspiration and water balance models are utilised to estimate first approximations of increased runoff associated with subdivision development in Middlesex County, N.J. The models indicate that annual runoff increases about 29 percent, but that there is a wide variation between wet and dry years. Most of the increase occurs during summer and autumn.

MULLER, W.J. 1971: "The contribution of rain runoffs to water pollution". Gas-Wasserfach (Wasser/Abwasser), Vol.112(1); p15-17.

Key words: water pollution sources; urbanisation; suspended solids; storm runoff; leaves; solid wastes; oil wastes; miscellaneous chemicals.

In the Federal Republic of Germany the median precipitation (forty-year average from those measured between 1891 and 1930) is 803 mm/year. Of this 365 mm or 45.5 percent reaches the ocean as direct runoff or indirect runoff or as waste water. The runoffs carry along numerous substances in dissolved or suspended form. For assessment of the contribution of rain runoffs to water pollution, the runoffs from residential and industrial areas are of concern. Urban areas span 9.6 percent of the total surface of the Federal Republic. The main runoff from these areas has been determined to be 10,140 million cbm/year. It carries street dust, manure, leaves, abrasions from street pavements and rubber from tyres of vehicles, oil and fuel lost by vehicles, and other inorganic matter. The content of suspended matter is particularly high. The BOD ranges on an average between 10 and 30 mg/litre. From tar and asphalt pavements carcinogenic matter is carried along. The great disadvantage of rain runoffs is that they burden the waterways spasmodically. With continuing urbanisation it will become necessary to collect the rain runoffs and purify them before they can enter the waterways.

MUNRO, C.H. 1976: "Case study of effect of increased urbanisation on flood damage for Mogill Creek, Brisbane (Australia)". In, Inst. Engineers Hydrology Symposium, Sydney, Australia, preprints of papers; p67-72.

Key words: urbanisation; flood discharge; peak discharge.

The effect of increased urbanisation of metropolitan suburbs on flood discharges is discussed, and a case study is presented for Mogill Creek, a tribu-

tary of the Brisbane River, with some reference to Breakfast Creek and Kedron Brook. Based on three procedures reported in U.S. literature, the conclusion of the study is that an increase in urbanisation rendering up to 20 percent of the catchment impervious causes only small increases in peak flood discharges, peak flood levels and average annual flood damage estimates. The outer suburbs of Brisbane are considered to be such that this percentage of impervious surface would rarely be exceeded.

NAKAMURA, M.N. and YOUNG, R.H.F. 1974: "Estimation of urban storm water quality in Kalihi Stream drainage basin, Oahu, Hawaii". Technical Memo. No.45, Water Resources Research Centre, Hawaii University, Honolulu; 39pp. (NTIS PB-247 101).

Key words: storm runoff; water pollution sources; urbanisation; solid wastes.

Urban runoff pollution potential can be linked to the constituents of street wastes as these wastes constitute the principal proportion of runoff contaminant material. This study was an attempt to correlate pollution associated with street litter with baseline quality data acquired in a previous study of Kalihi Stream. Correlations were made between street sweepings quality, length of street, land use, street surface characteristics, and rainfall intensity in order to estimate the concentration of pollutants in urban storm water. The overall comparability of obtained estimated with existent storm water quality data suggests the possibility of obtaining fairly acceptable quantification of pollution potential attributable to urban runoff by utilizing procedures described. However, the number of assumptions required leads to some inadequacies in predicting BOD5 and COD levels with actual field data. The good correlation of population density based formulæ for street length with actual street lengths indicates a simple method for approximating street refuse pollution based on loadings per length of curb.

NARAYANA, V.V. et al. 1969: "Analog computer simulation of the runoff characteristics of an urban watershed". Utah Water Research Laboratory, Logan, Utah. (College of Engineering, Utah State University), Rept. No.PRWG-56-1; 174pp. (NTIS PB-190 483).

Key words: mathematical models; analog models; surface runoff; flood routing.

In the synthesis of hydrograph characteristics of small urban watersheds, the distribution of water among the various phases of the runoff process is attempted by the concept of equivalent rural watershed. The urban parameters considered in the study are percentage impervious cover and characteristic impervious length factor. A mathematical model is developed for the equivalent rural watershed with precipitation as input. The hydrograph of outflow is obtained by chronologically deducting the losses due to interception, infiltration, and depression storages from precipitation and then routing through the watershed storage. This mathematical procedure is programmed on an analog computer and is tested with data from the Waller Creek watershed, at Austin, Texas. In the verification process, watershed coefficients representing interception, infiltration, and depression storage are established by trial and error such that the simulated and observed hydrographs are nearly identical with high statistical correlation. Sensitivity studies indicate

the relative influence of the watershed coefficients on the runoff process. The watershed coefficients determined by model verification for each year of study are related to corresponding urban parameters.

NARAYANA, V.V. et al. 1970: "Statistical relationships between storm and urban watershed characteristics". Utah Water Research Lab., Logan. PRWC-74-2 W71-05144, OWRR-B-025-UTAH(4); 62pp.

Key words: urban drainage; rainfall-runoff relationships; analytical techniques.

A procedure is proposed for predicting peak runoff rates from small urban and rural watersheds based upon measurable storm and watershed characteristics. The technique was tested for a number of runoff events on the Boneyard Creek watershed at Urbana, Illinois, and the results of this test are included. The procedure will be particularly useful for estimating runoff rates from small ungauged drainage areas, and thus will be directly applicable to both design and water management problems.

NARAYANA, V.V. et al. 1971: "Simulation of runoff from urban watersheds". Water Resources Bulletin, Vol.7(Pt.1); p54-68.

Key words: mathematical models; storm runoff; rainfall-runoff relationships; hydrographs.

A mathematical model for urban watersheds is being developed in stages at the Utah Water Research Laboratory, Utah State University at Logan. In verifying the watershed as a unit, watershed coefficients are determined on the computer, and related to the urbanisation characteristics. The second stage of verification consists of dividing the watershed into subzones, and determining the urban parameters within each subzone. Each subzone is then individually modelled, and outflow hydrographs are routed through succeeding downstream subzones to the gauging point. The model thus makes it possible to: (a) develop runoff models for subzone hydrographs within the urban watershed, and (b) accounts for spatial variations of storm and watershed characteristics. An attempt was also made to analytically model the outflow hydrograph based on storm and watershed characteristics.

NARAYANA, V.V. and RILEY, J.P. 1968: "Application of an electronic analog computer to the evaluation of the effects of urbanisation on the runoff characteristics of small watersheds". In, Proc. of the symposium on use of analog and digital computers in hydrology, IASH Publication No.80, Vol.1; p38-48.

Key words: analog models; rainfall-runoff relationships.

In the synthesis of hydrograph charac-

teristics of small urban watersheds, the distribution of the water among the various phases of the runoff process is attempted by the concept of "equivalent rural watershed". For a given input into the urban and equivalent rural models, the outputs are identical. The hydrograph of outflow from an urban watershed is obtained by chronologically deducting the losses due to interception, infiltration, and depression storage from precipitation and then routing it through the surface and channel storages. This is accomplished with an analog computer. Testing and verification is done with rainfall and runoff data from the Waller Creek watershed near Austin, Texas. Coefficients representing interception, depression storage, and infiltration are determined by trial and error so that the simulated hydrograph is nearly identical to the measured hydrograph of the prototype. The variation in the values of these coefficients from year to year is assumed to be due to the percentage impervious cover and the characteristic impervious length.

NATHAN, K. et al. 1970: "Hydrology of a small rural watershed under suburban development - Phase I". Rutgers, The State University, New Brunswick, N.J. Water Resources Research Inst.; 48pp. (NTIS PB-191 715).

Key words: mathematical models; surface runoff.

A small rural watershed in New Jersey is being studied for changes in hydrological characteristics during suburban development. Two stream gauging stations and two recording precipitation gauges have been established in the area. During phase one, covered in this report, regression models for the hydrological properties have been derived for the undeveloped basin. A standard unit hydrograph has also been established for this period. Monitoring of water quality has been initiated recently.

NATIONAL ASSOC'N OF COUNTIES RESEARCH FOUNDATION. 1970: "Urban soil erosion and sediment control". National Association of Counties Research Foundation, Washington; 113pp. (EPA-15030DTL05/70; NTIS PB-196 111).

Key words: erosion; sediment control; surface runoff; water pollution; watershed management.

A survey was carried out to determine the magnitude of the problem caused by soil erosion and the measures currently taken to control it. It was found that extensive soil erosion occurs in developing areas and it is a significant threat to both soil and water resources. Although methods are available for controlling sedimentation problems, better administrative approaches are required to include the various interests and pressures associated with urban and suburban development; at present establishing control of sedimentation problems requires the involvement of several local groups and

agencies. Also included in this report is a "community action guidebook" which describes methods by which local governments can organise, plan, staff, and implement urban sedimentation control problems.

NATIONAL WATER COUNCIL. 1976: "Working party on the hydraulic design of storm sewers, review of progress to June, 1975". Dept. of the Environment/National Water Council Standing Technical Committees, Report No.1 (From NWC, Queen Annes Gate, London, U.K.)

Key words: storm runoff; urban drainage.

In March 1975 following consultations between the Department of the Environment, the National Water Council and the regional water authorities, the Standing Committee on Sewers and Water Mains was set up to advise the above-mentioned bodies on the design, construction, operation and maintenance of sewers, water mains and ancillary works; to assess and where necessary monitor research works in progress and to recommend coordination where desirable; to study new techniques and materials and to advise on priorities for research; and to report as considered necessary but at least every two years.

The Working Party on the Hydraulic Design of Storm Sewers, previously set up by the Department of the Environment in March 1974 and now reporting to the Standing Committee, has produced a review of its progress during the period March 1974 to June 1975. This review has been considered by the Standing Committee on Sewers and Water Mains who recommend that it be published. The report contains information on current design methods, research and future development. The Working Party is continuing its work with the object of producing guidance and a manual of good practice for the design of storm sewerage systems.

NEBOISINE, R. and VERCELLI, G.L. 1974: "Is the separation of sewers desirable". In, Proceedings National Symposium on urban rainfall and runoff and sediment control, University of Kentucky, Lexington, Ky.; p115-123.

Key words: combined sewers; urban runoff; storm runoff; sewage treatment; heavy metals; water pollution.

All but the more recently built cities were originally provided with combined sewer systems. The concept of having two separate sewer systems gained ground some 50 years ago. The basic rationale for such a belief was that the storm runoff consisted of clean water that could be innocuously discharged without any treatment into the nearest water body. Whatever technical and economic justifications there may have been for such a rule, these have been weakened by recent developments. First, as urban growth has resulted in ever greater agglomerations of population and industry, and as street traff-

ic has intensified, it has been found that the runoff from the streets contains many contaminants in concentrations comparable to those in sanitary sewage. This paper contended when new sewage facilities are being planned, one must carefully weigh the advantages and disadvantages, both in ecological and economic terms, of the two alternatives, either: (1) building more costly separate sewer systems with the result that eventually treatment will be required not only of the dry weather flow, but eventually also the storm water flows; or (2) building a combined system with the necessary flow detention or equalising facilities that will permit treating not only the sanitary but also most of the first flush flows in one plant and cleaning up the storm water overflows by an appropriate process and equipment in another plant or plants.

NEGULESCU, M. and RABINOVICI, I. 1964: "Discharge of rain water from urban sewers into streams". Hidrotehnica, Vol.9; p205-209.

Key words: storm runoff; water pollution; water pollution control; urban drainage; combined sewers.

It is indicated that rain water discharged from combined or separate sewers in urban areas can have as great or even double the polluting effect of domestic sewage and can damage the receiving stream particularly if the areas are industrial. Storage reservoirs along the sewerage system or as part of the treatment plant are suggested as a means of protecting streams.

NELSON, T.L. 1970: "Synthetic unit hydrograph relationships, Trinity River tributaries, Fort Worth - Dallas urban area". In, Seminar on urban hydrology, Davis Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.6; 18pp.

Key words: urban hydrology; hydrographs; rainfall-runoff relationships; storm runoff; urban runoff; peak discharge; flood forecasting.

Fort Worth and Dallas, Texas are a rapidly expanding urban area. Although much of the growth has been orderly and well planned, development in many flood prone areas has resulted in severe flood damages and in the necessity for the construction of local or Federal flood control works. Relationships are presented to be used to develop synthetic unit hydrographs for ungauged areas in the Fort Worth-Dallas area. The method accounts for differences in urban development on adjacent areas and may be used to predict the affect that urban development might have on a given area. Preliminary calculations indicate that the lag relationship may also be valid in other parts of north-central Texas. Unit hydrograph determinations were made for each of eight stream gauges for each storm period which could be analysed. In order to generalise the results of these stu-

dies for use in ungauged areas, the coefficients were correlated with measurable watershed characteristics. Since in the Fort Worth-Dallas area full urbanisation of an entirely rural area reduces the lag time by about 50 percent, the peak discharge of the unit hydrograph will be approximately doubled.

NETTLES, M.C. and STAFFORD, D.B. 1974: "Determining landuse changes in watersheds by aerial photographic measurements". Clemson University, S.C., Water Resources Research Institute, WRRRI 47; 63pp. (NTIS PB-239 192).

Key words: aerial photography; urbanisation; remote sensing; landuse change.

Techniques are described for using aerial photographs to investigate landuse changes in watersheds. Landuse changes in two watersheds in western South Carolina were examined. Six sets of existing aerial photographs taken at approximately five year intervals were used to delineate, classify, code, and measure the areas of various land use classes in the two watersheds. The land use classes employed were those that had different runoff characteristics. The area occupied by each land use class was measured on scaled photographic enlargements by using a planimeter. Significant changes in land use were observed in the two watersheds over the study period. The results indicate that the use of aerial photographs to obtain data on the historical distribution of land use in watersheds represents a satisfactory approach that could be used more widely.

NEUBERGER, J.W. 1969: "Conservation programs in the urban fringe". J. Soil Water Conservation, Vol.24(6); p216-218.

Key words: erosion control; sediment control.

Solutions to land erosion and drainage problems caused by suburban sprawl in a Nebraska conservation district are outlined. Increased paving, roofing, and compacted soils result in erosion and flooding; therefore, the construction of major and minor storm drainage and water runoff systems is recommended. An Omaha program to reduce sedimentation from developing areas is detailed in addition to guidelines for good land resource conservation. Examples of developers' initiatives towards furthering the urban conservation program are cited.

NEUMANN, W. 1977: "The prediction of the rainfall-runoff behaviour in urban areas". Wasserwirtschaft, Vol.67(4); p89-93.

Key words: rainfall-runoff relationships; model studies; surface runoff; urban runoff.

A model for the prediction of urban ra-

infall-runoff relationships was presented. A division into surface and channel systems was necessary, and an overland flow model was especially important regarding the transfer of areal characteristics. A single linear reservoir model suffices if the parameter is based on specific area characteristic values. Variables considered included length of flow, roughness of area surface, and slope. Rainfall intensity influences were necessarily considered in the nonlinear rainfall-runoff process. The model provided practical solutions to this problem.

NEW JERSEY STATE CONSERVATION COMMITTEE. 1972: "Standards and specifications for control of sediment and erosion in urban areas for New Jersey". New Jersey State Conservation Committee Handbook, New Jersey Dept. of Agriculture.

Key words: sediment control; erosion control; hydrologic data.

A handbook to establish uniform criteria for the design, installation and maintenance of sediment and erosion control measures in urban areas. Contains standards and specifications for various erosion and sediment control. The appendix gives design aids, references, suggested maintenance, guidelines for erosion control along utility rights-of-way, protection for trees, mixtures and kinds of soil and seed, instructions for jutting waterways and data on erosion.

NEWTON, C.D. et al. 1974: "Street runoff as a source of lead pollution". J. Water Pollution Control Federation, Vol.46(5); p999-1000.

Key words: storm runoff; lead.

The possibility that this source could contribute a significant amount of lead may be seen from the following considerations. Lead is a primary contaminant of automobile emissions and tends to be deposited within a short distance of the roadbed. The highest concentration is deposited on the roadbed, where it tends to remain unabsorbed. A significant concentration of lead would then appear in the runoff (which is essentially complete) from the roadbed. Theoretical and experimental support for this theory is described.

NEWTON, S.G. and PAINTER, R.B. 1974: "A mathematical examination of urban runoff predictions". Proc. Inst. Civil Engineers, Part 2, Vol.57 (March); p143-157.

Key words: storm runoff; flood forecasting; mathematical models.

Annual expenditure on storm sewer systems in the U.K. exceeds 100 million pounds, and this figure is likely to increase as existing combined systems become inadequate or fail to meet the improved standards for water quality in rivers. The prediction of the amount

and distribution of storm runoff from impervious areas and its subsequent modifications in the pipe network are fundamental problems in storm sewer design. Many design methods exist, ranging from the rational formula put forward in 1925 to the more sophisticated Transport and Road Research Laboratory method of the mid-1950s. There remains considerable uncertainty concerning the underlying assumptions of the various methods and regarding the differences between them. This paper presents a rigorous mathematical examination of the more frequently used methods, thereby defining their true limitations and indicating where improvements should be made.

NICHOLIS, J. 1976: "Runoff pollution and the rehabilitation of an urban river". *Architecture Australia*, Vol.65(5); p52-57.

Key words: urbanisation; landuse change; pollution abatement.

Discusses the profound changes to the hydrological cycle in a natural catchment caused by urbanisation. The author outlines an environmental study and the landscape design which was prepared for the Cooks River Valley in Australia. Tree planting is increased to help transpiration: porous pavements increase infiltration through the soil: grassed channels for storm water trap solid matter and allow water to soak into the soil. These measures greatly reduce polluted runoff into the river. The land around the river is to be developed as a recreation area and bank treatments for rehabilitating the river are proposed as a means of improving physical access and its ability to support life.

NIGHTINGALE, H.J. 1970: "Statistical evaluation of salinity and nitrate content and trends beneath urban and agriculture areas - Fresno, California". *Ground Water*, Vol.3(1); p22-29.

Key words: water pollution sources; ground water resources; nitrates; salinity; chlorides.

The salinity and nitrate content of well water under Fresno and Clovis, Calif., and the immediately surrounding irrigated agricultural zone were studied using data for 1950 through 1967. Salinity of the urban zone ground water has increased with time, while that of the agricultural zone has fluctuated considerably. In a 12 square mile area northeast of Fresno and southwest of Clovis, ground water nitrate level was around 25 to 35 mg per litre downgradient from the Clovis sewage plant and leaching ponds, about the same as the nitrate concentration in an area of septic tank use.

NIGHTINGALE, H.J. 1975: "Lead, zinc and copper in soils of urban storm runoff retention basins". *J. American Water Works Association*, Vol.67(8); p443-446.

Key words: metals; lead; zinc.

A study was made to determine the amount of three metal contaminants found in the soils of urban storm runoff retention basins. Soil samples were taken at various depths in the basins and analysed for copper, lead and zinc. Results of the soil analyses are shown.

NIILSGARD, V. et al. 1976: "A characterisation of urban storm water runoff in Boulder, Colorado". M.S. Thesis, Dept. of Civil and Environmental Engineering, University of Colorado, Boulder; 170pp. (NTIS PB-264 710).

Key words: urban drainage; urban runoff; water pollution sources; pollution abatement.

This research was an initial study on urban storm water runoff in Boulder, Colorado. The objectives were to measure the pollution characteristics of storm water drainage, and to study its impact on the receiving water quality. Both snowmelt runoff and rainfall discharges were analysed to characterise the storm water with respect to physical and chemical parameters. The study provided the basis for developing a more complete picture of the need for storm water pollution abatement in Boulder.

NORTHROP, W.L. 1970: "Kansas City District experiences in urban hydrology". In, *Seminar on urban hydrology*, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.12; 25pp.

Key words: hydrographs; rainfall-runoff relationships; storm runoff; urban hydrology; urban runoff; peak discharge; urbanisation.

Detailed hydrologic criteria were developed for 10 small basins near Kansas City with very limited gauging records. These criteria have been used for flood plain reports, technical service-type information to local agencies, and survey-type studies for flood control measures. The effects of existing and projected urbanisation are factors in a majority of these projects. Discharge-frequency curves and standard project flood peaks were calculated for natural conditions, for existing development, and for proposed improvements in the drainage system. Satisfactory 100-year hydrographs were developed for all inflow points and tributary contributions. Routing studies assumed "road culvert" configuration at outlets and broadcrested overflow weirs control the 100-year pool elevation. A relatively small amount of storage has a large reducing effect on the peak discharges.

NOVOTNY, V. and GOODRICH-MAHONEY, J. 1978: "Comparative assessment of pollution loadings from nonpoint sources in urban land use". *Prog. Wat. Tech.*, Vol.10(5/6); p775-785.

Key words: nonpoint pollution sources;

model studies; computer models; water pollution control.

Large amounts of pollutants are washed into surface waters from nonpoint sources. The factors contributing to the nonpoint pollution from various urban land uses have been investigated using a calibrated and verified hydrologic transport model capable of simulating overland pollution loading and transport. The simulated seasonal loading provided a comparison as to the variability and potential danger to surface waters of typical urban land use activities. The simulated loadings, though typical for midwest urban areas, are not to be considered or used as absolute unit loading figures but rather as a weighted comparison among the land uses. With the exception of developing urban areas most of nonpoint urban pollution originates from impervious areas. The remedial and control measures should therefore be focussed on better maintenance of impervious areas, increased frequency of cleaning, application of pervious seepage beds within large impervious (paved) areas, limiting direct discharges from impervious areas into surface waters, decreasing curb heights and high median barriers, and, generally, increase perviousness of urban settings with concurrent protection of soils with poor permeability or high ground water table.

OBERTS, G.L. 1977: "Water quality effects of potential urban best management practices: a literature review". Wisconsin Dept. of Natural Resources, Madison. Bureau of Water Quality Technical Bulletin No.97; 24pp.

Key words: bibliographies; urban runoff; erosion control; storm runoff; nonpoint pollution sources; urban drainage.

The literature of management approaches to control of urban runoff is reviewed, with emphasis on analysis of water quality effects. Three basic alternative approaches to runoff control from sources as construction, streets, litter, and sewer overflow are discussed: (1) on-site source control, (2) collection and transport of runoff to a different location; and (3) treatment of runoff. Rainfall, which occurs on a predominantly impervious area, as runoff picks up sediments, nutrients, and metals and other toxicants and transports them into the storm water receiving system. The largest concentration, on the rising side of the runoff hydrograph, is termed the 'first flush'. Source control techniques include increased infiltration, retention of runoff/reduction of erosion, reduction of contaminant deposition, and removal of contaminants. Source control is the least expensive approach, and is suitable for small, upland basins. Collection system problems involve reduction of in-channel erosion, increase of runoff water infiltration, storage of runoff, and removal of contaminants. These systems cost more than source control, but are needed for many larger-scale problems. Treatment of discharge, including physical, chemical, biological, or mixed methods, is the most costly approach, but is often the only alternative for highly developed urban areas; the physical-chemical technique is the most cost-effective.

O'CONNOR, D.J. et al. 1973: "Dynamic water quality forecasting and management". Office of Research and Development, U.S. EPA, Washington, D.C. Ecological Research Series, Report No.EPA-660/3-73-009; 201pp.

Key words: mathematical models; computer models; water pollution; eutrophication; nutrients.

This report describes the formulation and initial verification of two modeling frameworks. The first is directed toward an analysis of the impact of the carbonaceous and nitrogenous components and waste water on the dissolved oxygen resources of a natural water system. The second modeling framework concentrates on the interactions between the discharge of nutrient, both nitrogen and phosphorus, and the biomass of the phytoplankton and zooplankton populations which result, as well as incorporating the overall impact on dissolved oxygen. The models are formulated in terms of coupled differential equations which incorporate both the effect of transport due to tidal motion and turbulence, and the kinetics which describe the biological and chemical

transformations that can occur. The modeling frameworks are applied to the Delaware and Potomac estuaries in order to estimate the ability of such models to describe the water quality. Differences between observation and calculation indicate that the major features of the impact of waste water components on eutrophication phenomena can be successfully analysed within the context of the models presented herein.

OERTLI, J.J. and BRADFORD, G.R. 1973: "Contribution to water pollution from agricultural and urban sources in Coachella Valley". Calif. Agric., Vol.27(7); p4-6.

Key words: water pollution sources; agricultural pollution; chemical analysis; miscellaneous chemicals.

The increased awareness of environmental qualities has made it desirable to obtain quantitative data on the contributions of agricultural and urban sources to water pollution. For this reason an investigation was initiated in the Coachella Valley (California) on: the chemical composition of drainage water from cropped fields under various agricultural managements, and the effluents from the nearby Indio sewage treatment plant. The research emphasis was on those nutrients suspected of playing a major role in eutrophication; but a large number of other chemical elements and various other properties were also included in the study. Water samples were collected periodically in late 1969 and the first half of 1970 and a number of stations were revisited in 1973. The samples were brought to the laboratory where chemical composition and electrical conductivity were determined. Results of the study are detailed in this report.

OFFNER, F.F. 1973: "Computer simulation of storm water runoff". J. Hydraul. Divn., Proc. ASCE, Vol.99(HY12); p2185-2194.

Key words: computer models; storm runoff; rainfall-runoff relationships; urban hydrology; urban runoff.

A computer program eliminates most of the intuition or experience required in calculating storm water runoff by the classical rational method. The program gives an approximate solution of the partial differential flow equation over the area. The area considered is divided into a grid of squares, with the elevation and soil condition (flow coefficient, initial surface retention, infiltration rate) tabulated for each grid element; often all these may be considered constant except elevation. Typical rainfall data are entered, and the program gives the runoff into drainage lines as a function of time. Depth of water standing in the area is also computed. Copies of the program are available.

OKE, T.R. 1974: "Review of urban climatol-

ogy, 1968-1973". World Meteorological Organisation, Geneva, WMO Technical Note No.134, WMO No.383; 132pp.

Key words: data collection; model studies; weather modification.

This publication reviews developments in the field of urban climatology since the Symposium on Urban Climates and Building Climatology held at Brussels in 1968 under the joint sponsorship of the World Health Organisation and WMO. During this relatively short period of time the importance of understanding the atmospheric environment of human settlements has become increasingly apparent and the amount of research has greatly expanded. The review is in two parts. The first part deals mainly with observational studies. This begins with a look at work aimed at elucidating the nature of the fundamental flows of energy and water in the city-atmosphere system, and ends with a summary of the continuing work of measuring the climatological effects of these flows. The second part is concerned with attempts to model the workings of urban climates using physico-mathematical techniques. In the review of each topic a short introduction is provided which places the recent findings in perspective. Significant new features and suggestions for areas of new research are briefly noted. Where possible, summary tables of typical results are presented.

OLIVER, B.G. et al. 1974: "Chloride and lead in urban snow". J. Water Pollution Control Federation, Vol.46(4); p766-771.

Key words: chlorides; lead; snowmelt.

The chloride and lead concentrations of snow and runoff in Ottawa, Canada, were determined in order to assess whether snow melting and snow disposal practices were adversely affecting the water of local rivers. The use of sodium chloride for road deicing was shown to increase chloride levels substantially in area rivers. A portion of the lead associated with the burning of leaded gasolines could be traced in the rivers. It was found that a considerable reduction of lead input to the rivers could be accomplished by maintaining snow disposal sites away from watercourses and flood plains.

ORLOB, G.T. 1974: "Selected case studies using storm water management models". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p250-268.

Key words: analytical techniques; computer models; urban runoff; peak discharge.

Investigations of Northwood Tract, Baltimore, Maryland; Pegel T1/T2, Hamburg, Germany; View Ridge, Seattle, Washington; Vine Street, Melbourne, Australia; and a special study of sta-

bility problems are used to illustrate application of the Storm Water Management Models. Observed and simulated runoff peaks were not coincident in time. Watershed yields disagreed. The simulated runoff pattern tended to be smoother and more attenuated than that observed. Simulated runoff was discontinuous. Sometimes initial peaks were not well simulated although subsequent peaks were, and vice versa. The computer runoff for Hamburg compared well with a measured flow for a storm with two distinct precipitation peaks. The model gave a good account of the peak flow for the View Ridge catchment, but was too low for the trailing portion of the storm. The SWMM proved superior in a comparison of models developed by England's Road Research Laboratory and the University of Cincinnati for Melbourne. Often it is difficult to distinguish numerically induced oscillations from hydraulic behaviour that sometimes produces real fluctuations. Numerically induced oscillations can often be eliminated by changes in time step, averaging, or computational techniques.

PACKMAN, J.C. 1974: "The application of unit hydrograph theory in catchments subject to urbanisation". Unpublished MSc Thesis, Imperial College, University of London.

Key words: mathematical models; hydrographs.

PAGE, A.L. and GANJE, T.L. 1978: "Accumulations of lead in soils for regions of high and low motor vehicle traffic density". Environmental Science and Technology, Vol.4(2); p140-142.

Key words: lead; heavy metals.

Accumulation of lead in soils over a period of approximately 40 years was compared for areas of high and low motor vehicle traffic densities. Where motor vehicle traffic density was less than 80 motor vehicles per square mile, no lead accumulations were observed, but where the motor vehicle traffic density was greater than 500 motor vehicles per square mile, the concentration of lead in the surface 2.5 cm. of soil increased by a factor of two to three times. Although large percentage increases were observed in the surface soils from the areas of high motor vehicle traffic density, the amount of lead found in the surface soil did not exceed 52 ppm, a level which is common to many soils from areas of low motor vehicle density and not subjected to atmospheric or industrial lead contaminations.

PALMER, C.L. 1950: "The pollutional effects of storm water overflows from combined sewers". Sewage and Industrial Wastes, Vol.22(2); p154.

Key words: combined sewers; overflows; storm runoff; bacteria; solid wastes.

Storm runoff from land surfaces was sampled at street catch basins in downtown Detroit in 1949. He found BOD's on the order of 96 to 234 mg/l; total solids, 310 to 914 mg/l; and coliform MPN's/100 ml of 25,000 to 930,000.

PALMER, C.L. 1963: "Feasibility of combined sewer systems". J. Water Pollution Control Federation, Vol.35(2); p162.

Key words: combined sewers; storm runoff; bacteria; suspended solids.

Storm runoff from land surfaces was sampled at street catch basins in downtown Detroit during a number of storms in 1960. In these instances, the pollution concentrations were high. Suspended solids means for a number of samples from two storms were 213 and 182 mg/l, respectively; coliform MPN's/100 ml for four storms ranged from 2,300 to 430,000. Concentrations varied widely between points and at the same point during runoff. In some cases the quality of the material became worse as the storm progressed and

in others it became better, and in still others no pattern was apparent.

PAPADAKIS, C.N. and PREUL, H.C. 1971: "Simulation of the rate of hydrologic runoff from an urban watershed". Seventh American Water Resources Association Conference, Washington, D.C.

Key words: urban runoff; mathematical models.

PAPADAKIS, C.N. and PREUL, H.C. 1972: "University of Cincinnati urban runoff model". J. Hydraul. Divn., Proc. ASCE, Vol.98(HY10); p1789-1804.

Key words: hydrographs; mathematical models; urban runoff.

The purpose of this model is to provide a reliable method for obtaining the hydrograph of runoff at any selected point in a sewer system for any given rainfall. This is accomplished by simulating separately the processes involved during a rainfall: infiltration, depression storage, overland flow, gutter flow, and routing through sewers. The model has been developed by using independent hydraulic and hydrologic principles and equations, and by combining the processes sequentially. It is believed that the output of this mathematical model may be helpful in the management of existing sewer systems. It also should be useful in the design of new sewer systems. The model is intended for an urban watershed of at least several hundred acres or more in area; however, it may be applied to any size by appropriate scaling. The main input information required for the simulation of the rate of hydrologic runoff includes a rainfall hyetograph and data from topographic maps or aerial photographs, or both.

PAPADAKIS, C.N. and PREUL, H.C. 1973: "Testing of methods for determination of urban runoff". J. Hydraul. Divn., Proc. ASCE, Vol.99(HY9); p1319-1335.

Key words: model studies; storm runoff; hydrographs.

A brief outline of various methods developed for the calculation of urban storm water runoff is presented. The Chicago Method, the Road Research Laboratory Method, the EPA Storm Water Management Model, and the University of Cincinnati Urban Runoff Model are tested in three urban watersheds: Chicago 10 acre tract, Oakdale 12.9 acre drainage area, and Bloody Run, 2,380 acre urban watershed. All four methods successfully simulate storm water runoff hydrographs in the case of the two small drainage areas. Runoff hydrographs obtained from (EPA) Storm Water Management Model and the University of Cincinnati Urban Runoff Model are compared with recorded hydrographs at the outlet of the Bloody Run Sewer watershed at Cincinnati, Ohio. The com-

parisons indicate that the estimation of the infiltration capacity to be used in these models is of predominant importance in the case of large urban drainage areas.

PARIZEC, R.R. 1971: "Impact of highways on the hydrogeologic environment". In, Environmental geomorphology, (ed. D.R. Coates). Proceedings First Annual Geomorphology Symposia Series, State University of New York, Binghamton, New York; p151-199.

Key words: ground water resources; surface runoff; urbanisation.

Highways may have favourable or unfavourable influences on our environment. These may be social, economic, or physical, chemical, and biological. Such possible changes include: (1) the behavior of aquifers when present in soils and shallow bedrock; (2) the development of extensive ground water drains where cuts extend below the water table; (3) damage and pollution of water supplies; (4) changes in ground and surface water divides and basin areas; (5) reduction of induced streambed infiltration rates due to sedimentation; (6) siltation of channels causing flooding, erosion, and reduction of recharge areas on flood plains; (7) obstruction of ground water flow by abutments, retaining walls, and sheet piling; and (8) changes in runoff and recharge characteristics. Water quality changes may result from: (1) sediment damage to surface and ground water supplies; (2) pollution, resulting from use of highways and related accumulations of oils, chemicals, and hazardous substances through accidental spills; and (3) roadside litter and debris. It is the intent of this paper to review some of the adverse influences that highways have had or may have on the surface water and ground water regimen.

PATRICK, C. 1975: "The nature and significance of sediment derived from roads". Proc. 9th Int. Conference on Sedimentology, Nice. Theme 10; p99-104.

Key words: storm runoff; water pollution sources.

This paper is a preliminary report on a project investigating the nature and extent of pollution to be expected from the discharge of road drainage water to natural streams. Sediment samples have been obtained from the road surface, settling tanks and the beds of streams receiving road drainage. The characteristics of these sediments are described and discussed.

PEAVY, H.S. 1970: "Effects of urban land use on storm water quality in Durham, North Carolina". Duke University Thesis; 101pp.

Key words: water pollution.

PEAVY, H.S. 1976: "Sedimentation from an established urban watershed". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p163-169.

Key words: urban runoff; sediment yield.

This paper briefly reviews the literature concerning runoff and sediment production in urbanising areas. The major thrust of the paper concerns the findings of a research project conducted by the author in Durham, North Carolina, in 1969-70 in which sediment production from an established urban area was monitored over a period of 18 months. Correlations are made between the rate of sediment release and the hydraulic discharge rate (on both rising and falling limbs of the hydrograph) and between sediment production and storm intensity, duration and antecedent rainfall conditions. Possible sediment control mechanisms are also discussed.

PERLMUTTER, N.M. et al.
1964: "Contamination of ground water by detergents in a suburban environment - South Farmingdale area, Long Island, New York". U.S. Geol. Survey prof. paper No.501-C; p170-175.

Key words: aquifers; detergents; water pollution sources.

Water in the upper 20 feet of the water table aquifer, composed of glacial outwash deposits, is contaminated by ABS (alkylbenzenesulphonate) in concentrations generally between 1 and 5 ppm but locally as high as 32 ppm. Most of the water in the remainder of the aquifer contains less than 1 ppm and does not foam. Effluent from hundreds of randomly distributed cesspools is the source of the contamination.

PERLMUTTER, N.M. and KOCH, E.
1971: "Preliminary findings on the detergent and phosphate contents of water of Southern Nassau County, New York". U.S. Geol. Survey prof. paper No.750-D; pD171-177.

Key words: detergents; phosphorus compounds; ground water resources.

The distribution of MBAS (methylene blue active substance) and phosphate in the water of Nassau County, Long Island, N.Y. were studied from 1966 to 1970. The MBAS, a detergent constituent, has entered the water in the sewage effluent from several hundred thousand cesspools and septic tanks. The phosphate has a mixed origin. Although some samples of shallow ground water had MBAS contents of as much as 2 mg/litre, this constituent is not a significant problem in the Magothy aquifer, the major source of public water supply. MBAS content of streams in some areas averaged as much as 0.48 mg/litre. A slight downward trend in MBAS content since 1966 may be due to natural dilution after a regional drought and introduction of a more bio-

degradable detergent in 1966. The phosphate content of shallow ground water averaged 0.07 mg/litre in some areas and of streams averaged 0.09 mg/litre. The low concentrations of MBAS and phosphate in most of the water are not known to be toxic.

PETERSON, F.I. and HARGIS, D.R.
1973: "Subsurface disposal of storm runoff". J. Water Pollution Control Federation, Vol.45(8); p1663-1670.

Key words: storm runoff; aquifers; ground water resources; dissolved solids; waste dilution.

Injection of storm runoff into the basal ground water body near Kahului, Hawaii, will occur in zones below the fresh water lens. The quality of the storm runoff generally is good, with low dissolved solids and low chloride concentrations. The general effect of injection will be a decrease in dissolved solids of the ground water near the wells. Some faecal coliform will undoubtedly be introduced into the aquifer through the disposal wells; however, dilution of the injected runoff by the ground water and the hostile environment presented by the saline water in the disposal zone should greatly reduce any contamination hazard represented by the faecal coliform. The suspended solids concentration may be as high as 55,000 lb of sediment for the maximum design storm of 2.5 million cubic feet of runoff. This amount of sediment, if it all entered the well, could significantly reduce the efficiency of the disposal operation.

PETERSON, J.T. 1971: "Climate of cities: a survey of recent literature". In, Man's Impact on Environment, by T.R. Detwyler (ed), McGraw-Hill, New York, p131-154.

Key words: weather modification.

City climate differs from that of the surrounding rural areas. This report reviews the literature on city climatology, particularly that written since a series of papers published by H. Landsberg (1956-62). The Landsberg papers provide the basis for review of city-rural meteorological differences. Cities and even small building complexes create nocturnal heat islands, and urban-rural differences in temperature depend strongly on local microclimatic conditions. The size of urban-rural temperature differences is highly correlated with the suburban low level temperature lapse rate. The relative humidity of towns is almost always lower than that of adjacent rural areas. When regional wind speeds are relatively low, speeds over cities are higher than those over the countryside, and fewer calms occur over the city than over the country. When conditions are conducive to heat island formation, the wind flow converges toward the city.

PHAMWON, S. and FOK, Y.S. 1976: "Storm

runoff simulation for urban area in Oahu, Hawaii". Paper presented at Annual Fall Meeting of the AGU, Washington, D.C. EOS, Vol.57(12); p919.

Key words: computer models; flood routing; storm runoff.

A digital computer model was developed, utilising available hydrologic data to simulate runoff from given rainfall patterns for urban Hawaiian small watersheds. The computer model was developed by rewriting and modifying the Illinois Urban Drainage Simulator (ILLUDAS) of the Illinois State Water Survey. The main emphasis was on the procedures for (1) runoff routing from pervious and impervious areas and (2) channel flow routing through gutters in storm drains. A numerical solution to the kinematic wave equations was utilised for water routing procedures. Also, five infiltration curves, designated as dry, damp, wet, very wet, and extremely wet were established, with the selection of one appropriate curve for a given watershed antecedent moisture condition. The results indicate that the measured and simulated storm runoff hydrographs are well matched when a 15-minute time interval is used for simulation. The simulated peak discharge is highly sensitive to the infiltration curve selected for the simulation. The model is useful for both storm drainage design and for evaluating existing drainage systems.

PHAMWON, S. and FOK, Y.S. 1977: "Urban runoff digital computer model". J. Hydraul. Divn., Proc. ASCE, Vol.103(HY7); p723-735.

Key words: urban runoff; computer models; urban hydrology; analytical techniques; rainfall-runoff relationships; urban drainage; flood control.

A digital computer model for simulating runoff from small urban watersheds was developed. The model utilised a numerical solution of the kinematic wave equations for overland flow and channel flow routing. The runoff from pervious areas was estimated by utilising appropriate infiltration curves whose initial and final infiltration rates varied, depending upon the soil type and moisture conditions. Runoff from paved and grassed areas was combined and routed through the gutter to sewer inlets, and the flow in the sewers was routed from one inlet to the other in the downstream direction. The model was tested on St. Louis Heights watershed in Hawaii. The slopes of the streets range from 1 to 29 percent. For the five storm events tested, the simulated peak flows were in the acceptable range of the observed. The choice of infiltration curves was shown to affect considerably the time to and the magnitude of the peak discharge.

PIRNER, S.M. and HARMS, L.L. 1978: "Rapid City combats the effects of urban runoff on surface water". Water and Sewage Works, Vol.125(2); p48-53.

Key words: urban runoff; data collec-

tion; water pollution sources; chemical oxygen demand; phosphorus compounds; suspended solids.

The primary basin selected for this study is referred to as the Meade Street drainage basin and is located in the southeastern portion of Rapid City, South Dakota, which has a population of 43,836 according to 1970 census. The total contributing area of the watershed was 2.70 sq miles, which comprises about 20 percent of the total city land area. Approximately 70 percent of the basin has been developed, and consists primarily of middle-class, single-family dwellings, together with the usual scattering of multiple-family units, light industry, shopping markets, and roadside services. Impervious surfaces such as paved streets, driveways, parking lots, and rooftops cover about 19 percent of the total land surface of the basin. Upper reaches of the watershed remain as grasslands and evergreen forests. The study indicated that runoff contributed gross quantities of sediment to the watershed, and that treatment should focus primarily on solids removal. However, it was cautioned that a substantial portion of the sediment contained in the runoff samples appeared as colloidal particles that will not be removed by simple clarification.

PISANO, M. 1976: "Nonpoint pollution: an EPA view of areawide water quality management". J. of Soil and Water Conservation, May-June; p95-100.

Key words: nonpoint pollution sources; agricultural pollution; nutrients; zinc.

People are becoming increasingly aware of the significant deleterious impact that nonpoint sources of pollution - agricultural and silvicultural runoff, acid mine drainage, urban runoff, and sedimentation from construction sites - have on the quality of America's national water resources. When the 1977 targets for best practicable technology for industry and secondary treatment for municipalities are achieved: (1) of the total point and nonpoint source loadings of 158 million pounds per day of suspended solids, nonpoint source loads will account for 145 million pounds or 92 percent; (2) of the total daily nitrogen loadings of 35.7 million pounds, nonpoint sources will contribute 28.3 million pounds or 79 percent; (3) of the 3.63 million pounds per day of phosphorus, nonpoint sources will provide 1.93 million pounds or 53 percent; (4) for both faecal and total coliform counts, nonpoint sources will account for over 98 percent of the remaining national loadings; (5) of the 119,000 pounds per day of zinc, 51,000 pounds or 43 percent will derive from nonpoint sources. The significance of these figures is clear: we must address the nonpoint source pollution problem now.

PITT, R.E. and AMY, G. 1973: "Toxic materials analysis of street surface contaminants". Report for EPA, Washing-

ton, 11023 FUJ-EPA-R273-283; 143pp. (NTIS PB-224 677/5).

Key words: water pollution; surface runoff; toxicity; metals; heavy metals; biochemical oxygen demand; lead; zinc; mercury; organic compounds; trace elements; arsenic compounds.

Mass spectrographic analyses were performed on various samples of street surface particulates. Using these results, the heavy metals which were determined to have the greatest water pollution potential (As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Sr, Ti, Zn, and Zr) were analysed in each of about 75 samples collected nationwide in 10 cities. Other analyses conducted included: size affinities of the metals, solubilities and toxicities of the road surface runoff mixture, and certain organic analyses on selected samples. Additional sampling was conducted on rural road, highway and airport surfaces and particulates were analysed for the following common water pollution parameters: BOD, COD and nutrients, plus selected heavy metals, for comparison with values representative of normal city streets.

PITT, R.E. and FIELD, R. 1974: "Water quality effects from urban runoff". Paper presented at 49th Annual Conference American Water Works Association, Boston, Mass., (June). (Also published in J. American Water Works Assocn., August, 1977; p432-436).

Key words: urban runoff; model studies; urban hydrology; watershed management; flood forecasting; hydrographs; sewage treatment; waste water treatment.

A hypothetical case study of the problems of water quality deterioration from urban storm water runoff is presented and recommendations to mitigate the problems made.

PLUHOWSKI, E.J. 1970: "Urbanisation and its effects on the temperature of streams on Long Island, New York". U.S. Geol. Survey prof. paper No.627-D; 110pp.

Key words: thermal pollution; surface runoff.

The thermal patterns of 5 streams (four urbanised, one 'rural') were studied to determine the effects of man on stream temperature. Man's activities have increased average stream temperatures in summer by 5-8 degrees C, and concurrent differences between sites on a stream may be as much as 8-10 degrees C. In winter, stream temperatures average some 1.5-3 degrees C lower than in 'rural' areas. Input of direct runoff from urban areas during a storm may raise stream temperatures significantly. Energy budget analyses indicate that short-wave radiation and ground water seepage are important controls on thermal patterns in streams, and these energy sources are susceptible to change as a result of man's activities.

Lakes and ponds also have a strong influence on downstream temperature patterns.

PLUHOWSKI, E.J. 1970: "Effects of urban development on the hydrology of Long Island, New York". In, Earth resources aircraft program status review, NASA, Houston, 1968-V.3. Hydrology, oceanography and sensor studies. Houston, Texas, Manned Spacecraft Centre; p21-1-21-9.

Key words: thermal pollution; remote sensing.

This study evaluates the use of infrared imagery in detecting man induced changes in the thermal patterns of water bodies and nearby land areas. Missions were flown near and parallel to the northern shoreline of Great South Bay on Long Island. Previously recorded temperature data for five streams were correlated with thermal patterns reflected by infrared imagery from the 8 μ to 14 μ wave length obtained in July 1967 during Mission 53. Variations in intensity of the image corresponded to variations in stream temperatures known to be affected by urban development or industry. Results of an August 1, 1968 thermal survey of a waterfront recreation area near East Islip also revealed a definite correlation between variations in intensity of the imagery and variations in actual ground surface temperatures.

POERTNER, H.G. 1968: "Urban hydrology, storm drainage and flood plain management in metropolitan areas of the United States". Georgia Institute of Technology Water Resources Centre Report. OWRR Project X-102; 28pp.

Key words: watershed management; urbanisation; storm runoff; urban hydrology.

Current practices in urban hydrology, storm drainage, and flood plain management are reviewed. These practices have characteristics which not only limit solutions to present problems but contribute to future problems. An illustration is the opposition by land owners and tax authorities to flood plain zoning. One alternative to the present unsatisfactory state of management is to establish a program responsive to all segments of the population. Major limitations to present practices in engineering and design are deficiencies in knowledge of urban hydrology, lack of analyses of accumulated data, and ineffective use of data for producing optimum designs of integrated drainage systems. Problems of urban drainage are primarily institutional. Enabling legislation is needed for management of water in entire metropolitan areas by a single authority. Programs on federal, state, and local levels for correction of deficiencies within present flood plains and drainage systems need development to serve existing communities as well as those that may emerge in the surrounding area.

POERTNER, H.G. 1973: "Detention storage of urban storm water runoff". APWA Reporter, Vol.40(5); p14.

Key words: urban runoff; waste storage; water pollution control.

POERTNER, H.G. 1974: "Practices in detention of urban storm water runoff". Special Report No.43, American Public Works Assoc., Chicago; 231pp. (NTIS PB-234 554).

Key words: urban runoff; urban drainage; flood control; flood routing; storm runoff; water pollution control; erosion control.

On-site detention of runoff was investigated as an alternative to other methods of urban storm water runoff management. It was found that this method, which involves collecting excess runoff before it enters the sewer system, can often be applied as an effective and economical means of reducing peak runoff flow rates to lessen or eliminate problems of flooding, pollution, soil erosion and siltation. The captured runoff sometimes can be used to augment water supplies for potable or non-potable uses, and the detention facilities can be designed to serve multiple-purpose uses, especially recreation. The use of on-site detention facilities has been given emphasis in those urban areas where flooding is a frequent problem. A 1972 survey of selected local jurisdictions in urban areas of the United States and Canada revealed that more than 1,400 facilities were operational in about 100 local jurisdictions reporting applications. Because only about 500 jurisdictions were contacted the actual number of such facilities in existence is thought to be many times more. Most of the representatives of the 230 public agencies and 40 engineering firms that responded to the survey questionnaire consider on-site detention of runoff in urban areas to be a useful storm water management method that is worthy of study and implementation. Many applications of the method were identified in which substantial cost savings over a conventional urban storm water drainage system had been realized by incorporating on-site detention of runoff into the system. The use of on-site detention facilities in managing runoff in urban communities can be expected to increase as the techniques and benefits become more widely known.

POERTNER, H.G. 1974: "An overview of urban hydrology and runoff management". Paper presented at the National Symposium on Urban Hydrology and Runoff and Sediment Management Seminar, College of Engineering, University of Kentucky, Lexington (July); p25-31.

Key words: urban hydrology; urban runoff; flood control.

One alternative to the present unsatisfactory state of runoff control and flood plain management is to establish a modern program of management responsive to all segments of the population.

Major limitations of present practices in engineering and design are: deficiencies in knowledge of urban hydrology, lack of analyses of accumulated data, and ineffective use of data for producing optimum designs of integrated drainage systems. Problems of urban drainage are primarily institutional. Enabling legislation is needed for management of water on a watershed basis, in entire metropolitan areas, by a single authority. A regional entity can produce a more uniform approach to the solution of water problems and replace present piece-meal and ineffective procedures with coordinated and competent planning, engineering, construction, and management. Action programs should be developed on federal, state and local levels to improve drainage systems and correct deficiencies within existing flood plains. This would be beneficial to existing communities as well as those that may emerge in the surrounding areas. Such programs should be flexible and should be integrated. Research in both management and engineering now demands full-time attention.

POERTNER, H.G. 1976: "Urban storm water detention and flow attenuation". Public Works, Vol.107(8); p83-85.

Key words: urban runoff; storm runoff; flood control.

Methods for achieving storm water detention and flow attenuation in urban areas are discussed, with particular emphasis on detention ponds on earth surfaces, detention of rainfall on rooftops, and rainfall detention on parking lots. The following criteria for designing detention facilities are discussed: the prevention of excess storm water buildup in habitable areas, the provision of a positive outlet for discharge of inflows when storage capacity is exceeded, the construction of sufficient slopes for detention areas, the proper location of the deeper portions of storage areas, an evaluation of runoff that is likely to enter the storage site from upstream areas, the provision for uniform regulation of release flow rates, the planning of storage areas for more than one purpose, and the calculation of storage volume requirements. The development of storage ponds into recreational facilities is also discussed.

POLLOCK, S.J. and TOLER, L.G. 1973: "Effects of highway deicing salts on ground water and water supplies in Massachusetts, environmental degradation by deicing chemicals and effective counter measures". Highway Research Record, No.425; p17-22.

Key words: chlorides; ground water resources.

The concentration of chloride in some public water supplies has increased significantly during the last few years. The increase corresponds to the increased use of salts for deicing highways, and this correspondence has not gone unnoticed. In some localities

ties, the concentration of chloride has increased beyond the 250 mg/litre recommended by the U.S. Public Health Service as an upper limit for drinking water supplies. Where this has happened, local public health authorities have sometimes condemned the supply, and the practice of highway salting has thus received much criticism. According to data furnished by the Massachusetts Department of Public Works, the use of highway deicing chemicals, mainly sodium chloride and calcium chloride, on state highways in Massachusetts has increased nearly eightfold in the last 15 years. The concentration of chloride in ground water may be responsive to many factors including (a) rate of application of deicing chemicals, (b) type of soils and geologic materials, (c) type, intensity, and quantity of precipitation, and (d) highway drainage design.

POLLS, I. et al. 1977: "Sampling program for characterising the quality of storm water runoff from fourteen homogeneous land uses in northeastern Illinois". Paper presented at Annual Spring Meeting of the AGU, Washington, D.C. EOS, Vol.58(6); p388.

Key words: data collection; storm runoff; nonpoint pollution sources.

Recent assessments of the environmental impact of nonpoint sources of pollution have created the need for precise and detailed meteorological, hydrological and water quality measurements of storm water runoff for watersheds of homogeneous land uses. A brief review of the problems and characteristics associated with measuring the quality and quantity of storm water runoff is given, followed by a discussion of a 208, nonpoint, land use, runoff sampling program in northeastern Illinois. The quality of storm water runoff from fourteen typical land uses will be sampled during 1977 using stage activated automatic water samplers. The land use classifications are as follows: a forest preserve, an interstate highway, 2 light industrial parks, 3 agricultural areas, a commercial-office complex, 4 single family residential sites, and 2 multi-family residential areas. The level of water flowing through a sewer, culvert, ditch or other watercourse will be continuously recorded, and flow calculated at each sampling site. Precipitation will also be measured by a continuous rain recording gauge located in each of the 14 watersheds. Included is a discussion of the methodology for selecting the land use sites, desirable features of the automatic water samplers, stage level selection for activation of samplers, intake location, number of samples per event, 21 parameters to be measured, sampling frequency, and overall logistics of the sampling and analysis program.

POPE, E.P. 1973: "A method for determining peak flows and detention storage requirements in urbanising areas". Indiana Technical Note, Engineering-2, USDA, Soil Cons. Service, Indiana

State Office, Indianapolis, Indiana.

Key words: analytical techniques; peak discharge.

POPE, W. et al. 1978: "Urban runoff from a road surface - a water quality study". Prog. Wat. Tech., Vol.10(5/6); p533-543.

Key words: urban runoff; model studies; water pollution sources; surface runoff; oil wastes; trace elements; solid wastes.

Preliminary results from an investigation into the quality of surface water from a motorway catchment are reported. The removal of several contaminants has been studied as a first stage in the generation of a model for quantifying the environmental impact of urban runoff. Hydrological conditions have been routinely monitored in three adjacent drainage systems. Automatic sampling systems have been installed, and the levels of vehicle oils, specific hydrocarbons, trace metals and solids, in runoff, have been estimated. Tentative correlations between contaminant concentrations and environmental conditions are proposed.

POPKIN, B.P. 1972: "Effect of a grass and soil filter on Tucson urban runoff: a preliminary evaluation". In, Hydrology and water resources in Arizona and Southwest, Vol.2, Proc. of the 1972 meeting of the Arizona Section AWRA, and Hydrology Section, Arizona Academy of Science; p235-261.

Key words: urban runoff; chemical oxygen demand; turbidity; watershed management; water pollution control.

Because storm runoff from the Tucson metropolitan area requires processing for most uses, a grass and soil filter lysimeter was constructed and evaluated as a water quality treatment facility. The 200x4x5 foot lysimeter contains homogeneous calcareous loam covered by common grasses. Less than a cubic foot per second of storm runoff flows by gravity over the lysimeter where surface inflow, surface outflow and subsurface outflow are measured and sampled. Four discrete trials were conducted in the fall of 1971, where water samples were analysed for inorganic chemical constituents, chemical oxygen demand (COD), coliforms, turbidity and sediment. Concentrations of COD, coliforms, turbidity and sediment in subsurface outflow samples decreased significantly during each trial, though early trials showed extensive leaching. Surface outflow samples had lower turbidity, COD, coliforms and sediment than inflow samples. Turbidity, suspended and volatile solids, coliforms, and COD in runoff samples may be reduced by grass and soil infiltration. Grass development and soil settling work to produce a better quality outflow. Quantification of a lysimeter's effectiveness will be useful for urban watershed management in arid lands.

POPKIN, B.P. 1973: "Effect of mixed grass and native-soil filter on urban runoff quality". Masters thesis, Arizona University, Tucson, Dept. of Hydrology and Water Resources; 112pp. (NTIS PB-237 683).

Key words: waste water treatment; storm runoff; urban runoff; chemical oxygen demand; turbidity; suspended solids; leachate; bacteria.

A grass-covered soil filter of native calcareous loam, 200 feet long, 4 feet wide and 5 feet deep, was tested for effectiveness as a water quality treatment for Tucson urban storm runoff. Water was pumped from Arcadia Wash and applied to the filter in four trials in Fall 1971. Inflow and outflow volumes were measured, sampled and analysed for important water quality variables. For grass and grass-soil filtration respectively, the following maximum percent reductions, compared to untreated runoff, occurred: For chemical oxygen demand (COD), 19 and 88; for suspended solids, 34 and 99.6; for volatile suspended solids, 26 and 97; for turbidity, 97 and 98; for total coliforms, 84 and 98; and for faecal coliforms, 50 and 98. Grass-soil filtration, during the four trials, produced water too saline for most uses. After the initial stabilisation period, grass-soil filtration was more effective than grass filtration in water quality improvement. Grass-soil filtration had, with time, increasing COD and salt concentrations in the early part of each trial, and decreasing infiltration rates. Grass maturity and soil compaction, following construction of the filter, initially increased efficiency of the water quality improvement process. Grass filtration upgraded cool-season urban runoff for recreation, irrigation, artificial ground water recharge, fisheries and wildlife, except in the initial part of some trials and in the grass-establishment period when COD volatile suspended solids and coliforms increased. Chlorination of treated runoff is necessary, particularly for warm-season flows, when recreational water use is anticipated.

POPKIN, B.P. 1974: "Hydrologic aspects of land use planning at Tumamoc Hill, Tucson, Arizona". In, Vol.4, Hydrology and Water Resources in Arizona and the SW. Proceedings 1974 Meeting of the Arizona Section AWRA and the Hydrology Section, Arizona Academy of Science; p309-324.

Key words: watershed management; urbanisation; hydrologic data; erosion control.

Tumamoc Hill is an 869 acre desert area near Tucson, Arizona which is being considered as a controlled access environmental site. The site's geology, soils, vegetation, wildlife, and archaeology are affected by water. The largest of the three watersheds that drain the hill is rapidly being urbanised upstream presenting potential flooding and erosion hazards. These problems may be reduced simply, economically, and wisely in a land use plan. The region may be managed to reduce hydro-

logic hazards by widening stream channels, installing low check dams, and vegetating the drainageways. These procedures would slow runoff velocities, increase the cross sectional area of flow and the roughness coefficient, and provide more water for vegetation and wildlife. The land use plan should also include environmental education programs which would present important effects of water on the natural ecology and hydrologic aspects of watershed urbanisation.

POUSTIS, J. et al. 1976: "Contribution to the study of runoff in an urban environment". Techniques et Sciences Municipales, Vol.71(4); p179-181. (In French, English summary).

Key words: heavy metals; storm runoff; organic compounds.

The potential hazards of storm water for recreational uses were studied at Cesson-Sevigne, France. Levels of zinc, lead and copper in runoff were monitored at 5 stations which had different combinations of urbanisation, traffic density, and rates of flow. The amounts of lead, zinc and copper found averaged 71, 201, and 46 micrograms per litre, respectively, and non-negligible amounts of hydrocarbons were also found. COD was maximal after one hour's rain and greater after a long dry spell, but pollution carried by runoff remained fairly small.

PRATT, J.M. and COLER, R.A. 1976: "A procedure for the routine biological evaluation of urban runoff in small rivers". Water Research, Vol.10; p1019-1025.

Key words: water pollution; bioindicators; urban runoff; benthic fauna.

A rationale and stepwise procedure for the biological evaluation of urban runoff in small rivers is described. The protocol is predicated on the application of the Brillouin diversity index to collections of benthic macroinvertebrates isolated from artificial substrates in the course of a year.

PRAVOSHINSKI, N.A. 1968: "Description of the drainage of street flushing waters". Soviet Hydrol., Selected Papers, Issue No.2; p168-170.

Key words: water pollution sources; urbanisation; organic compounds; oil wastes; bacteria.

The quality and quantity of runoff from street washing operations in Minsk were measured to study the contribution of street washing to water pollution. Data from earlier studies in Moscow and Leningrad are included for comparison. The BOD of street cleaning runoff is 6-223 mg/litre, petroleum products are up to 110 mg/litre, and coliforms are nearly as abundant as in waste water. These waters, unless they are treated, can be a major source of pollution.

PRAVOSHINSKI, N.A. and GATILLO, P.D. 1968: "Calculation of water pollution by surface runoff". Water Research, Vol.2(1); p24-26.

Key words: data collection; surface runoff; biochemical oxygen demand.

The extent of surface runoff pollution was calculated in the Minsk and Soligorsk districts using the five-day BOD as the main index. Other data were accumulated to determine the variations in the quality of the water when compared with the type of storm, the length of the previous dry weather period, the season, the surface of the region, and the amount of transport and pedestrian traffic. With these results, evaluations can be made of the influences of the pollutants and of the effects of measures such as catch basins, settling basins, storm sewers, and increased sewer capacity, on the maintenance of sanitary pond conditions.

PRAVOSHINSKY, N.A. and GATILLO, P.D. 1969: "Determination of the pollutional effect of surface runoff". In, Proc. 4th Int. Conference Water Pollution Research, Prague; p187-195 and p197-203.

Key words: water pollution sources; storm runoff; surface runoff; urbanisation; water pollution control.

To investigate the pollution of rivers and lakes by runoff from urban areas, which at present receives no treatment in the USSR, the Institute of Water Problems has made systematic observations of the quality and quantity of runoff collected in the storm sewage systems in densely populated areas of Minsk and, for comparison, in the rapidly developing town of Soligorsk. Factors affecting the polluting effects of runoff are considered and observations are discussed individually for runoff derived from storms, street washing, and snowmelt. A formula is also derived for calculating the resulting 20-day BOD in a stream receiving surface runoff (storm or street washing water), taking into account the fate of the dissolved, suspended, and colloidal matter entering the stream, and the portion of the pollutants which produces bottom deposits, which depends on the velocity of streamflow and the particle size of the suspended solids. The combined effects of pollutants discharged from the outlets of several storm sewage collectors in a receiving body of water was also considered. Methods are also considered for calculating the concentration of dissolved oxygen in the receiving water and the dispersion of discharges in a non-turbulent reservoir. Recommendations for controlling pollution of urban water bodies by surface runoff include location of outfalls below the town; augmentation of streamflow, as required, to dilute the polluting matter; and the interception and removal of waste waters from markets and industrial areas for treatment with domestic sewage.

PREUL, H.C. 1967: "Urban runoff characteristics". School of Engineering, University of Cincinnati, Cincinnati.

Key words: flood discharge; urban drainage.

This study is mainly concerned with sewer drainage area and capacities with regard to flooding.

PREUL, H.C. 1974: "Assessment of urban runoff quantity and quality". In, Proceedings of the International Seminar and Exposition on water resources instrumentation: volume 1 - measuring and sensing methods, IWRA, Illinois; p517-537.

Key words: analytical techniques; combined sewers; urban runoff.

This paper presents an approach for the assessment of urban runoff quantity and quality. Following an initial discussion of urban runoff characteristics, typical results are shown from monitoring a combined sewer watershed in Cincinnati, Ohio, U.S.A. A suggested program is outlined for monitoring the overflow discharges from a combined sewer system. This outline then is followed by a format for assessing the frequency and magnitude of the pollutional discharges.

PREUL, H.C. and PAPADAKIS, C. 1970: "Urban runoff characteristics". Cincinnati University, Ohio, Dept. of Civil Engineering. Water Pollution Control Research Series, W71-12703, EPA-WQO-11024-DQU10/70; 362pp. (NTIS PB-202 865).

Key words: data collection; model studies; urban runoff.

Detailed information on the watershed characteristics and data on runoff quantity and quality have been compiled from a one year study of a combined sewer watershed of approximately 2380 acres in Cincinnati, Ohio. Collection of these data is planned to continue over a several year period. The information collected will be used to test and develop practical storm water management models.

PREUL, H.C. and PAPADAKIS, C.N. 1973: "Development of design storm hyetographs for Cincinnati, Ohio". Water Resources Bulletin, Vol.9(2); p291-300.

Key words: urban hydrology; rainfall-runoff relationships; urban runoff; storm runoff; urban drainage; mathematical models; model studies.

A synthetic storm rainfall hyetograph for a one year design frequency was derived from the one year intensity-duration curve for Cincinnati, Ohio. Detailed rainfall data for a three year period were collected from three raingauges in the Bloody Run Sewer watershed, an urban drainage area of 2,380 acres. The synthetic storm

pattern is obtained from an analysis of the antecedent precipitation immediately preceding the maximum period of three selected durations. Only rains which produced excessive runoff were considered. The same approach can be used for other design frequencies. The purpose of this study is to provide synthetic storm hyetographs to be used as input in deterministic mathematical models simulating urban storm water runoff for the design, analysis, and possible surcharge prediction of sewer systems.

PREUL, H.C. and PAPADAKIS, C.N. 1976: "Urban runoff characteristics. Volume I. Analytical studies". Divn. of Water Resources, Cincinnati University, Ohio, Final Report; 353pp.

Key words: urban runoff; hydrologic data; rainfall-runoff relationships; mathematical models; computer models; combined sewers; storm runoff; urban hydrology; water pollution sources.

The report is on analytical studies and field investigations for the characterisation of urban runoff and combined sewer overflows. The report is divided into two volumes: 1 - Analytical Studies; 2 - Field Investigations.

PREUL, H.C. and PAPADAKIS, C.N. 1976: "Urban runoff characteristics. Volume II. Field investigations". Divn. of Water Resources, Cincinnati University, Ohio, Final Report; 781pp.

Key words: data collection; urban runoff; water pollution sources; combined sewers; model studies; hydrologic data.

A compilation of hydrologic and water quality data collected over a three year period from a typical combined sewer watershed of 2380 acres in Cincinnati, Ohio.

PUBLIC HEALTH SERVICE. 1964: "Pollutional effects of storm water and overflows from combined sewer systems - a preliminary appraisal". Public Health Service, Washington, D.C. Division of Water Supply and Pollution Control. PHS Publication No.1246; 44pp. (NTIS PB-217 169).

Key words: overflows; water pollution; combined sewers; storm runoff; water pollution control.

It is known that the overflows from combined sewer systems and the discharge of storm water from storm sewers create real pollution problems. The report examines and assesses in a preliminary way existing data on storm water and combined sewer overflows in regard to characteristics and pollutional effects, and investigates existing and possible corrective measures for dealing with the problem.

PUBLIC HEALTH SERVICE. 1965: "Activities

report, July 1, 1964 to June 30, 1965". Washington, D.C., U.S. Public Health Service, Div. of Water Supply and Pollution Control; 53pp.

Key words: storm runoff; water pollution sources; urban drainage; water pollution control; waste dilution.

This report reviews research carried out from 1964 to 1965 to determine causes and methods of control of water pollution. The work includes studies on the chemical and microbiological analysis of wastes; the polluting effects of urban and rural runoff; the persistence of organic chemicals in surface waters and their biological degradation; the effects of pollution on aquatic life and on municipal water use; methods of waste treatment, including advanced treatment of sewage; and control of surface water quality by dilution and by removal of nutrients from effluents. A list of papers published during the year is appended.

PURVES, D. 1972: "Consequences of trace element contamination of soils". Environmental Pollution, Vol.3; p17-24.

Key words: trace elements; lead; zinc.

The chemical composition of the bulk of the food we eat has been profoundly modified by the intensification of the means of food production and as a result of the general contamination of the environment. Contamination of the soil in urban and industrial areas with potentially toxic elements is an important aspect of environmental pollution which can affect the composition of food. Contamination of soils with elements such as copper, lead and zinc appears to be largely irreversible and sources of this kind of contamination are discussed. Evidence is presented that the trace element content of plants grown on contaminated soils can be enhanced and that deleterious effects on plant growth are possible.

PUTNAM, A.L. 1972: "Effects of urban development on floods in the Piedmont Province of North Carolina". U.S. Geol. Survey open-file report; 87pp.

Key words: urban runoff; peak discharge; urbanisation; flood forecasting; hydrologic data.

The study relates peak discharges on selected streams in North Carolina to drainage area, stream length, stream slope, and percent of the basin covered by impervious surfaces. The relationships are based on an analysis of flood information from approximately 200 sites in the Piedmont area of the state and apply to streams that are unaffected by artificial storage or diversion. The relationships can be used to estimate peak discharges in basins of varying degrees of urbanisation; the users of the equations must supply the actual values for the basin in question, e.g. drainage area and amount of impervious land cover. The study found that as a

basin changes from rural to urban the basin lag time can decrease to as little as one-sixteenth of what it was originally and that the peak discharge may increase as much as a factor of five.

PUTNAM, A.L. 1972: "Rainfall and runoff in urban areas - a case study of flooding in the Piedmont of North Carolina". In, Proc. Urban rainfall management problems, University of Kentucky, Lexington, Kty.

Key words: rainfall-runoff relationships; flood forecasting.

Urban development changes the relationship between rainfall and runoff. Probably the most striking change is that associated with the time required for streamflow to respond to rainfall. Basin lag is used to estimate this variable. The empirical formula developed to estimate basin lag time indicates that urban development can reduce this variable to one fourteenth of its value for natural conditions. This decrease in lag time means that the bulk of storm water becomes runoff during a given rain. These two effects combine to increase the magnitude of a flood significantly. For floods of short recurrence interval, the increase in the magnitude of the discharge is most drastic. For floods of longer recurrence interval, the increase is not as great but is, nevertheless, extremely significant. The dramatic comparisons of flood discharge are between floods of short recurrence interval for developed watersheds and floods of longer recurrence interval for natural watersheds. A 5 year flood discharge for a watershed with development associated with 25 percent impervious cover is approximately equal to a 40 year flood discharge for the same watershed with natural drainage conditions.

RABE, F.T. and HUDSON, J.F. 1975: "Highway and sewer impact on urban development". J. Urban Planning and Development Divn., Proc. ASCE, Vol.101(UP2); p217-231.

Key words: water pollution; mathematical models.

Public investments in highways and sewerage facilities have an important influence on the form, location, and timing of urban development. However, the magnitude and variability of this influence remains uncertain. Statistical analyses of historical highway and sewer investments in four U.S. metropolitan areas suggest that the role of these public investments in bringing about new urban growth depends upon local land market conditions, as well as existing levels of waste water and transportation service. Simple models were estimated that relate the amount of residential, commercial, and industrial development to the availability of vacant land, sewer service, proximity to highways, and residential vacancy rates. These models provide a preliminary analytical basis for projecting the likely effects of proposed highway and sewer projects on local urban development.

RADZIUL, J.V. et al. 1973: "Does storm water pollute"? Water Pollution Control Association of Pennsylvania 45th Annual Conference, Pennsylvania State University, August, 1973.

Key words: storm runoff; water pollution.

RADZIUL, J.V. et al. 1975: "Effects of nonpoint discharge on urban stream quality". In, Urbanisation and water quality control, Proc. American Water Resources Assoc., No.20; p201-210.

Key words: combined sewers; nonpoint pollution sources; analytical techniques; pollution abatement.

The Philadelphia Water Department has cooperated with the U.S. Geological Survey in a quantity and quality study of five Philadelphia streams. Flow frequency curves have been developed for each stream and used in conjunction with monthly water quality data to generate mass loadings for each basin. Basins with nonpoint combined sewer sources contribute significantly higher levels of pollution than separately sewered basins. However, other subtle variations have been noted within basins of similar nonpoint sources. Multiple linear regression techniques have been used to predict these variations. Regression equations relate basin and stream morphology to the mass loadings. Further research is needed to test the validity of these equations for transferability to other urban areas. Total nonpoint BOD5 loads for Philadelphia have been calculated and found to represent 15 percent of the output from the city's three waste water plants. However, these loads are transient in nature, with durations often measured in hours. The dynamic

nature of these nonpoint problems must properly be addressed before cost-effective planning can commence or reasonable regularity legislation be promulgated. The Water Department is conducting further research to quantify these transient loadings in relation to their time frame. This analysis should provide further insight for selection of nonpoint abatement alternatives.

RADZIUL, J.V. et al. 1977: "Design of a point and nonpoint source abatement master plan for metropolitan areas". Paper presented at Annual Spring Meeting of the AGU, Washington, D.C. EOS, Vol.58(6); p387.

Key words: pollution abatement; point sources (pollution); nonpoint pollution sources; data collection; network design; model studies.

A program has been developed, in conjunction with a regional 200 study, to determine the relative impact of point and nonpoint source pollution, to allow the prediction of urban runoff water quality based on measurable regional parameters such as imperviousness and land use, to evaluate the effectiveness of structural and nonstructural abatement techniques, and to institute a master plan for abating point and nonpoint pollution in the Philadelphia metropolitan area cost-effectively. A data collection network has been instituted to obtain a characterization of storm water from a variety of urban land use types in both separated storm and combined sewers. The Storm Water Management Model is being adapted to allow for inclusion of this water quality data, urban land use categories, imperviousness, population data, etc. to predict urban runoff quality in the Philadelphia area and with the use of design storm analysis to set allocations of pollutants in water quality limited segments of both metropolitan tributaries and of a heavily industrialised zone of the Delaware Estuary. A research project has been established to evaluate the state of the art in structural and nonstructural control techniques and measures are being taken to institute a coordinated, interagency, multi-disciplined master plan for pollution abatement within the City of Philadelphia and contiguous suburban-rural areas.

RAGAN, R.M. et al. 1975: "Dimensionless inlet hydrograph model". J. Hydraul. Divn., Proc. ASCE, Vol.101(HY9); p1185-1195.

Key words: urban hydrology; hydrographs; urban runoff; storm runoff; mathematical models; model studies.

A number of mathematical models used to estimate storm hydrographs in urban areas consider runoff as a deterministic process and link a series of submodels to simulate the behaviour of the various components of the runoff cycle. Because of the number of interrelated formulations in these linked system models, a large core computer is general-

ly required for their proper use. A dimensionless inlet hydrograph was presented that can be developed from a complete linked system model and used as a substitute in some planning and design situations. The central objective was to develop a method for estimating the hydrograph entering an inlet or catch basin that would be simple enough to allow hand computations while retaining good agreement with the computer-generated hydrographs obtained with a complete linked system model.

RAGAN, R.M. et al. 1977: "The impact of urbanisation on stream quality". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p324-333.

Key words: urbanisation; remote sensing; peak discharge.

This study evaluates the impact of urbanisation on the stream quality of a 1160 sq km area in the suburbs of Washington, D.C., U.S.A. The emphasis was to examine differences in the characteristics of streams collecting runoff from natural basins and those receiving storm water runoff from urbanised areas within the same region and at the same time. Urban development in the study area is primarily recent and well planned. Data from the Landsat satellite were successfully used to separate urban and rural land use categories. Except in areas found to have sanitary sewage entering the streams, the water quality in the urbanised areas was good. The magnitude of frequent floods was found to have increased substantially as a result of urbanisation. This new hydrological regime has resulted in high sediment loads and has reduced the aesthetic value of many streams because of channel widening and degradation. There has also been a sharp reduction in fish species diversity in the urban areas, probably because of habitat destruction rather than water quality degradation.

RAGAN, R.M. and DIETEMANN, A.J. 1975: "Impact of urban storm water runoff on stream quality". In, Urbanisation and water quality control. Proc. Symp. American Water Resources Assoc., No.20; p55-61.

Key words: storm runoff; sediment yield; streamflow.

The purpose of the study is to evaluate the impact of storm water runoff from urbanised areas on stream quality. The term "stream quality" as opposed to "water quality" is used because, when evaluating the impact of urbanisation, more than just the chemical, physical, and biological characteristics of the water being conveyed must be considered. Flow characteristics, diversity of aquatic life that the stream supports, stability of the bed and banks, and aesthetics can reflect more than water quality alone. Specifically, the study evaluated: (1) differences in several water quality parameters collected from urbanised and rural wat-

ersheds; (2) changes in fish species diversity that have occurred on several watersheds that have experienced urban development; and, (3) the impact in changes in flow regime and sediment production on channel stability in urbanised watersheds. Most of the water quality data were obtained from the Montgomery County Department of Environmental Health. These particular data were collected biweekly during 1971-1972 from 93 stations on 449 square miles of drainage area. These drainage basins varied from 1.7 to 101 square miles and ranged from almost 100 percent urbanised to areas having only scattered rural residences. The basis for evaluating changes in fish species diversity was a series of 24 surveys that had been conducted prior to urbanisation. That part of the study concerned with sediment and channel stability was concentrated in the Anacostia River basin.

RAGAN, R.M. and MILLER, J.F. 1974: "Maryland highway drainage study. Volume V. A dimensionless hydrograph for estimating storm runoff from urban areas. Final report 1967-74". Maryland University, College Park, Dept. of Civil Engineering; 166pp.

Key words: urban runoff; hydrographs; model studies; mathematical models; computer models; storm runoff; urbanisation.

Presents a dimensionless inlet hydrograph that can be developed from a complete linked system model and used as a substitute in some planning and design situations.

RAMSEY, R.H. et al. 1976: "Analysis of flows from a semi-arid urban watershed in Lubbock, Texas". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p297-337.

Key words: analytical techniques; data collection; nutrients; solid wastes; biochemical oxygen demand; chemical oxygen demand; low flow; storm runoff.

Water samples and flows were obtained from storm events and dry weather flows occurring on a 1,499 acre urban watershed over a nine month period from September 1974 through May 1975. The watershed was monitored daily by an automatic sampler, automatic flow recorder, and raingauges. Hourly flow samples from 59 precipitation events and 199 dry weather flows were combined into a daily composite which was analysed for COD, BOD, total solids, total suspended solids, orthophosphate and nitrate. Volume and quality of dry weather and storm runoff events were compared. Low correlations between antecedent storm characteristics and dry weather flow concentrations were exhibited. Storm flows contributed more pollutants than dry weather flows but the concentrations were much higher for dry weather flows in every category but TSS. For example, the 31.5 acre-feet

of dry weather flow yielded 21,458 pounds BOD whereas the 737.9 acre-feet of storm runoff yielded 27,032 pounds. Observed flows were compared to results obtained from flow models to identify the models that would best predict outflow characteristics. Criteria for selection were the time, money, and effort required for implementation. The following models were used: Rational; Viessman, Keating, and Srinivasa; Viessman and Miller; and British Road Research Laboratory. For the study data, the Viessman, Keating, and Srinivasa method yielded a correlation coefficient of 0.91 to best predict the total runoff from a precipitation event. The BRRL Method had a correlation coefficient of 0.45 - the best in predicting the peak rates.

RANDALL, C.W. et al. 1975: "Characterisation of urban runoff in the Occoquan watershed of Virginia". In, Urbanisation and water quality control. Proc. Symp. American Water Resources Assoc., No.20; p62-69.

Key words: pollution abatement; water pollution sources; organic compounds; nutrients; flood control.

The nature and magnitude of nonpoint source pollution in urban or urbanising areas is largely unknown and this lack of knowledge introduces a measure of uncertainty into all basin-wide pollution abatement programs. Historically, it has been assumed that the pollutional effects of storm water are insignificant. The data from this preliminary investigation clearly show that organic and nutrient contributions from urban runoff constitute a sizeable fraction of the total quantities entering Bull Run and, therefore, the Occoquan Reservoir, and that this source of pollution should be considered in formulating any future policies for the Occoquan watershed. In the past nearly all of the emphasis of pollution abatement in the watershed has been placed on the construction of elaborate waste water treatment plants. It seems obvious that this needs to be re-evaluated with consideration given to control of runoff. Without doubt further expenditures for the greater removal of organic matter at the sewage treatment plants cannot be justified economically. How much nitrogen and phosphorus removal could be justified at the treatment plants would require a much more extensive analysis than is possible with the data presented in this paper, but it seems reasonable that an analysis of this type should be performed before vast sums of money are expended for advanced waste water treatment. In short, the entire approach to pollution abatement and control in the Occoquan Watershed needs to be rethought with due consideration given to the non-recorded sources of pollution. Failure to do so could result in the expenditure of large sums of money without measurable benefits.

RANDALL, C.W. et al. 1977: "The significance of storm water runoff in an urban watershed". Water & soil technical publication no. 15 (1979)

banising watershed". Prog. Water Tech. Vol.9, Pergamon Press; p547-562.

Key words: storm runoff; urban runoff; pollution abatement; organic compounds; nutrients.

The purpose of this study was to perform a preliminary investigation of the importance of urban runoff to pollution abatement efforts in the Occoquan watershed of Northern Virginia. The data clearly show that organic and nutrient contributions from urban runoff constitute a sizeable fraction of the total quantities entering Bull Run and, therefore, the Occoquan Reservoir, and that this source of pollution should be considered in formulating any future policies for the Occoquan watershed. In the past nearly all of the emphasis of pollution abatement in the watershed has been placed on the construction of elaborate waste water treatment plants. It seems obvious that this needs to be re-evaluated with consideration given to control of runoff. Without doubt further expenditures for the greater removal of organic matter at the sewerage treatment plants cannot be justified economically. How much nitrogen and phosphorus removal could be justified at the treatment plants would require a much more extensive analysis than is possible with the data presented in this paper, but it seems reasonable that an analysis of this type should be performed before vast sums of money are expended for advanced waste water treatment. In short, the entire approach to pollution abatement and control in the Occoquan watershed needs to be rethought with due consideration given to the non-recorded sources of pollution. Failure to do so could result in the expenditure of large sums of money without measurable benefits.

RANDALL, C.W. et al. 1978: "The impact of atmospheric contaminants on storm water quality in an urban area". Prog. Wat. Tech., Vol.10(5/6); p417-431.

Key words: air pollution effects; chemical oxygen demand; total organic carbon; nutrients; heavy metals; surface runoff.

Composite precipitation samples were collected by recording raingauges at nine stations in the Virginia portion of the greater Washington, D.C. metropolitan area. The samples were analysed for COD, TOC, all nitrogen and phosphorus forms, and seven heavy metals; iron, zinc, lead, copper, cadmium, chromium and manganese. The results showed that washout of the atmospheric contaminants occurred during the early stages of precipitation events, and that these contaminants are present in sufficient quantity to have a significant impact on surface water quality. Samples tended to contain similar amounts of pollutants after the same rainfall event regardless of land use location and distance from the centre city up to 33 miles. Ranking techniques indicated, however, that precipitation in agricultural and land disturbance areas tends to contain more nutrients. Principal factors affecting

the total quantity of pollutants in rainfall are atmospheric conditions (stagnant or turbulent) and antecedent conditions (time since previous precipitation event).

RANTZ, S.E. 1970: "Urban sprawl and flooding in Southern California". U.S. Geol. Survey circular No.601-B; 11pp.

Key words: flood control; peak discharge.

The floods of January 1969 in south coastal California provide a timely example of the effect of urban sprawl on flood damage. Despite record breaking, or near record breaking, stream discharges, damage was minimal in the older developed areas that are protected against inundation and debris damage by carefully planned flood control facilities, including debris basins and flood conveyance channels. By contrast, heavy damage occurred in areas of more recent urban sprawl where the hazards of inundation and debris or landslide damage have not been taken into consideration, and where the improvement and development of drainage or flood control facilities have not kept pace with expanding urbanisation.

RANZAU, C.E. 1976: "Hydrologic data for urban studies in the Houston, Texas metropolitan area, 1974". U.S. Geol. Survey open-file report; 228pp.

Key words: hydrologic data; urban hydrology; streamflow; urban runoff; rainfall-runoff relationships; chemical analysis.

Basic data collected in the Houston urban area for the 1974 water year (October 1973 to September 1974) are presented. Precipitation data are based on 29 recording raingauges in the Houston metropolitan area. Rainfall for the year was unevenly distributed over the area. Individual station totals ranged from 32.8 inches at the Old Richmond Road raingauge to 61.8 inches at the Llano Street raingauge. The 30-year average (1941-70) is 48.19 inches at the Houston Intercontinental Airport raingauge. The only area-wide storm selected for analysis was the storm of January 19. Runoff data are based on discharge measurements and stage records at 19 continuous-record stream-gauging stations, 6 partial-record stream-gauging stations, and 2 reservoir-content stations. A tabulation of water quality data is included for 19 sites.

RANZAU, C.E. 1977: "Hydrologic data for urban studies in the Houston, Texas metropolitan area, 1975". U.S. Geol. Survey open-file report 77-274; 306pp.

Key words: rainfall-runoff relationships; storm runoff; urban runoff; urban hydrology; streamflow; hydrographs; data collection; hydrologic data.

Detailed rainfall-runoff computations,

including hydrographs and mass curves, are presented for nine storm periods during the 1975 water year in drainage basins in the Houston, Texas metropolitan area. The information will be useful in determining the extent to which progressive urbanisation will affect the yield and mode of occurrence of storm runoff.

RAO, R.A. et al. 1972: "Conceptual hydrologic models for urbanising basins". J. Hydraul. Divn., Proc. ASCE, Vol.98(HY7); p1205-1220.

Key words: mathematical models; hydrographs.

After a preliminary analysis of several conceptual models, the single linear reservoir and the Nash Model were selected for further study. Analysis of about 200 storms from watersheds with different degrees of development indicated that the parameters of the aforementioned two models varied not only with the urbanisation factor (related to the ratio of the built-up area in a watershed to the total watershed area) but also with other physiographic and meteorological factors. Regression relationships between the parameters of the models and the more significant meteorological and physiographic factors including the urbanisation factor were developed. These regression relationships were used to simulate the instantaneous unit hydrographs on a watershed for various urbanisation factors. Changes in runoff from a watershed with increasing urbanisation factors were then simulated for a variety of rainfall characteristics.

RAO, R.A. and DELLEUR, J.W. 1974: "I.U.H.'s, peak discharges, and time lags in urban basins". Bulletin IAHS, Vol.19(2); p185-198.

Key words: hydrographs; computer models; analytical techniques.

The effects of urbanisation of a basin on the runoff have been investigated in the past by the use of linear conceptual models in which the time lag appears as an important parameter. However, in this approach the effects of noise in the data, of sampling rate, of errors due to the lack of synchronisation between the effective rainfall and runoff on the instantaneous unit hydrograph do not become readily apparent. A case in which the cumulative effects of these factors are predominant is presented as an example of the possible difficulties which might be encountered in the analysis of urban hydrologic data by the unit hydrograph method. The disadvantages of relating the peak discharge, the time to peak discharge, and the time lag to the physiographic characteristics alone have been discussed. Alternative regression relationships which involve storm characteristics along with the physiographic characteristics to estimate the peak discharge, time to peak discharge and unit time lag have been presented.

RAO, R.A. and RAO, R.G. 1974: "Comparative analysis of estimation methods in nonlinear functional models of the rainfall-runoff process". Purdue University, Lafayette, Water Resources Research Centre Technical Report No.56; 107pp. (NTIS PB-244 887).

Key words: rainfall-runoff relationship; hydrographs; model studies.

The methods of estimation of kernel functions of nonlinear functional models proposed by Brandstetter and Amorocho, Boneh and Diskin, Bidwell and Roy and Sherman are compared. The rainfall-runoff data from an urban (Ross Ade) watershed in West Lafayette, Indiana were used in the study. The computational complexity, the performance of the estimated kernels in both the regeneration and prediction modes were used for comparing the different methods of estimation of kernel functions. The analysis was conducted to select a method which can be easily used and which is also accurate. The method of kernel function estimation by Brandstetter and Amorocho was selected as the most desirable method on the basis of computational ease, flexibility and accuracy. The second objective was to demonstrate the utility of the functional series models in simulating the short time increment runoff process. The nonlinear functional models can be used for simulation of runoff provided the kernel functions of these models are accurately estimated.

RAO, R.G. and RAO, R.A. 1976: "Analysis of the effects of urbanisation on runoff characteristics by nonlinear rainfall-runoff models". Technical Report No.58, Water Resources Research Centre, Purdue University, Lafayette, Ind.; 62pp. (NTIS PB-249 737).

Key words: urban hydrology; urban runoff; storm runoff; rainfall-runoff relationships; mathematical models; model studies; urbanisation.

The objective was to analyse the effects of urbanisation on daily runoff characteristics. The daily rainfall and runoff from Salt Creek watershed near Chicago was used in the analysis. Two types of mathematical models, the functional series model and a nonlinear stochastic model were used to analyse the effects of urbanisation on runoff. A new method is proposed for estimation of kernel functions of the functional series models. The application of a nonlinear stochastic model to characterise the rainfall-runoff process in which the time derivatives of rainfall sequence are used as additional inputs to the model introduces a new type of model. The role of validation tests in rainfall-runoff models is also emphasised. The models were validated both in prediction and simulation modes and the performance of both models was found satisfactory. The effects of urbanisation on runoff characteristics such as the histograms, correlograms, mass and flow duration curves, and extreme values were analysed by using both the observed and the simulated runoff. All these characteristics were

shown to be significantly affected by urbanisation, and the changes brought about by urbanisation on these characteristics are discussed quantitatively.

REED, L.A. 1971: "Hydrology and sedimentation of Corey Creek and Elk River basins, North Central Pennsylvania". U.S. Geol. Survey water supply paper No.1532-E; 27pp.

Key words: suspended solids; sediment control; agricultural pollution.

Analysis of data collected from two small agricultural basins in north-central Pennsylvania during the period May 1954 to September 1967 indicates that conservation measures reduced the quantity of suspended sediment leaving the Corey Creek basin as a result of frequent storms during the growing season. Extensive soil conservation treatments were applied in the 12.2 square mile Corey Creek basin, but only minor treatments were applied in the adjacent 10.2 square mile Elk Run basin. These treatments included the construction of ponds and diversion terraces and altering land use by such measures as establishing permanent hay land and changing marginal pasture land to woodlands. Elk Run basin, which is topographically and hydrologically similar to the Corey Creek basin, was used as an external control to assist in detecting and evaluating the hydrologic changes in Corey Creek.

Trend analysis of data from both basins indicate a 47 percent decrease in sediment discharge from Corey Creek during the frequent storms that occur in the May to October growing season. Six percent of the sediment discharged from Corey Creek during the period of this investigation (1954-67) was discharged during these frequent growing season storms. The remaining 94 percent of the sediment was discharged during the November to April dormant season and during two major events during the growing season, one October 1955 and one May 1961. No decrease in sediment discharge was observed for these events or for this period.

The adjacent basin of similar size, topography, and hydrologic characteristics, Elk Run, was not scheduled for extensive conservation treatment; it was selected as a control for this study because of the assumption that any changes in precipitation and runoff patterns would affect both basins in a similar manner. Rainfall, runoff, sediment, and stream channel data are used in this report to estimate the probable hydrologic behavior of the Corey Creek basin provided the intensive conservation program had not been undertaken.

REICH, B.M. 1968: "Flood computations for suburbs". American Water Resources Association, Proc. 4th American Water Resources Conference; p276-294.

Key words: mathematical models; flood forecasting; hydrographs.

Although the notion of multiple use of

land and water has reached the planning of suburb communities, the necessary flood hydrographs for minimising cost-benefit ratios have been lacking. Techniques are available for rural watersheds and highly urban areas but not for suburbs. Therefore, three rural methods and one urban procedure were modified for use on three suburban watersheds in southeastern Pennsylvania. These methods were: McSparran's Pennsylvania Synthetic Hydrograph (M); Reich's Small Rural Synthetic Hydrograph (R); Soil Conservation Service's Curvilinear Hydrograph (S); and John Hopkins Urban Inflow Hydrograph (J). Discussion of each method and its development is given along with a table listing the hydrograph parameters of each method. The input to all four methods was rainfall with both reservoir and channel routing involved in this problem. Using the three watersheds with 2, 10, and 100 year storms, five measurements were constructed for each method. These included: inflow hydrographs, outflow at lowest point of combined and routed flood, non-reservoir synthetic hydrograph computed at lowest point, rise times, and scour durations. It is concluded that extrapolation of these four hydrograph methods to suburban design in terms of the 'blue and green' requirements give incompatible results. Radically different structural dimensions would result from each alternative hydrograph procedure. Economic analysis would be correspondingly variable. Finally, the recent stimulus in obtaining hydrologic data for such suburban watersheds should be urgently pursued.

REICH, B.M. 1970: "Simplification of integrated storm water planning for modern multiple land use in urban and suburban developments". Project Technical Completion Report, Pennsylvania State University, Institute for Research on Land and Water Resources; 62pp. (NTIS PB-192-750).

Key words: mathematical models; surface runoff; hydrographs.

Four synthetic hydrograph methods were applied on five watersheds in hopes of simplifying planning decisions for reserved space in valley bottoms of suburbia headwaters. Both routing and hydrograph procedures were programmed for digital computer evaluation for the more than 300 cases considered. General conclusions include the following. (1) No simple rules can be given on width of floodways to planners. Each case must be individually investigated. (2) Computer methods greatly facilitate routing and synthetic hydrograph computations. (3) Generalisations are impossible because interactions occur between the method used, the return period, and the percentage of the watershed above the reservoir among other things. (4) A great need exists for data based methods for predicting suburban design hydrographs in ungauged situations. (5) A new course on urban hydrology was developed from the study results. The course is designed to teach hydrologists the modern techniques which are being developed to

solve this set of urban problems.

REID, C.W. and CLEVELAND, J.A. 1967: "Evaluation of dispersed pollutional loads". ASCE Environmental Engineering Conference - preprint 422; 10pp.

Key words: storm runoff; urban drainage; data collection; analytical techniques.

Experimental technique proposed is to determine quality of storm water from individual drainage basins that make up Tulsa City-County, Okla., and by using component analysis technique, evaluate effects of land use practice on quality of runoff. Stream is sampled twice monthly during dry weather flow, and several times during storm runoff period. It is estimated that at least 1 or possibly 2 yr. of data will be needed to make representative estimation of true quality and quantity of runoff. Principal components of many variables will be estimated by component analysis technique. Knowing principal component regression analysis can be used to determine best model and predictive equation.

REIMER, P.O. and FRANZINI, J.B. 1971: "Urbanisation's drainage consequences". J. Urban Plann. Develop. Divn., Proc. ASCE, Vol.97(UP2); p271-237.

Key words: flood control; watershed management; urban drainage; model studies.

A step toward the concept of urban systems engineering has been made by George S. Nolte and Associates in connection with a Flood Control and Drainage Background Study for San Diego County, California as part of that County's Comprehensive Planning Program. In an addition to an inventory of storm water hazards and existing protective measures in San Diego County, the Nolte Report includes policy recommendations for flood plain zoning and for regionalised flood control. A special output of the study is an operational computer program which allows the preliminary costing of channel improvements for flood protection in relation to alternate distributions of land use in the tributary watershed. Our program has been given the acronym URB DRA CONS, short for URBanisation's DRainage CONSequence, and this paper deals with the application of the URB DRA CONS computer methodology to a pilot watershed in San Diego County.

The specific purpose of URB DRA CONS is to allow the rapid determination of flood flows for different levels of inundation protection resulting from alternate land use distributions. As currently programmed, URB DRA CONS outputs dollar costs for anticipated lined channel improvements required to accommodate flood flows resulting from a given land use pattern and a given level of protection. Because computational and input time for alternate land use configurations is minimal, the

planner is encouraged to test different urban patterns and to ascertain their impact on required flood control protection by the direct comparison of dollar costs. As an additional advisory, URB DRA CONS staged flows can be related to natural watercourse topography and thus define flood plain limits. This step allows comparison to be made between the cost of flood plain acquisition and channel improvement with an evident iterative effect upon the original land use distribution.

REMSON, I. 1971: "Hydrologic and disposal problems in urban areas". In, Environmental planning and geology, proc. of symposium on engineering geology in the urban environment, San Fransisco, California. Geological Survey, et al., cooperative report; p36-41.

Key words: urban hydrology; watershed management; urbanisation; waste water treatment; waste water disposal; sewage treatment.

An important objective of regional planning is to minimise damage stemming from urbanisation. Some of the hydrologic problems of urbanisation are illustrated by preliminary hydrologic analysis and design for the watershed of the Upper East Branch of the Brandywine Creek in Chester County, Pa. A plan was prepared for the orderly development of this basin. The stated objective was to plan the urban development with the minimum of damage and disruption to the water, scenic, and other natural resources. The average annual surplus of precipitation in excess of evapotranspiration is 16.7 inches. Although large volumes of water would move through the local hydrologic system, the natural capacities to provide a source of potable water and to absorb wastes would be exceeded for the design population, despite the favourable hydrological characteristics. Furthermore, a completely acceptable hydrologic environment could not be engineered for the design population, using currently available technology, at an acceptable cost. This led to the development of a philosophical approach to hydrologic design for urbanisation. It might be possible to go beyond the confines of the developed watershed for water supply and waste disposal, to restrict the density of development, or to engineer the watershed more intensively. For example, the eutrophication problem could be solved by a chemical precipitation facility. However, every increase in technology involves costs that increase nonlinearly with population. It is the role of the hydrologist to provide the urban developer with basic data and hydrologic predictions upon which management decisions can be based. Hydrologists find hydrologic models useful for this prediction and extrapolation.

RESNICK, S.D. and DECOOK K.J. 1970: "Hydrological and environmental controls on water management in an arid urban area". Paper AAAS Annual meeting, Chicago, Illinois, December 1970; 16pp.

Key words: urbanisation; watershed management; bacteria; environmental effects; chemical oxygen demand; turbidity; data collection; mathematical models; storm runoff; flood control.

Southwestern arid cities are rapidly growing. Additional wells, which support subdivisions, grassed medians, parks and water-based recreation, contribute to perennial water-level declines. Storm sewers are usually nonexistent. Vehicles may be washed away, and urbanites may drown during summer convective storms. A more reasonable urban plan includes: (1) allow homes only outside flood plains; (2) create greenbelts along channels; (3) manage storm runoff to reduce peaks, provide storage, treatment and reuse; and (4) depress medians. Field data from urban areas, regarding storm volumes and intensities, and mathematical models and simulations for analysing rainfall-runoff-water quality processes need to be developed, refined and applied. Data is being collected on 3 urban and 2 rural watersheds in Tucson by the University of Arizona as a data base. About 2.5 percent of the rainfall becomes runoff in the rural watersheds. Urban runoff is low in turbidity, which may be reduced by alum, and high in COD and faecal coliforms, particularly after sustained dry periods. Chlorination would allow irrigation or water-contact recreation; an activated carbon process, before chlorination, would allow domestic use. Future work includes detailed rainfall and runoff water-quality analysis, treatment, storage and recharge studies, economic analysis and pilot studies.

RICE, L. 1971: "Reduction of urban runoff peak flows by ponding". J. Irrig. and Drainage Divn., Proc. ASCE, Vol.97(1R3); p469-482.

Key words: flood control; storm runoff.

The methods used and the advantages which can be obtained by incorporating the concept of roof top ponding and short term on site detention storage into the design of urban storm drainage facilities are described. By limiting the rate of runoff from flat roofs and other applicable flat areas to predetermined rates, the peak rate of runoff to the receiving storm drainage system can be reduced. On site detention ponding can also be used to reduce peak runoff rates. These techniques have been used to advantage in the Denver region to minimise the impact of new developments on the storm drainage system. Effective design of ponding and detention features requires careful analysis of regional rainfall characteristics. Because storage volumes are relatively small and the runoff hydrographs involved have short time bases with steep peaks, it is necessary to consider fully the magnitude-frequency relationship and intensity-duration characteristics of rainfall as well as its geographic distribution.

RICKERT, D.A. et al. 1972: "A method for evaluating water resources for urban planning". In, short papers of the 8th American Water Resources Conference, St Louis, Missouri, American Water Resources Assoc., Proc. Series No.16; 41pp.

Key words: urban hydrology; data collection.

A water resource evaluation matrix provides a means for determining the relative importance of water-related problems, and for identifying the data needed to evaluate these problems for the purpose of urban planning. The matrix columns list nine subject categories in which water-related urban problems may occur. The matrix rows list possible types of data inputs to evaluate the water-resource problems. The inputs include the standard type of basic hydrologic data as well as information based on interpretation and analysis of these data. In addition to water resource items, the list includes inputs on the interfacing factors of climate, land, and culture. The relative importance of problem categories and data inputs are ranked on a numerical scale. From this, an index is derived that assesses the relative importance of each data item to the overall program. From the completed matrix, the hydrologist can determine the availability of data to meet the identified requirements. Determination can then be made as to priorities on work elements which will provide the planner with maximum information in minimum time.

RIGGS, H.C. 1965: "Effect of land use on the low flows of streams in Rappahannock County, Virginia". U.S. Geol. Survey prof. paper No.525-C; p196-198.

Key words: landuse change; low flow; analytical techniques.

Analysis of discharge measurements for nine small streams in the Piedmont physiographic province, made during summer and fall in the years 1961-64, indicates that discharge per square mile is directly related to the percentage of the drainage basin which is cleared of trees and brush. Clearing of land along the stream channel seems to produce a greater effect on discharge than clearing over the basin generally. This effect of clearing is most pronounced at extremely low levels of discharge and becomes negligible at high discharges.

RILEY, J.P. et al. 1975: "Regional analyses of runoff characteristics for small watersheds". Utah Water Research Lab., Logan, Completion Report PRWG 87-1; 69pp. (NTIS PB-243 517).

Key words: urban runoff; storm runoff; computer models; mathematical models; peak discharge; model studies; rainfall-runoff relationships.

A general method was developed for es-

timating runoff rates and associated confidence limits of a given recurrence interval for ungauged small watersheds. The utility of the method developed was demonstrated through its application to a southeast region of Texas. Some 200 historical rainfall-runoff events from 40 watersheds in Houston, Austin, Dallas, and Fort Worth urban areas were analysed. Watershed data such as drainage area, percent of urbanised area, channel length, average channel slope, land slope, and soil type are documented. Total rainfall amounts, intensities, durations, and mass-time distributions were determined for each storm and used to develop a rainfall generating model. Peak runoff, total runoff volume, and runoff generation are also determined. Statistical analyses were performed to develop regression models to relate peak runoff and total runoff volume with rainfall and watershed characteristics as independent variables. An urban watershed runoff model, based on the Utah Simulation Model, was used to identify the model parameters for each watershed by reproducing the historical storms. Relationships between model parameters and measured watershed variables were established. By combining the rainfall generating model and the watershed runoff model, peak runoff rates and total runoff volumes for different conditions were generated for chart construction.

RILEY, J.P. and DHURVA NARAYANA, V.V. 1969: "Modeling of the runoff characteristics of an urban watershed by means of an analog computer". In, Section 3, urban watersheds: effects of watershed changes on streamflow, (eds. W.L. Moore; C.W. Morgan), University of Texas, Austin.

Key words: urbanisation; rainfall-runoff relationships; computer models; analog models; hydrographs; storm runoff; peak discharge; urban hydrology.

In the synthesis of hydrograph characteristics of small urban watersheds, the distribution of the water among the various phases of the runoff process is attempted by the concept of 'equivalent rural watershed'. For a given input into both the models, the outputs must be identical. The hydrograph of outflow from an urban watershed is obtained by chronologically deducting the losses due to interception, infiltration, and depression storage from precipitation on the equivalent rural watershed and then routing it through the surface and channel storages. This is being approached by computer simulation. Testing and verification of the basic mathematical model is being done by using observed rainfall and runoff data from well instrumented runoff areas. Coefficients representing interception, depression storage, and infiltration are determined by the trial and error process on the analog computer in such a way that the outflow hydrograph predicted by the model is nearly identical to the measured prototype hydrograph. Relationships between these coefficients and various urbanisation characteristics or parameters are established. Sensitivity

which investigate the significance of each of the watershed coefficients on the outflow characteristics are also undertaken.

ROBBINS, W.D. 1970: "Annual compilation and analysis of hydrological data for urban studies in the Austin, Texas metropolitan area, 1969". U.S. Geol. Survey basic-data report; 46pp.

Key words: hydrologic data; data collection; rainfall-runoff relationships.

Rainfall and runoff data are presented to compare the urban Waller Creek and the rural Wilbarger Creek study areas for the 1969 water year. The Waller Creek drainage area lies entirely within the city of Austin, with the headwaters in the northern part of the city. Storm sewers and street gutters divert runoff both into and out of the natural drainage basin. The weighted mean rainfall upstream from 38th Street was 30.25 inches, 7 percent below the mean annual rainfall for Austin of 32.58 inches. Mean daily discharge was 1.38 cfs; annual runoff was 8.08 inches, or 27 percent of rainfall. Wilbarger Creek is in a rural area about 15 miles north of the city of Austin. Weighted mean rainfall in this study area was 27.92 inches, 14 percent below the mean annual rainfall for Austin. Mean daily discharge was 1.49 cfs; annual runoff was 4.40 inches, or 16 percent of the rainfall.

ROBBINS, W.D. 1971: "Annual compilation and analysis of hydrologic data for urban studies in the Bryan, Texas, metropolitan area, 1969". U.S. Geol. Survey open-file report; 49pp.

Key words: hydrologic data; hydrographs; data collection; rainfall-runoff relationships; streamflow; urbanisation; watershed management.

This report contains the rainfall, runoff, and storage data collected during the 1969 water year for the Hudson Creek and Burton Creek watersheds in the vicinity of Bryan, Texas. Average rainfall over the Burton Creek study area during the water year was 49.67 inches, or 27 percent more than the 30 year (1931-60) average. Mean daily discharge was 3.25 cfs, and the total runoff was 2,360 acre-feet, or 33.24 inches (67 percent of rainfall). Average rainfall over the Hudson Creek study area during the water year was 49.36 inches, or 26 percent more than the 30 year (1931-60) average. Mean daily discharge was 2.42 cfs, and the total runoff was 1,750 acre-feet, or 16.94 inches (34 percent of rainfall). Computations, hydrographs, and mass curves for each storm are included.

ROBERTS, M.C. 1972: "Watersheds in the rural - urban fringe". In, Watersheds in transition, proceedings of a symposium held at Fort Collins, Colorado. *Water Res. Soil Technol. J. Water Res. Soc. Am.* Vol. 15 (1979) No. 14; p388-393.

Key words: urbanisation; environmental effects; urban hydrology; urban runoff; storm runoff; urban drainage.

The impact of urbanisation on rural watersheds is discussed with the aid of specific examples from the Jackson Creek watershed near Bloomington, Indiana. The expansion of non-farmland use was mapped over a 32 year time period in the Jackson Creek basin. The spatial pattern is an asymmetric one reflecting the concentration of new development on the east side of the watershed, this pattern is a response to the city policy of sewers and waterlines being provided to areas immediately adjacent to previous developments. A sampling of land use intensity indicates that since 1939 there has been a drop in the amount of impermeable surface in residential areas from 34 percent to 15 percent (the newer subdivisions are being developed with larger lot sizes). However, extensive commercial developments, having 100 percent impermeability, have been built as well. Newly constructed urban areas often produce so much extra runoff that the land downstream is periodically inundated. The costs are carried by the people who did not initiate the cause for them. Planners should be able to predict such outcomes of modifying the environment.

ROBEY, D.L. 1970: "Effects of urbanisation on peak flow frequency analysis". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper No.3; 14pp.

Key words: urban hydrology; storm runoff; flood forecasting; urban runoff; peak discharge; rainfall-runoff relationships.

Urban hydrology was originally concerned only with the downtown paved area; this is not sufficient today because of urban sprawl. The frequency of flooding is a necessary consideration in planning land use and development. Relationships for estimating the magnitude and frequency of occurrence of flood peaks on a drainage basin having a high degree of urban and suburban development are reviewed; their results vary greatly. The basin used in this study is Fourmile Run located in northern Virginia. The drainage area is 14.4 square miles, and the channel capacity is approximately 2,700 cfs. In recent years the area has undergone considerable development and redevelopment. Flood conditions are produced by intense rainfall of short duration. Lag time, the parameter most affected by urbanisation, is for a completely storm sewer system about one-eighth that of a comparable natural system. On small, steep basins, drainage improvements alone may triple average flood discharges, and complete development of stream channels and basin surface may increase average floods by a factor of 8. A complete impervious surface will increase the average size flood by a factor of 2.5 but may decrease the discharge of a larger than average flood. For the 100 year flood

the discharge estimates ranged from 12,740 to 29,600 cfs. The use of the log-Pearson Type III distribution, modified to include the recent U.S. Geological Survey study, is recommended to define the mean annual flood.

ROBINSON, A.M. 1976: "The effects of urbanisation on stream channel morphology". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; pl15-127.

Key words: urbanisation; flood discharge; sediment yield; channel erosion; data collection; sediment control.

Study of eight streams draining 1.0 +/- 0.1 square mile basins in the Piedmont province of the Baltimore, Maryland-Washington, D.C. metropolitan area indicates that urbanisation, resulting in increased magnitude and frequency of flood flows and changes in sediment yield, has considerable impact upon stream channel morphology. Three watersheds were rural, three urban, one partially urbanised, and one was undergoing development. Width, depth, wetted perimeter, and cross-sectional area were determined at twenty sections for each stream. Channel area of the urban streams was on the order of 2 times and width/depth ratios 1.7 times those of the rural channels. The size distribution of bed material was altered by a reduction in the fractions of silt and sand as well as by increase in the cobble fractions. Channel geometry progressively changes from an equilibrium form prior to urbanisation to a state of disequilibrium during and following development to a new form, characterised by larger cross-sectional area and width/depth ratios, coarser bed material, and lower ratios of wetted width to channel width at base flow. It is postulated that a new equilibrium form is not achieved for at least fifteen years. Increasingly, maintenance of stream channel size and character is being presented as a goal of and a justification for storm water management programs. Cost of dredging sediment eroded during channel enlargement ranges from \$55,000 per sq mile to \$220,000 per sq mile for a doubling of channel volume in a 10 sq mile basin. Structures on and adjacent to the flood plain, especially storm sewer outfalls, sanitary sewers, and bridges, are commonly undermined and damaged. While difficult to quantify, the esthetic quality of the channels also changes. Effective sediment and storm water control programs can reduce channel enlargement and associated costs.

ROBINSON, A.R. 1970: "Technology for sediment control in urban areas". In, Proceedings of National Conference on Sediment Control, Washington, D.C. Environmental planning paper, Department of Housing and Urban Development; 7pp.

Key words: erosion control; erosion; sediment yield; urbanisation; sediment transport; channel erosion.

Under urban construction activity, sediment loads of 25,000 to 140,000 tons per square mile have been measured. Erosion and sediment are usually liabilities, and specific efforts to reduce or manage the adverse effects are required for successful or satisfactory development in use of water and related land resources. Reduction of sediment problems requires information and technology on the mechanics of erosion and sedimentation. The physical and chemical properties of soils also are important factors in the control of erosion. There are needs for new knowledge and methods particularly adapted to the situation where large areas are suddenly changed to urban uses. Generally overlooked is the fact that a flowing stream is a dynamic body which has the energy to transport silt and sediment. Unless flowing in a channel that is nonerodible, such as concrete, the stream will attempt to transport sediment up to its energy ability, and may erode or degrade the bed or surface to obtain this material. If it is carrying a load greater than the available energy, then deposition will occur. Therefore it must be considered to be almost a living, viable body and treated as such. Recommended control measures are presented under the following headings: Permanent Vegetation; Diversions; Outlet Channels; Bench Terraces; Waterway Stabilisation; Structures; Bank Erosion Structures; Stream Channel Construction; Sediment Basins; and Timing of Construction.

ROBINSON, R.C. 1970: "Minimising soil erosion and water and air pollution at SCS construction sites in Georgia". ASAE Paper No.70; p703.

Key words: erosion; sediment control; pollution abatement.

Sediment results from construction sites when high intensity rainfall hits areas lacking proper cover. Much sediment can be moved from the site at these times and extensive damage will take place to partially finished construction. The Soil Conservation Service is interested in preventing the movement of sediment wherever it occurs and has instructed all field offices to incorporate into construction contracts measures to reduce sediment movement at construction sites. Many of the practices that are applied on agricultural land to prevent erosion can be used on construction sites. These include diversions, waterways, and various structural practices such as debris basins or sediment traps constructed either on a permanent or temporary basis. Temporary seedings can also be used. Timing of construction operations is also important so that the whole site is not stripped of cover at one time. Preventing sediment movement along channel construction is more difficult but some abatement practices can be used. The basic channel design must first be adequate. The shaping of spoil and placing structures to bring in tributary water will further help the situation. Sediment traps can also be utilised. All these various items have been included in construction contracts in Georgia. The effect depends

a great deal on the timeliness of their applications. This requires close cooperation between the landowner, the SCS and the contractor. Pollution abatement measures add expense, but as long as the public demands them they will be included.

RODIER, J.A. 1977: "Research in West Africa on the effects of urbanisation on surface flow". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAMS Publication No.123; p79-82.

Key words: peak discharge; surface runoff; analytical techniques.

This paper presents briefly: (1) the results of research carried out on urban basins in Brazzaville (Congo) in 1954; (2) the systematic study on urban basins in Niamey (Niger) in 1963; (3) the experimental results obtained; (4) the attempts to adapt the French Caquot formula for the computation of maximum discharge for the 10-year flood by changing different factors (adjustment for the Ivory Coast and the Sahelo-Sudanese zone; (5) the attempt to use another formula starting from the 'rational method'; (6) the research programme lead by CIEH (Inter-African Committee on Hydraulic Research) and ORSTOM in West Africa for improving knowledge about the runoff coefficients, the shapes of hydrographs and the shapes of intensity-duration curves for very short periods of time, and the general results of this new programme.

ROESNER, L.A. 1974: "Quality aspects of urban storm water runoff". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p138-158.

Key words: analytical techniques; biochemical oxygen demand; chemical oxygen demand; combined sewers; urban runoff.

It has only been about ten years since sanitary engineers began to realise the significance of urban runoff as a source of pollution in receiving waters. Historically, the earliest sewers were built for the collection and disposal of storm runoff. For convenience, these sewers discharged to the nearest watercourse. In later years, domestic and industrial waste waters were discharged into these sewers, thereby converting them to the combined sewers. As the significance of the pollutional effects of discharging raw sewerage to the watercourses became recognised, the major cities embarked upon programs of interceptor sewers to divert some multiple (generally 1.5 - 5) of the average dry weather flow to a central location for treatment prior to disposal.

Even with interceptors however, storm water overflows from these combined systems were still observed to carry significant pollution loads. It is apparent that the BOD and solids loads in

urban runoff are significantly higher than those found in combined overflows which represent a mixture of sanitary sewage and storm water. As a result of these findings, the emphasis on storm water pollution control is now being placed on controlling the pollutant load of all storm water discharges whether they emanate from a combined system or from a separate storm sewer system.

ROESNER, L.A. 1974: "Impact of storm water runoff on receiving water quality". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p159-176. (NTIS PB-247 163).

Key words: urban runoff; storm runoff; waste water disposal.

At the present time, every city in the United States ultimately disposes of most of its storm water runoff in a natural watercourse. The impact of these discharges on the water quality of the receiving waters depends principally on three items: (1) the quantity and quality of the storm water discharges; (2) the type of waterbody into which the discharge occurs; (3) location of the outfalls. The author shows the pollutional potential of storm water and presents some examples of its impact on different receiving waters. The last section of the paper contains general discussion on considerations involved in assessing the impact of storm water discharges on receiving water quality.

ROESNER, L.A. et al. 1972: "Use of storm drainage models in urban planning". In, Watersheds in transition, proceedings of a symposium held at Fort Collins, Colorado. AWRA Proc. Series No.14; p400-405.

Key words: urban hydrology; model studies; urbanisation; urban drainage; storm runoff; urban runoff; water pollution sources.

The use of storm drainage models is demonstrated for evaluating the effect of land use changes on the quality and quantity of urban runoff. The demonstration is made by application of the models to the Selby Street drainage basin in the city of San Francisco. Comparisons are made between the quantity and quality of urban runoff under present land use conditions and a modified land use condition in which a 305 acre park is assumed to be multiple residential housing. The simulation results show that the changed land use has a significant effect on the combined sewer overflows from the system. The suspended solids concentrations for the multiple residential land use case are higher than for the park, and the peak concentration is lagged. The increased concentration is due to the increased washoff of surface pollutants as the result of the increased runoff. The reason for the lag in the peak concentrations is not apparent.

ROESNER, L.A. et al. 1974: "A model for evaluating runoff quality in metropolitan master planning". ASCE Urban Water Resources Research Program, Technical Memo. No.23; 73pp. (NTIS PB-234 312).

Key words: urbanisation; computer models; pollution abatement; erosion; rainfall-runoff relationships; water pollution sources; overflows; waste water treatment.

Documented is a computer model that should see extensive use in total-jurisdiction preliminary master planning for abatement of pollution from storm sewer discharges and combined sewer overflows. It is presently the outstanding tool available for that purpose. The computer program and a user's manual are available to the public. Water Resources Engineers (WRE) employed the initial version of the model in part of the development of the Department of Public Works, City and County of San Francisco, Master Plan for combined sewer overflow abatement, using 62 years of hourly rainfall data. WRE developed a more comprehensive version for The Hydrologic Engineering Centre, Corps of Engineers, as part of a training course; the version is documented. Examples of planning applications are included, together with samples of computer output for a San Francisco drainage area including summary and event statistics for rainfall, storage, overflow, treatment and quality. Related management issues are presented in a companion report.

ROESNER, L.A. et al. 1977: "Urban runoff quality in the Detroit area". Paper presented at Annual Spring Meeting of the AGU, Washington, D.C. EOS, Vol.58(6); p388.

Key words: mathematical models; urban runoff; dissolved oxygen; biochemical oxygen demand; nutrients; algae; heavy metals.

As part of the Southeast Michigan Council of Governments' (SEMCOG) 208 water quality planning study, a mathematical model was developed to simulate wet weather pollution loads and receiving water response (streams) to these loads. This paper describes the mathematical model and shows the results of the application to the Rouge River Basin (1195 sq km, 467 sq ml) in Southeastern Michigan. The model simulates runoff from 7 urban land categories and 5 rural land categories. Up to 14 water quality parameters can be simulated, including dissolved oxygen, biochemical oxygen demand, nutrients, algae, and heavy metals.

ROFFMAN, H.K. et al. 1975: "The effects of large shopping complexes on storm water runoff". Paper in proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Ky.

Key words: storm runoff; environmental effects.

Large enclosed shopping complexes provide convenience to the consumer by offering ample parking space, a greater selection of stores and merchandise at one weather protected facility. Concentration of all shopping needs at one location also allows for time savings and saving of the presently more important commodity gasoline. Such complexes supply a complete range of living requirements and provide a rational focal point for mass transit in the suburban metropolitan setting. This water quality study was conducted to determine the environmental impacts from runoff from large parking areas associated with such shopping centres. Findings of this study indicate that properly sited and designed large shopping complexes should not have adverse effects on the local water quality and can be environmentally acceptable.

ROGERS, P. and STEINITZ, C. 1970: "A study of resource use in urbanising watersheds". Harvard University, Cambridge, Mass. Dept. of Landscape Architecture, Contract Report No. CR-2; 190pp.

Key words: mathematical models; water pollution; urbanisation; urban hydrology.

The report describes a simulation model constructed to enable planners to evaluate quickly the damaging impact of urbanisation (and changing land uses) on the runoff characteristics of a river basin. The model area involves a small part of the Charles River basin, Massachusetts. It also deals with visual consequences of urbanisation upon waterways which flow through the developing area.

ROOT, M.J. and RAGAN, R.M. 1974: "Maryland highway drainage study: Volume 3 - a linked system model for the synthesis of hydrographs in urban areas". Maryland University, College Park, Dept. of Civil Engineering, Report AW74-073-046-3; 84pp.

Key words: urban hydrology; model studies; mathematical models; computer models; hydrographs; urban runoff.

The algorithm developed in this report made use of the equations for one-dimensional, unsteady, spatially varied open channel flow and an empirical overland flow mathematical model. The technician or engineer does not need a knowledge of the equations used since he is required only to describe the physical features of the drainage area and to select the hydrograph. The computer automatically develops the hydrograph and returns the value of the discharge at pre-selected time intervals.

ROSENKRANZ, W.A. 1970: "Storm and combined sewer demonstration projects". Federal Water Pollution Control Administration, Washington, D.C. Division of Applied Science and Technology, FWPCA-DAST-36

W70-05467, FWPCA-11000-12/69; 124pp. (NTIS PB-190 799).

Key words: abstracts; water pollution; overflows; combined sewers.

Studies of combined storm and sanitary sewers and treatment of combined wastes are listed, abstracts of completed reports are presented, and active projects are described in information sheets. Subjects needing more research are also listed and described. Equipment, data methods, and criteria for urban drainage projects are outlined.

ROUX, J.C. 1977: "Pollution of the chalk aquifer under the industrial built - up area of Rouen in the Seine Valley". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p408-420.

Key words: chemical wastes; industrial wastes; aquifers; trace elements; organic compounds; detergents.

This note discusses a case of permanent chemical pollution from industries situated on an alluvial plain. From 1973 to 1976 numerous analyses of samples from drillings in industrial areas in the Valley of the Seine near Rouen (France) resulted in the area being delimited into five zones of pollution around the main chemical industries. The chalk and alluvial aquifer were polluted by excessive amounts of major elements, as well as minor elements and trace metals, hydrocarbons and detergents. The observations over the study period reveal, on the one hand, a great variation in some elements and, on the other hand, an extension and increase of the pollution.

ROVEY, E.W. and WOOIHISER, D.A. 1977: "Urban storm runoff model". J. Hydraul. Divn., Proc. ASCE, Vol.103(HY11); p1339-1351.

Key words: computer models; urban runoff; storm runoff; hydrographs; urban drainage; model studies.

Kinematic equations for overland flow and flow in an open channel, as well as the derivation of an infiltration curve as a function of time from ponding and infiltration rate, are presented. A computer model has been developed to approximate the response of a watershed to a specified rainfall event with respect to overland flow on a rectangular surface, open channel flow in a trapezoidal channel, free surface flow in a circular conduit, and general watershed geometry. Input required for the model includes geometric parameters estimated from a topographic map of the watershed, parameters for surface resistance to flow, and infiltration parameters for pervious surfaces. Overland flow resistance coefficients are listed for various surface types. The 165-acre Hillcrest Drain watershed in Northglenn, a suburb of Denver, Colorado

do, is cited as an example of the use of the model to simulate runoff hydrographs with input of several observed rainfall hyetographs. Simulations of three observed storms were marked by underestimation of the initial peak of discharge and overestimation of the peak rate and volume, although peaking time prediction was good. For a storm which consisted of two definite pulses of rainfall, the first peak was underestimated while the second peak was overestimated. The inability to predict the difference between actual rainfall and all losses is suggested as contributing to the differences between actual and computed results. Problems associated with estimation of the antecedent moisture condition of the soil and with the spatial distribution of gauging stations within the watershed are discussed.

RUANE, R.J. and FRUH, E.G. 1973: "Effects of watershed development on water quality". J. Amer. Water Works Assoc., Vol.65; p358-363.

Key words: data collection; bacteria; waste water treatment; water pollution control.

The authors present, with graphs and tables, a review of water quality monitoring records collected at two water treatment plants on the Colorado River at Austin, Tex. It is shown that immediately after the construction of upstream impoundments, bacterial concentrations decreased significantly both in range of variation and average concentration. Such reductions are apparently dependent on detention period in the reservoir, temperature, presence of predators, and sedimentation. Bacterial concentrations gradually increase again with increased urbanisation of the drainage area. Comparison of Town lake with the upstream reservoir, Austin lake, showed increases in bacterial concentrations and hardness of water in Town lake, which also indicate the effects of urbanisation.

RUMKER, R.V. et al. 1972: "The use of pesticides in suburban homes and gardens and their impact on the aquatic environment". EPA, Washington, D.C. Office of Water Programs. Pesticide study series No.2; 501pp. (EPA-68-01-0119; NTIS PB-213 960/7).

Key words: pesticides; water pollution.

The present study is concerned with the use of pesticides in suburban homes and gardens in three different metropolitan areas: Philadelphia, Pennsylvania; Dallas, Texas; and Lansing, Michigan. The report describes the following: analyses, describes, and documents quantitatively the use of pesticides in suburban homes and gardens; evaluates and documents quantitatively the direct and indirect impact on the natural environment resulting from pesticide uses, with special emphasis on the movement of pesticides and their possible metabolites and degradation products; pinpoints areas of actual or

potential environmental damage; provides a basis for systematic correction of such damage to the natural environment; and describes applicable local and state laws and regulations, and evaluates their effectiveness in preventing environmental damage.

RYDEN, J.C. et al. 1972: "Nutrient enrichment of runoff waters by soils. Phase I: phosphorus enrichment potential of urban soils in the city of Madison". Wisconsin University, Madison, Water Resources Centre; 79pp.

Key words: phosphorus compounds; nutrients; suspended solids.

An extensive review of the literature pertaining to phosphorus in runoff and streams was prepared. Methods were evaluated for determining the potential of eroding noncalcareous and calcareous soil horizons collected from an urban development site for the phosphorus enrichment of streams, based on the phosphorus sorption-desorption characteristics of the soil materials as a function of dissolved inorganic phosphorus concentrations in systems simulating the stream environment. The experimental approach developed provides a basis for predicting the phosphorus enrichment potential not only of soils eroding from urban development sites, but also those carried in runoff from agricultural lands.

RYDEN, J.C. et al. 1972: "Potential of an eroding urban soil for the phosphorus enrichment of streams. I: Evaluation of methods. II: Application of adopted method". J. Environment Quality, Vol.I; p430-438.

Key words: erosion; phosphorus compounds; nutrients; analytical techniques.

Three methods were studied for determining the potential of soil horizons, collected from an urban development site, for the phosphorus enrichment of streams, including evaluation of the sorption and desorption of phosphorus. A simplified simulation of the stream environment was developed for use in a routine test for evaluating the potential of soil materials for the phosphorus enrichment of streams. The application of this method to systems containing mixtures of varying proportions of contrasting horizons from an eroding soil is discussed together with its validity.

SAAH, A.D. and WATSON, E. 1976: "Santa Clara Valley water district urban hydrology: use of the Corps of Engineers flood hydrograph package HEC-1 as a predictive model". In, National Symposium on urban hydrology, hydraulics, and sediment control, University of Kentucky, Lexington, Ky.; p203-214.

Key words: model studies; mathematical models; hydrographs.

The effect of urbanisation on floods has been successfully modeled. The model couples concepts that simplify the urban hydrologic system, without loss of appropriate response, with an existing nonproprietary computer program. It is also easy and inexpensive to utilise and has given results consistent with statistical analysis of observed data. The concepts were developed and tested in the large metropolitan area of San Jose, California. The first part of the paper develops a concept of subdividing an urban area into hydrologically equivalent pervious and impervious elements. For each of these elements, synthetic unit hydrograph parameters were calculated separately, and inflow hydrographs at storm drain system inlets were obtained. The second part presents the storage-discharge relationships determined from storm drains, manholes, gutters, and streets. This storage-discharge relationship is regional in nature and applicable to urban areas of the type found in San Jose for the purpose of flood routing. In general, the model accounts for the effects on runoff due to two major urban changes, increased imperviousness and channelisation. It uses the existing HEC-1 computer program developed by the Corps of Engineers Hydrologic Engineering Centre. This paper discusses the assumptions and the required inputs of the program. It does not discuss the theory or logic of the program itself; preknowledge of the program is assumed.

SAGER, P.E. and WIERSMA, J.H. 1975: "Phosphorus sources for Lower Green Bay, Lake Michigan". J. Water Pollution Control Federation, Vol.47(3); p504-514.

Key words: phosphorus compounds; water pollution sources; nonpoint pollution sources.

The objective of this study was to determine major sources of phosphorus entering Green Bay from the Fox River drainage basin. Of particular interest was an assessment of the relative importance of nonpoint sources in the drainage basin.

SAMAR, P. et al. 1976: "Physical - chemical treatment improves Iran's urban runoff". Water and Sewage Works, Vol.123(8); p77-79.

Key words: urban runoff; waste water treatment; turbidity; chemical oxygen demand; heavy metals; lead; suspended solids.

Environmental studies in Iran have revealed that a physical-chemical process consisting of coagulation, flocculation, sedimentation, and carbon adsorption is effective in treating urban land runoff. A system employing coagulation with alum, sedimentation, and adsorption with powdered activated carbon yielded average removal efficiencies of 97, 85, and 100 percent for turbidity, chemical oxygen demand, and lead respectively. By comparing removal efficiencies in various stages of the treatment process, it was established that turbidity, chemical oxygen demand, and lead are mostly in the settleable and suspended forms. Consequently, coagulation, flocculation, and sedimentation result in high removals for these parameters. The optimum dosage of powdered activated carbon was chosen according to the adsorption efficiency of carbon for dissolved organics and averaged 58 milligrams/litre.

SARGINSON, E.J. 1973: "A statistical treatment of urban drainage design". J. Inst. of Municipal Engineers, Vol.100; p152-154.

Key words: storm runoff; analytical techniques.

In a previous paper, the Transport and Road Research Laboratory (TRRL) method of computing urban storm water discharges was discussed in detail, and attention was drawn to certain anomalies in the theoretical basis of the method. In the same paper, an attempt was made to develop a method of computation which would more accurately reproduce the mechanics of urban runoff. It was also proposed that losses should be treated by adopting the TRRL principle of 'percentage runoff', i.e. by assuming that losses were a fixed percentage of the rainfall on the paved area at all stages of the storm. However, this was subsequently found to give rise to serious errors when combined with the method then proposed. It is now suggested that a statistical treatment of existing urban runoff data in terms of the 'rational' formula should provide a more reliable method of computing storm water flows.

SARGINSON, E.J. 1974: "Relationship of rainfall and runoff in urban areas". In, Proceedings CIRIA/Bristol University research colloquium on rainfall, runoff and surface water drainage of urban catchments, Bristol, April 1973; p9-1-9-8.

Key words: rainfall-runoff relationships; mathematical models.

The present paper describes a proposed mathematical 'model' relating rainfall and runoff in urban areas. In constructing such a model, it is possible to define three desirable features: (1) The model should attempt to reproduce the mechanics of urban runoff. (2) It should consistently predict sewer discharges accurately. (3) It should be relatively simple to apply to design problems. The proposed mathe-

mathematical model is the result of a fairly exhaustive examination of 55 storms on four catchments in the USA.

SARGINSON, E.J. and BOURNE, D.E. 1969: "The analysis of urban rainfall, runoff and discharge". J. Inst. of Municipal Engineers, Vol.96; p81.

Key words: hydrographs; analytical techniques; flood routing.

This paper considers phenomena which modify a rainfall hydrograph for an urban catchment, and it examines the extent to which these modifications are satisfied by existing design methods. The theory presented accounts for phenomena concerned. A method for analysis of existing urban rainfall and discharge records is given. This design method was developed with the hydrograph based on a standard storm which is successively routed over the ground and through a sewer, assuming a linear flow relation for each.

SARGINSON, E.J. and NUSSEY, B.B. 1975: "A mathematical model for urban runoff". In, Symposium on the application of mathematical models in hydrology and water resource systems, Bratislava. IAHS Publication No.115; p209-213.

Key words: urban runoff; mathematical models; rainfall-runoff relationships; storm runoff; hydrographs; model studies; surface runoff; flood forecasting; analytical techniques.

The mathematical model assumes that after deducting losses for surface depression and infiltration, the excess rainfall from the whole catchment is routed successively overland and through the pipe system. This process is equivalent to flow through two equal linear reservoirs in series, and leads to a linear second-order differential equation. The total rainfall loss during a storm is a linear function of the total rainfall and the slope and impermeability of the catchment. In combination with a standard design storm such as the one suggested by the Meteorological Office of the United Kingdom, the 'model' results in a simple formula for the discharge, incorporating 'reduction factors' which depend on the rainfall loss coefficient and the linear pipe routing parameter, which can be computed from the dimensions of the pipe system. A statistical analysis of existing data shows a linear correlation between the percentage runoff and the catchment slope, and leads to a modification of the 'rational' formula, which incorporates this correlation.

SARMA, P.B.S. 1970: "Effects of urbanisation on runoff from small watersheds". Dissertation; 307pp.

Key words: rainfall-runoff relationships; urban hydrology; urbanisation.

Urban and suburban development changes the quantity and time distribution of runoff. Investigation of the effect of

urban development on the rainfall-runoff relationships was the main objective of this study. Quantitative evaluation of effects of urbanisation on runoff would be relatively simple if rainfall and runoff data for both urban and pre-urban conditions of watersheds were available. Due to a lack of availability of such data, evaluation of changes in runoff characteristics caused by urbanisation is not possible by direct data comparison and analysis. Data for the study were obtained principally from watersheds in West Lafayette, Indiana. Hydrologic data from several other urbanised watersheds were also used to make the study more general. Linear system analysis was used in the study. The single linear reservoir model, the double routing method, Nash model, the single linear-reservoir linear-channel model, and the Fourier transform method of obtaining the kernel function were used in the analysis of data. The parameters of the instantaneous unit hydrographs for the first four models were determined and also optimised for some of the conceptual models. Similarly, the kernel functions were determined by the Fourier transform method. The regeneration performance of all these models was then tested. The single linear reservoir model was selected to simulate the rainfall-runoff process on small urban watersheds. On the basis of its satisfactory regeneration performance and some other factors, the Nash model was similarly selected for simulation of the rainfall-runoff process on larger watersheds. The parameters of the single linear reservoir model and the Nash model were then studied in detail. The variation of the parameters and their relationships with the physiographic characteristics of the watersheds including the urbanisation factor, and the storm characteristics, were studied mainly by using the techniques of regression analysis. From this analysis, the effects of urbanisation on time lag, the magnitude of peak discharge, the time to peak discharge, and the frequency of peak discharge were quantitatively deduced.

SARMA, P.B.S. et al. 1969: "A program in urban hydrology, Part II. An evaluation of rainfall - runoff models for small urbanised watersheds and the effect of urbanisation on runoff". Tech. Report No.9, Water Resources Research Centre, Purdue University, Lafayette, Indiana; 262pp. (NTIS PB-189 043).

Key words: analytical techniques; model studies; computer models; storm runoff; hydrographs; rainfall-runoff relationships.

The data for the study were taken from four watersheds with varying degrees of urbanisation located in West Lafayette, Indiana. The analytical approach adopted was the linear (time variant, lumped) system analysis. The conceptual linear systems considered in the analysis of the data were the single linear reservoir model, the Nash model, and the single linear reservoir with linear channel model.

SARMA, P.B.S. et al. 1973: "Comparison of rainfall - runoff models for urban areas". J. Hydrology, Vol.18(3/4); p329-348.

Key words: rainfall-runoff relationships; mathematical models.

The relative regeneration performances of five linear rainfall excess-direct runoff models are compared for several urban watersheds with varying degrees of development. The five models considered are the single linear reservoir, the Nash model, the double routing method, the linear channel-linear reservoir model and the instantaneous unit hydrograph (IUH) obtained by the Fourier transform method. The IUH always gives the best regeneration performance among the four conceptual models tested. The optimised single linear reservoir constant differs from the theoretical time lag value, but is related to the latter, and for each watershed varies from storm to storm. For larger watersheds the Nash model gives the best regeneration performance among the four conceptual models tested. The model parameters for each watershed are found to vary from storm to storm. The quality of regeneration for larger basins is less than that found for the smaller basins.

SARTOR, J.D. and BOYD, G.B. 1972: "Water pollution aspects of street surface contaminants". URS Research Co., San Mateo, California. EPA, Office of Research and Monitoring Report R2-72-081; 242pp. (NTIS PB-214 408/7).

Key words: surface runoff; water pollution; biochemical oxygen demand; heavy metals; pesticides; chemical oxygen demand; solid wastes; Kjeldahl nitrogen; nitrates; phosphorus compounds.

Materials which commonly reside on street surfaces have been found to contribute substantially to urban pollution when washed into receiving waters by storm runoff. In fact, runoff from street surfaces is similar in many respects to sanitary sewage. Calculations based on a hypothetical but typical U.S. city indicated that the runoff from the first hour of a moderate to heavy storm would contribute considerably more pollution load than would the same city's sanitary sewage during the same period of time. This study provides a basis for evaluating the significance of this source of water pollution relative to other pollution sources and provides information for communities having a broad range of sizes, geographical locales, and public works practices. Information was developed for major land use areas within the cities (such as residential, commercial and industrial). Runoff was analysed for the following pollutants: BOD, COD, total and volatile solids, Kjeldahl nitrogen, nitrates, phosphates, and a range of pesticides and heavy metals.

SARTOR, J.D. et al. 1974: "Water pollution aspects of street surface contami-

nants". J. Water Pollution Control Federation, Vol.46(3); p458-467.

Key words: urban runoff; water pollution sources; pollution abatement; water pollution control.

Results are reported of studies on the polluting potential of runoff from urban areas. The major constituent of street surface contaminants was found to be inorganic mineral like matter, and the amount found at a given site depended on the period since the site was last cleaned, either by sweeping or flushing, or by rainfall. Factors affecting removal of loose particulate matter from street surfaces by rainfall were identified, and the need for improved street cleaning practices is emphasised.

SAUER, V.B. 1974: "An approach to estimating flood frequency for urban areas in Oklahoma". U.S. Geol. survey water resources investigations, No.23-74; 10pp.

Key words: peak discharge; flood forecasting.

Flood frequency studies for urban areas in several parts of the United States and flood frequency relations for natural streams of Oklahoma were used to develop a set of flood frequency equations for urban areas of Oklahoma. Equations are presented for estimating the 2-, 5-, 10-, 25-, 50-, and 100-year peak flood discharges for basins of 0.5 to 100 square miles.

SAVINI, J. and KAMMERER, J.C. 1961: "Urban growth and the water regimen". U.S. Geol. Survey water supply paper No.1591-A; 43pp.

Key words: rainfall-runoff relationships; sediment yield; landuse change; salinity; ground water resources.

The continuing growth and concentration of population and industry in urban and suburban areas in recent decades has caused a complex merging of social, economic, and physical problems. The interrelationships of man and his use and development of the land and water resources is a particularly significant aspect of urbanisation, but there has been relatively little study to date of the effect of urban man upon natural hydrologic conditions. As urban man changes an area from one of field and forest to one of buildings and streets, he covers land where water once entered the soil, and thus creates or aggravates problems of drainage, including storm water runoff. As he requires increasing amounts of water for home and factory, he drills deeper wells, and builds longer aqueducts and larger dams and reservoirs. As he disposes of unwanted waste materials, he either treats them by using water or pollutes the receiving body of water. As he dredges and deepens coastal streams carrying salt water, and as he pumps greater quantities of water from wells in coastal areas, he increases the lik-

elihood of salt-water contamination. These and many other urban effects upon hydrology deserve increasing study if we are to provide the best use of the water and land resources available to the Nation's urban centers.

SAWYER, C.N. 1947: "Fertilisation of lakes by agricultural and urban drainage". J. New England Water Works Association, Vol.61; p109-127.

Key words: agricultural pollution; urban drainage; lakes; water pollution sources; eutrophication; nutrients.

Agricultural drainage near Madison, Wis., contributes annually about 4,500 pounds of nitrogen and 255 pounds of phosphorus per square mile of the watershed. Treated sewage supplies annually approximately 6.0 pounds of nitrogen and 1.2 pounds of phosphorus per capita, thus equating one square mile of agricultural drainage to 750 persons for nitrogen and 212 persons for phosphorus. In 1946, lakes on the outskirts of Madison received approximately 1,300 tons of nitrogen and 215 tons of phosphorus. The lakes retained from 30 to 60 percent of nitrogen received. The phosphorus concentration in Lakes Waubesa and Kegonsa attained above 0.25 parts per million as compared with 0.01-0.02 ppm concentration found in less polluted lakes of southern Wisconsin. *Microcystis aeruginosa* was a particularly obnoxious by-product of eutrophication.

SAWYER, R.M. 1963: "Effect of urbanisation on storm discharge and ground water recharge in Nassau County, New York". U.S. Geol. Survey prof. paper No.475-C; p185-7.

Key words: storm runoff; urbanisation; rainfall-runoff relationships; landuse change.

A comparison of concurrent stream flow records for Mill Neck Creek (11.5 sq miles) and East Meadow Brook (31 sq miles) in Long Island, New York, show that a definite change in runoff relations occurred with the urbanisation of East Meadow Brook. A comparison of precipitation and average annual total, direct and base runoff for both streams for the periods 1938-51, unurbanised; and 1952-1962, urbanised; gives the following: at Mill Neck Creek, the increases in percentage of total runoff, direct runoff, and base runoff are similar, ranging from 6.1 percent to 7.3 percent, and are closely comparable with the 9.4 percent increase in precipitation. At East Meadow Brook, on the other hand, total runoff increased 1.15 in., or 15.8 percent; direct runoff increased 0.80 in., or 123.1 percent; base runoff increased 0.35 in., or only 5.3 percent. The changes in East Meadow Brook are probably due to the change in land surface from pervious to impervious material as well as to the increase in precipitation. Comparison of annual peak discharge shows a marked increase with urbanisation.

SCHAAKE, J.C. 1965: "Synthesis of inlet hydrograph". John Hopkins University, Dept. Sanitary Engineering and Water Resources, Tech. Report No.3; 105pp.

Key words: hydrographs; surface runoff; analytical techniques.

Method is presented for synthesising hydrograph of runoff from paved portions of drainage area. Method involves application of equations of gradually varied unsteady flow in open channels to describe mechanics of surface runoff. Method of synthesising inlet hydrograph will provide means for developing records of runoff for inlet areas of sufficient length to have statistical significance. Advantage of method is that drainage area behaviour can be simulated on a computer so response of area to arbitrary or spatially varied rainfall can be accurately predicted.

SCHAAKE, J.C. 1968: "Response characteristics of urban water resource data systems". ASCE Urban Water Resources Research Program, Report No.TM-3; 64pp.

Key words: mathematical models; instrumentation.

The types of system components that might be included in a pilot system to initiate an open watershed program for urban areas have been the subject of this special study. These are classified into three groups of instrumentation: for rainfall, for runoff, and for water quality. Separate investigation of each of these has been made and is reported. In the final section on water quality, an optimisation scheme is suggested for sampling water quality.

SCHAAKE, J.C. 1971: "Deterministic urban runoff model". In, Treatise on urban water systems, Colorado State University, Fort Collins; p357-383.

Key words: mathematical models; hydrographs; urban runoff.

This is a general description of a deterministic model for computing storm runoff from rainfall in urban areas. It is based on theoretical motion of kinematic waves in uniform channels with both lateral and upstream inflows. Kinematic wave theory is applied to urban catchments by decomposing the catchment into segments. The resulting model is a conceptual or hypothetical model of the real catchment. It is a deterministic model because all of the input data are given functions of time or are related uniquely to the physical properties of the catchment. A general system for creating deterministic models of any urban catchment has been created as a Fortran program. This program requires data input which describes the physical features of the catchment and which describes the occurrence of a storm as it is distributed both spatially and temporally over the catchment. The program prints out the outflow hydrographs at selected points throughout the catchment. Runoff

data is not required to use this model. All parameters can be estimated on the basis of physical features alone. However, if runoff data are available, they can be used to adjust parameter values to improve the "fit" of the model to the catchment.

SCHAAKE, J.C. 1971: "Modeling urban runoff as a deterministic process". In, Treatise on urban water systems (eds. M.L. Albertson, et al.), Fort Collins, Colorado State Univ.; p343-349.

Key words: mathematical models; storm runoff; urbanisation; rainfall-runoff relationships.

A model of a hydrologic system is an abstraction, a simplified representation of the system and not a complete or exact duplication of it. Natural hydrologic systems are complex, so any model must neglect at least some aspects of the natural systems. One of the most promising approaches to nonlinear modeling of hydrologic systems is to use the differential equations that describe hydrologic phenomena. Much progress has been made in applying the equations for unsteady flow in open channels to describe surface runoff and streamflow. Flow in streams and sewers may be described by the unsteady flow equations. If the kernel of the linear system is known, calculation of the system response is simply evaluating the correlation integral. The calculations are inherently stable, and no numerical difficulties are encountered. The response of the system to many different inputs may be obtained using little computer time, even for distributed parameter models. In comparison, nonlinear models based on the kinematic wave equations may require computer time one or more orders of magnitude longer than a linear model.

SCHAAKE, J.C. 1971: "A general rationale for modeling urban runoff". In, Treatise on urban water systems (eds. M.L. Albertson, et al.), Fort Collins, Colorado State Univ.; p350-356.

Key words: mathematical models; storm runoff; urbanisation; rainfall-runoff relationships.

A general rationale for modeling urban runoff is proposed. Fundamentally there are seven basic steps that should be followed in any modeling procedure. These are: (1) carefully identify and evaluate the objectives; (2) select criteria for meeting these objectives; (3) seek the best of all possible models that satisfy these criteria; (4) estimate model parameters; (5) establish the adequacy of the model; (6) design appropriate input and output systems for the model; and, (7) use the model according to the objectives.

SCHAAKE, J.C. 1972: "Water and the city". In, Urbanisation and environment, (eds. T.R. Detwyler; M.G. Marcus), Duxbury Press, Belmont, California; p97-133.

Key words: urbanisation; urban hydrology; urban runoff.

Urban development results in an increased flood risk because of four things; (1) the increasing proportion of impervious surfaces increases runoff rates; (2) the straightening of channels speeds the rate at which water enters the main drainage channels; (3) distances to streams tend to be shortened; (4) filling modifies natural storage patterns. Sediment discharge is greatly increased, especially during construction periods. Urban heat loss will tend to modify the temperature gradients of streams and lakes. Sewage disposal presents a problem and must be geared to water supplies and to the transport potential of the stream. An increasing demand for water by urban areas is modifying the subsurface conditions and in places introducing salt water intrusion.

SCHAAKE, J.C. et al. 1967: "Experimental examination of the Rational Method". J. Hydraul. Divn., Proc. ASCE, Vol.93(HY6); p353-370.

Key words: rainfall-runoff relationships; storm runoff; data collection; peak discharge; urban drainage.

Rainfall and runoff data collected in Baltimore, Md., from 20 gauged urban drainage areas ranging in size up to 250 acres have been used in study of Rational Method. Results suggest that frequency of occurrence of computed design peak runoff is same as frequency of occurrence of rainfall intensity selected by designer with appropriate C. In accordance with their usual design procedures, five storm drainage designers used Rational Method to estimate 5 year design peak runoff rates for six gauged drainage areas. These values are compared with runoff values from runoff frequency curves for these gauged areas.

SCHEIDT, M.E. 1967: "Environmental effects of highways". J. Sanitary Engineering Divn., Proc. ASCE, Vol.93(SA5); p17-25.

Key words: erosion; water pollution sources; environmental effects; oil wastes; miscellaneous chemicals; herbicides; peak discharge; solid wastes.

The pollutional effects of highways are varied and appear at several stages in the life of the highway. First, erosion during construction of the highway produces troublesome sediment. Pollution may also occur from oils, chemicals, and other substances used during the construction process. Secondly, pollution can result from operation and maintenance of the highway. Involved are such things as flooding, pollution of adjacent land and water areas by chemicals used to melt ice, and the effects of herbicides and other spray materials used to control roadside vegetation. Finally, pollution can result from use of the highway itself, including for example, accidental

spills of chemicals, oils and other materials in transport, roadside litter and debris thrown or blown from vehicles, pollution of the air from engine exhausts, and oils, greases and other substances deposited on the road surface in the normal use of the highway by motor vehicles.

SCHMER, F.A. 1969: "Investigation of a linear model to describe hydrologic phenomena of drainage basins". Texas A. and M. University, College Station, Water Resources Institute, Technical Report No. TR-19; 116pp.

Key words: mathematical models; rainfall-runoff relationships.

The investigation is concerned with the applicability of the linear convolution relationship for approximating the rainfall-runoff phenomenon for small drainage basins. A solution for the transfer function of the convolution relationship is obtained by employing discrete mathematics similar to the Wiener-Hopf equation. The solution is obtained, based on the restraints of the physical system by linear programming. In this investigation, the hydrologic system is analysed as a truly linear system. Recorded rainfall intensity is the input of the system, and recorded runoff output. A major concern of the study involves the effects of antecedent moisture conditions on the transfer function. Two basins are used to test the model - an urban basin located within the city limits of Bryan, Texas and a rural basin approximately three miles east of Bryan, Texas. Results are presented which substantiate the use of the proposed linear model as an approximation to the hydrologic system. Generalised transfer functions are developed for each basin and tested with independent events. Antecedent moisture conditions are shown to have a definite predictable effect on the transfer function, and rainfall events are classified with an antecedent moisture condition criteria in order to select the proper transfer function for the event.

SCHMER, F.A. et al. 1969: "Application of the linear convolution model in describing the rainfall-runoff relationship of an urban drainage basin". Paper presented at the AGU 1969 National Fall Meeting.

Key words: rainfall-runoff relationships; model studies.

This investigation is concerned with the applicability of the linear convolution relationship for approximating the rainfall-runoff phenomenon for an urban drainage basin. A solution for the transfer function of the convolution relationship is obtained by employing discrete mathematics similar to the Wiener-Hopf equation. The solution is obtained, based on the restraints of the physical system by linear programming. In this investigation, the hydrological system is analysed as a truly linear system. Recorded rainfall intensity is the input of the system,

and recorded runoff the output. A major concern of the study involves the effects of antecedent moisture conditions on the transfer function. Results are presented which substantiate the use of the proposed linear model as an approximation to the hydrologic system. Generalised transfer functions are developed for each basin and tested with independent events. Antecedent moisture conditions are shown to have a definite predictable effect on the transfer function, and rainfall events are classified with an antecedent moisture condition criteria in order to select the proper transfer function for the event. Comparisons are made with more conventional hydrologic analysis.

SCHMIDT, M.O. 1950: "Flood runoff from urban areas with special reference to the surface hydrology of Boneyard Creek watershed, Champaign - Urbana, Illinois". PhD Thesis, University of Illinois, Urbana, Illinois.

Key words: urban runoff; flood discharge; hydrographs; analytical techniques.

This thesis was intended as a first stage report of a long term study of the title basin. Some 16 flood hydrographs from the short (22 month) record were analysed. The 4.45 sq mile watershed is defined in terms of percent imperviousness, lag time and percent runoff.

SCHNEIDER, W.J. 1968: "Water data for metropolitan areas". U.S. Geol. Survey water supply paper No. 1871; 397pp.

Key words: data collection; hydrologic data; urbanisation.

Expansion of metropolitan areas poses persistent problems in management of the hydrologic environment. Adequate hydrologic data are prerequisite to proper planning and engineering design of urban environments. Some such data are available and are tabulated for each Standard Metropolitan Statistical Area in the United States. Information for each area consists of (1) data on size and population, (2) a short statement of the hydrology of the area, (3) a summary of current data-collection activities in the area, (4) a listing of current U.S. Geological Survey investigational projects in the area, and (5) a short listing of reports to the hydrology of the area.

SCHNEIDER, W.J. 1969: "The U.S. Geological Survey urban water program". In, Effects of watershed changes on streamflows, (eds. W.L. Moore; W. Morgan), University of Texas Press, Austin.

Key words: urbanisation; data collection; watershed management; storm runoff; urban hydrology.

The Water Resources Division of the U.S. Geological Survey is currently

expanding its role in urban hydrology as rapidly as possible to meet new demands. Almost since the first stream gauging stations were established, more than 80 years ago, water resources data have been collected in urban areas. Today, some data are available for every one of the 222 standard metropolitan areas in the United States. In addition to the collection of basic data, the Water Resources Division has conducted studies either within or including urban areas. These have resulted in numerous reports published in the Survey publication series and in outside technical journals. In recent years, the emphasis of these studies has been on the assessment of changes in the water resources caused by urbanisation. Storm drainage today is still largely designed on the basis of the empirical rational formula using rainfall intensity modified by a coefficient of runoff. The inefficiency of this method is well recognised. Greater knowledge of the part of the hydrologic cycle involving rainfall-runoff relations in urban environments is needed. A study, currently under way, will consider the data needs for urban runoff studies, appraise available and needed instrumentation for collection of these data, and advise on types of networks for collection of these data. The study is for design of pilot areas.

SCHNEIDER, W.J. 1970: "Hydrologic implications of solid waste disposal". U.S. Geol. Survey circular No.601-F; pl.

Key words: solid wastes; sewage disposal; environmental effects; ground water resources; leachate.

The disposal of more than 1,400 million pounds of solid wastes in the United States each day is a major problem. This disposal in turn often leads to serious health, aesthetic, and environmental problems. Among these is the pollution of vital ground water resources. Of the six principal methods of solid waste disposal in general use today, four methods - open dumps, sanitary landfill, incineration, and onsite disposal - carry an inherent potential for pollution of water resources. Seepage of rainwater through the wastes leaches undesirable constituents which reach the ground water in the area. This leachate is generally both biologically and chemically contaminated. The extent of the pollution from this leachate is largely dependent upon the geologic environment in which the solid wastes are deposited. Pollution potential is highest in permeable areas with a shallow water table where the wastes are in direct contact with the ground water. In a relatively impermeable area, the pollution is generally confined locally to the vicinity of the waste disposal site. Site selection for disposal of solid wastes must be based on adequate water resources information if pollutional potential is to be minimised. This will require regional as well as localised data on the water resources of the area. Only through such an approach can adequate protection be afforded to the environment in general and the water resources

in particular.

SCHNEIDER, W.J. 1971: "Hydrologic data for storm drainage design". ASCE preprint No.1328; 12pp.

Key words: storm runoff; hydrologic data; model studies; rainfall-runoff relationships.

Public comfort and safety requires that storm water be removed rapidly from urban areas to prevent serious flooding. Despite the tremendous investment in storm drainage facilities in the United States, the criteria for design are among the oldest and most poorly defined of all criteria used by the engineering profession. The current practices emphasise that not enough knowledge of storm runoff is available for optimum design. Most storm drainage design is based upon the "rational formula". There are wide variations in the interpretation and application of this formula in practice. Perhaps the strongest criticism that can be made of it is that it provides an estimate of only the flood peak. As emphasis shifts from simple removal of storm runoff to its management, estimates of the entire runoff hydrograph will be needed. Recently, consideration has been given to rainfall-runoff relationships. New methods are evolving slowly because sound hydrologic data necessary for their development are lacking. More and better data on rainfall, runoff, and water quality must be collected for proper management of urban storm runoff.

SCHNEIDER, W.J. et al. 1973: "Role of water in urban planning and management". U.S. Geol. survey circular No.610-H; 10pp.

Key words: urbanisation; urban hydrology; hydrologic data; data collection; watershed management; rainfall-runoff relationships.

The concentration of people in urban areas has modified the natural landscape, bringing about water problems. Although water resources in urban areas are altered by urbanisation, the deleterious effects can be minimised or corrected by comprehensive planning and management. Water resource information for urban planning is badly needed, but urban planners are not generally able to identify the data that are needed. To help satisfy this need, a water resource evaluation matrix was developed. The graphic matrix provides a means for organising the relative importance of water-related problems, and for identifying the data needed to evaluate these problems for the purpose of urban planning. The matrix lists nine subject categories in which water related urban problems may occur. The matrix also lists 51 possible data inputs for evaluation of the problem areas. The inputs include the standard types of hydrologic data as well as information based on interpretation and analysis of these data. The list also includes the factors of climate, land, and culture. The matrix aids in the development of

resource evaluation in two ways: first, by promoting interdisciplinary discussion, it leads to a mutual understanding of the water related problems; secondly, it serves as a check list for determining the data needs for evaluation of each problem.

SCHNEIDER, W.J. and GODDARD, J.E. 1974: "Extent and development of urban flood plains". U.S. Geol. Survey circular No.601-J; 14pp.

Key words: urbanisation; analytical techniques; storm runoff.

A study of 26 urbanised areas in the United States indicates that the amount of urban area in flood plains ranges from 2.4 percent for Spokane, Wash., to 81 percent for Monroe, La. The median value is 16.2 percent. The amount of development on these flood plains also varies widely, from 11.3 percent for Lorain-Elyria, Ohio, to 97 percent for Great Falls, Mont. The median value is 57 percent, and the weighted average is 52.8 percent. Attempts to correlate either the extent of urban area in flood plain or amount of development with three readily available indices - depth of flooding, precipitation, and physiography - showed no strong relationships. Some correlation was found between the extent of urban area in flood plain and index of depth of flooding.

SCHULTZ, N.U. and WILMARTH, A. 1978: "Water quality simulation and public law 92-500. Case study: Southwestern Illinois". Water Resources Bulletin, Vol.14(2); p275-287.

Key words: mathematical models; point sources (pollution); nonpoint pollution sources.

Section 208 of the Federal Water Pollution Control Act Amendments of 1972 has provided the Southwestern Illinois Metropolitan and Regional Planning Commission (SIMAPC) with a unique opportunity for comprehensive planning of the region's water quality. SIMAPC initiated the 208 study by researching available technology for the analysis of point and nonpoint sources of pollution and establishing criteria by which to judge the various techniques. This led to SIMAPC's choice of continuous simulation of stream and reservoir water quality as the most appropriate analytical tool for their needs. A continuous simulation model was calibrated and verified on three basins in the SIMAPC region. It was then used to produce load source analysis, pollution event frequency analysis, and pollution event duration analysis for ten pollutants under existing stream conditions and then under alternative future conditions. These results enabled the weighting of pollutant sources, analysis of the effectiveness of control measures, and quantitative analysis of the marginal benefit of each alternative.

SCHULZ, E.F. et al. 1974: "Flood measurements in an urban environment: a data user's viewpoint". In, Proceedings of the Paris symposium on flash floods, IAHS Publication No.112; p87-92.

Key words: urban runoff; flood control; hydrologic data; urban hydrology; urban drainage; model studies.

The need for flood measurements in an urban environment was shown, and the role of a local flood control district in helping local government entities was outlined. The value of a coordinated plan in the preparation, execution, and operation of flood control measures was discussed. The need for high-quality flood data was emphasised. The problems of measuring floods on small, ephemeral streams in an urban environment were discussed. The possible uses of the data were outlined. It was concluded that flood measurements are essential in an urban environment for: (1) planning purposes, (2) developing model parameters, (3) project operations, and (4) public relations and assessment of project performance.

SCHULZ, E.F. and LOPEZ, O.G. 1974: "Determination of urban watershed response time". Colorado State University, Hydrology Papers, No.71; 44pp.

Key words: rainfall-runoff relationships; mathematical models; hydrographs; urbanisation.

Various methods for quantifying the effects of urbanisation are discussed and a stepwise multiple regression technique was used to select the best parameter of urbanisation. The rainfall and flood events from nine urban watersheds in the Denver Metropolitan region were analysed and unit hydrographs were derived from these. The hydrograph parameters were correlated with storm and physical watershed parameters. It was found that changes in the unit hydrograph in the urban region were related to the decrease in the watershed response time (defined by the lag time). Previous work in this subject is also reviewed.

SCHWENGEL, F. 1972: "Pollution from developing rural and urban areas". Congressional Record, Vol.118; pE6843.

Key words: urbanisation; sediment yield; sediment control; sediment transport; storm runoff; urban drainage; erosion control.

No longer is there a clearcut distinction between urban and rural interests in the use and management of natural resources. Similarly, both urban and rural areas contribute to the pollution problem. In developing land from rural to urban uses the need for controlling runoff, erosion and sediment has not been recognised. Developing rural-urban areas involve smaller drainage areas, constitute more highly dynamic and complicated environmental interactions, involve expensive exposure of soils and subsoils and result in in-

creased runoff and excessive sediment or water discharge. Urban areas in the development stage produce erosion and sediment disproportionate to comparable areas in the agricultural sector. Urban development has diminished the absorptive capacity of natural flood water storage areas and overburdened urban drainage systems. Legislation has been introduced authorising the Secretary of Agriculture to cooperate with developing areas and furnish financial and technical assistance to states, counties and municipalities in formulating development land use plans and controlling erosion and sediment in developing rural and urban areas.

SCOTT, K.M. 1973: "Scour and fill in Tujunga Wash - a fanhead valley in urban southern California - 1969". U.S. Geol. Survey prof. paper No.732-B; 29pp.

Key words: urban hydrology; erosion; urbanisation.

In Tujunga Wash in southern California, extensive scour and fill occurred during the record breaking 1969 floods in this 3 mile long, partly urbanised fanhead valley. Maximums of 20 feet of net scour and 35 feet of net fill were measured. The causes of the scour and fill were: (1) the unexpected yet possible natural diversion of floodflow to a major distributary channel of the wash in which urbanisation had progressed, (2) local reduction in base level which occurred when flood flow in both of the main distributary channels entered a large gravel pit, and (3) lateral scour of an aggradational surface within the wash because of a natural adjustment of a distributary channel to flood discharge. Additional scour and fill were due to locally raised base level and to the natural lateral shift characteristic of channels in the broad, ephemeral washes of arid and semi-arid regions. Damage at most, if not all, localities could be directly ascribed to man's disregard of natural geomorphic processes on alluvial fans and in fanhead valleys. Urban development on the unstabilised cutbank of a natural flood channel on an alluvial fan or fanhead valley is generally a poor risk.

SCOTT, W.S. 1976: "The effect of road deicing salts on sodium concentration in an urban watercourse". Environmental Pollution, Vol.10(2); p141-153.

Key words: chlorides; snowmelt; waste dilution.

Results are given of a study on the amount of road deicing salts entering Black Creek, a stream in metropolitan Toronto, and on the pattern of movement of the salt, both spatially and temporally. During one thaw period, sodium concentrations in the stream increased 50-fold and remained greater than background levels for several days, before being diluted by snow melt. The data indicate that salt runoff occurs in waves, depending on temperature, and that similar patterns of movement may

result from similar thawing conditions.

SCOTTON, J.W. et al. 1974: "Directory of EPA, State and local environmental quality monitoring and assessment activities". EPA Office of Research and Development, Washington, D.C.; 384pp. (NTIS PB-241 757).

Key words: air pollution effects; water pollution; solid wastes; pesticides.

The directory describes State and local environmental quality monitoring programs of the United States. It also includes the Environmental Protection Agency's (EPA) national programs and systems which collect, analyse and evaluate these data. It will serve a useful need as a reference and guide for more detailed information.

SEABURN, G.E. 1969: "Effects of urban development on direct runoff to East Meadow Brook, Nassau County, Long Island, New York". U.S. Geol. Survey prof. paper No.627-B; 14pp.

Key words: storm runoff; rainfall-runoff relationships; landuse change; flood forecasting.

The study described in this report is concerned with the effects of intensive urban development on direct runoff to East Meadow Brook, a southward flowing stream in central Nassau County, N.Y., during the period 1937-1966. The specific objectives of the study were: (a) to relate indices of urban development to increases in the volume of annual direct runoff to the stream; (b) to compare hydrograph features at different periods during the transition of the drainage basin from rural to urban conditions; and (c) to compare the rainfall-runoff relations for periods before and after urban development. On the basis of the present zoning regulations and an assumption that an additional 320 acres in the Hempstead sub-area will be serviced by storm sewers that discharge into East Meadow Brook, direct runoff from the sub-area is expected to increase in the future to an estimated 4,000-4,500 acre-feet per year.

SEABURN, G.E. and ARONSON, D.A. 1974: "Influence of recharge basins on the hydrology of Nassau and Suffolk Counties, Long Island, New York". U.S. Geol. Survey water supply paper No.2031; 66pp.

Key words: storm runoff; urban hydrology; ground water resources; urban runoff; aquifers.

The hydrology of three recharge basins on Long Island, N.Y. (Westbury, Syosset, and Deer Park basins) was studied. The average percentages of precipitation flowing into each basin were roughly equivalent to the average percentages of impervious areas in the total drainage areas of the basins. Inflow hydrographs for each basin typi-

fy the usual urban runoff hydrograph - steeply rising and falling limbs, sharp peaks, and short time bases. Infiltration rates averaged 0.9 fph (feet per hour) at the Westbury recharge basin, 0.8 fph at the Syosset basin, and 0.2 fph at the Deer Park recharge basin. Low infiltration rates at Deer Park resulted mainly from silt, clay, and organic debris washed in from construction sites, and a lack of a well-developed plant-root system on the floor of the basin. The apparent rate of movement of storm water through the unsaturated zone below each basin averaged 5.5 fph at Westbury, 3.7 fph at Syosset, and 3.1 fph at Deer Park. On the average, a 1-inch rainfall resulted in a peak rise of the water table directly below each basin of 0.5 foot; a 2-inch rainfall resulted in a peak rise of about 2 feet. The mound commonly dissipated within 1 to 4 days at Westbury, 7 days to more than 15 days at Syosset, and 1 to 3 days at Deer Park. Average annual ground water recharge was estimated to be 6.4 acre-feet at the Westbury recharge basin, 10.3 acre-feet at the Syosset recharge basin, and 29.6 acre-feet at the Deer Park recharge basin. Ground water recharge in the areas where recharge basins are used is probably equivalent to or may slightly exceed recharge under natural conditions (about 148 mgd).

SELAKE, M. et al. 1976: "Water pollution modeling in the Detroit metropolitan area". EPA Conference on Environmental Modeling and Simulation; p50.

Key words: storm runoff; mathematical models; model studies; computer models; waste water treatment.

The Storm Water Management Model (SWMM) was used to simulate waste water flow. After several minor modifications to SWMM, the simulated results from the Runoff and Transport blocks compared favourably with observations by the computerised monitoring system. The output from the SWMM Transport block was routed to a simulation of the Detroit Waste Water Plant called STPSIM. This model enables the user to evaluate the effect of storm flow on plant performance and to compare various strategies for treating the stored waste water. The simulated results from STPSIM appear to be representative of the actual treatment plant performance, but model calibration has been difficult due to a shortage of real-time sample analysis from the plant.

SELTUN, N.R. 1976: "Urban hydrologic modeling and catchment research in Norway". ASCE, New York, Urban Water Resources Research Council, Technical Memo., TM-IHP-9; 27pp.

Key words: urban runoff; computer models; mathematical models.

Prepared in support of International Hydrological Programme Project 7. Ninth of a special ASCE Urban Water Resources Research Program technical memo. series of national state-of-the-art reports. Modeling and

catchment research for Norwegian underground conduit drainage systems is emphasised.

SEVUK, A.S. et al. 1973: "Illinois storm sewer system simulation model: user's manual". University of Illinois, Water Resources Centre, Research Report No.73; 176pp.

Key words: computer models; mathematical models; flood forecasting.

A mathematical model is presented for sewer design and flow prediction utilising the Saint Venant equations to route unsteady flows through tree-type sewer networks. An overlapping segment scheme is used in the numerical solutions to account for the backwater effects and mutual influences of the sewers and junctions. The program is written in PL/1 and assembler language and can be executed on most large IBM 360 and 370 systems. User-oriented information is provided. An example on sewer design is also given.

SHAHEEN, D.G. 1975: "Contributions of urban roadway usage to water pollution". Biospherics Inc., Rockville, Md.; 359pp. (EPA/6002-75-004; PB-245 854/SWP).

Key words: solid wastes; point sources (pollution); air pollution effects; storm runoff.

Street surface contaminants are deposited on roadways from many sources within an urban area. Industrial operations, land use activities, fallout of air pollutants, roadway usage and other activities contribute to the loading of particulates on urban roadways. These materials are then carried into receiving waters by storm runoff where they constitute a substantial portion of the overall water pollution problems of cities. Metropolitan Washington, D.C., with its low background of industrial emissions, was the area chosen for study of contributions of motor vehicle usage to urban roadway loading factors. Specified roadway study sites within this area were selected so as to provide minimal interference from non-traffic-related land use activities and thus isolate, as much as possible, the traffic-related depositions.

SHANKS, R.W. and RAO, A.R. 1977: "The effects of urbanisation on low flows and total runoff". Purdue University, Lafayette, Water Resources Research Centre, Technical Report No.94; 101pp.

Key words: rainfall-runoff relationships; urban runoff; urban hydrology; storm runoff; urban drainage; urbanisation; low flow; streamflow.

The objective was to investigate the effects of urbanisation on the low flow and total runoff characteristics of streams. The data used in the analysis included the 1- and 7-day flows and total annual runoff sequences from six

urban streams located throughout the United States. The observed flow sequences were analysed by using mass curve analysis in order to determine the time at which changes in the flow sequence patterns took place. The year in which these changes became evident was then used to separate the flows into two groups. The period before the year of change represented the flows unaffected by the urbanisation process. The period after the year of change represented the affected flows. In an attempt to explain these changes in the observed flow sequences, rainfall data were examined by similar mass curve methods. The rainfall characteristics remained approximately the same through the period of record. The rainfall-runoff relationships for each watershed were analysed in order to determine the extent of the changes in the total annual runoff. The analysis was accomplished by linearising the rainfall-runoff relationships by the transformation technique developed by Box and Cox. The slopes of the relationships for the unaffected and affected periods were compared to determine the magnitude of the changes which had taken place. Models of only the observed flows were also developed and analysed.

SHAW, T.L. 1973: "Urban rainfall, runoff and surface drainage". Surveyor, Vol.141(4223); p33-34.

Key words: urban hydrology; rainfall-runoff relationships; mathematical models; urban drainage.

A report of a symposium held at the University of Bristol in April 1973, concentrating on the hydrologic and hydraulic problems of surface channels and sewage systems in large (25 sq km and upwards) urban catchments. A number of related, interdisciplinary topics were covered, ranging from rainfall analysis, through hydrologic models, to design criteria and problems.

SHEAFFER, J.R. and ZEIZEL, A.J. 1966: "The water resource in Northeastern Illinois: planning its use". N.E. Illinois Planning Commission Technical Report No.4; 182pp.

Key words: urbanisation; watershed management.

The study stresses the advantages of closely coordinating water resource management with alternative patterns of urban development. Surface water is pointed to as one of the chief natural attributes of the region that should be featured in land use planning on both metropolitan and local scales. The study assesses the potential of the various water sources available, analyses the manner in which they are used, presents numerous alternative water management measures, and balances supply against future demands under various types of management. Legislation related to water management is analysed and recommendations are advanced for legal areas where changes are deemed desirable. Problems focused

upon in this report include pollution of surface and ground water, falling water levels in wells, damaging shortage of water-oriented recreational facilities, and the general overall laxity in applying known management techniques. The general categories of management measures include: (1) storage of surface water and interbasin transfer; (2) management of the withdrawal and replenishment of ground water; (3) possibilities for conjunctive use of surface and ground water; (4) water quality management; and, (5) management of water use.

SHERWOOD, C.B. and MATTRAW, H.C. 1975: "Quantity and quality of runoff from a residential area near Pompano Beach, Florida". Proc. Storm Water Management Workshop, Orlando, Florida, Florida Technological University; p147-157.

Key words: storm runoff; urban runoff; water pollution.

SHERWOOD, C.B. and MATTRAW, H.C. 1976: "Quantity and quality of urban storm water in southeast Florida". In, Proceedings International Seminar on Developments in Hydrometry, Volume 2, University of Padua, Italy. WMO Report No.427; p94-108.

Key words: urban hydrology; storm runoff; data collection; chemical analysis; bacteria.

Rainfall, runoff and water quality were monitored in a residential area in southeast Florida starting in March 1974. Rainfall was measured at three points in the area and the resulting runoff was measured in a storm sewer. Water samples were automatically collected in the storm sewer at intervals of 144 seconds throughout the period of runoff. By September 1974, 19 of 104 rainfalls produced runoff great enough to trigger the water-sampling mechanism. The chemical quality of the storm sewer runoff was highly variable. Precise relations between loads, concentrations, and runoff have not yet been established. In general, however, the highest concentrations of chemical constituents were found in runoff that occurs after long dry periods, and lowest concentrations in runoff that occurs during a period of frequent rainfall. Peak concentrations for individual storms - in milligrams per litre - ranged from 5.3 to 0.7 for nitrogen, 1.35 to 0.15 for phosphorus, and 290 to 15 for chemical oxygen demand. A 1.1-inch rainfall of 30 minutes duration on June 16 had a peak flow of 19 cubic feet per second and loads of 1.4 pounds of nitrogen, 0.5 pounds of phosphorus, and 15 pounds of chemical oxygen demand. Total coliform bacteria counts in some storms were as high as 1.8 million colonies per 100 millilitres of water.

SHIGORIN, G.G. 1956: "Problems in the pollution of urban surface runoff". Vodospabzhenie i Sanitarnaia Tekhnika,

No.2; p19.

Key words: urban runoff; storm runoff; water pollution sources; suspended solids; biochemical oxygen demand.

A translation of a report on the results of a sampling study of storm water runoff in Moscow, U.S.S.R., in 1936, indicated BOD's of 186 to 285 mg/l and suspended solids of 1,000 to 3,500 mg/l. Runoff samples from Lenin-grad's cobblestone paved streets in 1948-50 contained BOD's of 36 mg/l and suspended solids of 14,541 mg/l.

SHIH, G.B. et al. 1975: "Regional analysis of runoff characteristics for small urban watersheds". Utah Water Research Lab. Report No. PRWG-87-1, Utah State University, Logan; 77pp. (NTIS PB-243 517).

Key words: rainfall-runoff relationships; computer models; urban runoff; flood forecasting.

Increasing urbanisation will affect the rainfall-runoff pattern, and the danger of flooding will increase. The Utah Water Research Laboratory has already developed deterministic and statistical urban watershed hydrological models, and in this study these are used in an attempt to develop a generalised model for prediction of regional watershed behaviour from measurable characteristics. Rainfall data is the only climatological factor used, and the prediction of runoff is confined to relative changes with urbanisation, no attempt being made to deduce absolute values.

SHIH, G.B. et al. 1976: "Application of a hydrologic model to the planning and design of storm drainage systems for urban areas". Utah Water Research Lab., Logan, Publication PRWG86-1; 79pp. (NTIS PB-258 639).

Key words: hydrographs; model studies; storm runoff; urban drainage; urban runoff.

A generally applicable hybrid computer program is developed to simulate runoff from urban watersheds, and is applied to represent the outflow hydrographs of three urban watersheds located within Salt Lake County, Utah. The gauged outflow of the watersheds provided a means for comparing the observed and simulated final outflow hydrographs. Each of the three watersheds was subdivided into spatial units or subzones, and the outflow hydrographs for each subzone were obtained by abstracting interception, infiltration and depression storage from the rainfall hyetograph of each subzone. The resulting hydrograph outflow of each subzone was then routed to the Jordan River, the final outflow point of the three watersheds. The final hydrographs of the three watersheds were combined and compared with the gauged flow. The unique features of this model are its ability to (1) accept a wide range of input hyetographs; (2) accommodate variable loss rates; (3) combine subzone hydro-

graphs; and (4) combine watershed hydrographs into a single runoff function. In addition to numerical output, graphs can be plotted for visual inspection. This characteristic enables designers and planners to use the model to examine quickly both the physical and economic impacts of various possible input conditions and management alternatives.

SHUBINSKI, R.P. 1974: "Simplified methods of computing the quantity of urban runoff". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p200-213.

Key words: analytical techniques; urban runoff; peak discharge; storm runoff; hydrographs; rainfall-runoff relationships.

Regional flood frequency relations were developed for 40 non-urban watersheds in the San Francisco Bay area by means of multiple regression. The regression equations were developed for basins larger than 5 sq miles under essentially non-urban conditions, and increasing urbanisation will tend to change the coefficients and exponents. The rational method is based on the equation setting the maximum runoff rate equal to the product of a runoff coefficient representing the effects of rainfall losses, the average intensity of rainfall for the travel time, and the drainage area. The method's two principal assumptions are that the maximum runoff rate occurs when the entire area is contributing flow and the maximum rate of rainfall occurs during the time of concentration and the design rainfall depth during the time of concentration can be converted to an average rainfall intensity. The unit hydrograph (UH) is based on the assumption that the ordinates of a direct runoff hydrograph are proportional to the ordinate of the UH times the rainfall excess in a given time interval. Using the UH involves derivation of the UH for a specified duration and application to a given rainfall event to determine the corresponding hydrographs of direct runoff. Computation of rainfall excess is based on known rainfall rates and estimates of losses. The UH can be used in comprehensive watershed simulation to evaluate the hydrologic effects of urbanisation and costs of required drainage facilities.

SHUBINSKI, R.P. 1974: "Introduction to urban storm water runoff models". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p177-199.

Key words: urban runoff; storm runoff; mathematical models; peak discharge; model studies.

Storm water runoff models were applied to a simplified urban drainage system. This system was composed of subsystems dealing with surface runoff, transport and quality of flow, and receiving waters. The surface runoff subsystem was

a drainage area tributary to a sewer inlet - a system of surface elements, gutters, and drainage ditches. The transport system is the physical works which carry storm waters and their pollutant load from inlets through underground conduits to a point of disposal. Receiving systems could be streams, lakes, estuaries, or coasts. The hydrologic effects of urbanisation and the characteristics of the urban watershed were considered. Factors controlling urban runoff include rainfall, infiltration, depression storage, surface detention and gutter detention, and storage in house drains, catch basins and major sewage elements. Land use influences imperviousness and surface cover which regulate surface depression, detention, and infiltration. A storm drainage model should analyse storm drainage from urban runoff by dividing the total basin into smaller homogeneous units to calculate individual runoff contributions. Collection of individual sub-basin outflows and their routing through main storm sewers allow determination of total watershed outflow at the basin outlet.

SHUBINSKI, R.P. 1974: "The WRE STORM model". In, Proceedings of a short course on applications of storm water management models, University of Massachusetts, Amherst; p214-242.

Key words: waste water treatment; analytical techniques; biochemical oxygen demand; urban runoff; model studies; water pollution sources; storm runoff; erosion; watershed management.

The WRE STORM model was developed to help determine future magnitudes of urban runoff pollution loads from a given watershed, to help determine the pollution load for average and extreme events, and to determine the occurrence of a given extreme event. The STORM (storage, treatment, overflow, and runoff model) considers interactions of precipitation, air temperature for snowpack accumulation and snowmelt, runoff, pollutant accumulation on land surface, land surface erosion, treatment rates, storage, and overflows from the storage/treatment system. Land uses considered in this model include: single family residential, commercial, industrial, parks, and non-urban or undeveloped areas. It is used with many years of continuous hourly precipitation records and may be used for selected single events as well as for continuous simulation.

SHUBINSKI, R.P. and NELSON, S.N. 1975: "Effects of urbanisation on water quality". ASCE Water Resources Program, Tech. Memo. No.26; 34pp. (NTIS PB-242 297).

Key words: urbanisation; water pollution sources; erosion; environmental effects; combined sewers; overflows; waste water treatment.

The intended audience for this Technical Memorandum is urban planners. Numerical values are given whenever

available. Land use and water quality relationships are outlined, including the relations between source and type of water pollution. Effects of land use on point discharges are enumerated, for residential, commercial, industrial and power generation land uses. A parallel evaluation is made of nonpoint discharges from urban storm runoff, agricultural drainage, construction runoff and resource extraction. Also, effects of land use are categorised within environmentally sensitive areas, such as flood-plains and shorelines, aquifer recharge areas and estuaries and wetlands.

SHUBINSKI, R.F. and ROESNER, L.A. 1970: "A mathematical model of urban storm drainage". In, Systems analysis of hydrologic problems, Proc. of the 2nd International Seminar for hydrology professors, Utah State University, Logan; p379-406.

Key words: urban hydrology; mathematical models; storm runoff; urban drainage; urban runoff; water pollution; model studies; computer models.

A storm water model under development was described. The model is capable of representing urban runoff phenomena, both quantity and quality, from the onset of precipitation on the basin through collection, conveyance, storage, and treatment systems to points downstream from outfalls which are significantly affected by storm discharges. Each of the three parts, urban runoff, storm water transport, and receiving water, were described and the composite model was demonstrated on four basins.

SHUIMAN, M.D. and BROTA, E.A. 1974: "Investigation of the effects of urbanisation on precipitation type, frequency, areal and temporal distributions: Phase II". Water Resources Research Institute, Rutgers University, New Brunswick, N.J., Technical Completion Report; 83pp. (NTIS PB-227 232).

Key words: weather modification; urbanisation; hydrologic data.

From a previous phase of research fifty years of daily precipitation values were available on tape for a network of 20 stations in the N.Y. metropolitan area. The earlier study showed that under certain wind conditions, precipitation augmentation was discerned downwind of the urban complex. However, the present study indicates that the urban area does not have any effect on daily precipitation patterns. Analyses were also made of probabilities of wet and dry periods of different lengths using the Markov chain probability model. These results will be valuable in many areas of planning, especially activity scheduling and economic risk taking. Also, the analysis of the average year at Highstown gives an insight into the processes which govern precipitation patterns in this area. One of the major goals was accomplished with the establishment of a

huge data bank with daily precipitation values for a network of stations. Many future analyses can now be run on these data, especially if data from other stations become available.

SHULMAN, M.D. and GREENWAY, A.R. 1971: "Investigation of the effects of urbanisation on precipitation type, frequency, areal and temporal distribution". New Jersey Water Resources Research Institute, New Brunswick, completion report; 83pp. (NTIS PB-204 866).

Key words: environmental effects; urbanisation; weather modification.

An investigation into the effects of urbanisation on precipitation for the northern New Jersey - New York metropolitan area was undertaken. Analyses were performed on monthly precipitation data for a network of 20 urban and rural stations in New Jersey, New York and Connecticut from 1900 to 1970. Individual storm totals stratified according to wind direction at the surface and 850 mb were analysed for a network of 91 stations from 1951 through 1969. Results indicate that precipitation variability and total amounts were greater in surrounding areas than in the central urban complex and that these differences are due primarily to summer precipitation. It was found that during periods of drought, precipitation differences between urban and rural areas are minimised while homogeneity increases. In addition, homogeneity of precipitation variability was a function of the distance from New York City. During the period of study 14 out of 20 stations tested for trends showed decreasing annual precipitation totals with time. Analysis of variance indicates a tendency for increased precipitation downwind of the centre city with northwest and southwest winds both at the surface and aloft, while with northeast surface winds and southwest or southeast winds aloft a more complicated pattern occurs.

SICKLE, D.VAN. 1962: "The effects of urban development on flood runoff". Texas Engineer, Vol.32(12).

Key words: flood discharge; rainfall-runoff relationships; analytical techniques; mathematical models; hydrographs.

An example is given of the adaption of preliminary research data to the development of new drainage design criteria for a major metropolitan area. The new criteria should be closer to the actual needs than the old rational method criteria. The Houston metropolitan area, one of the most rapidly urbanising areas in the United States, was used to establish and test the new urban runoff criteria. In order to apply the urbanisation factor data to design, the following procedures are followed: (1) develop the mean basin length and mean basin slope values from topographic maps; (2) estimate the degree of development anticipated in the watershed

for the period of design; (3) estimate drainage density for each of the areas of use; (4) multiply the drainage density for each type of land use to get total channel length; (5) determine the basin factor; (6) from the curves, determine the time to peak and the unit hydrograph peak for the degree of development involved; and, (7) develop the unit hydrograph. A simpler way to use the criteria is to develop them as empirical curves of drainage area versus discharge, of specific use only in the urban area and for the storm frequencies for which they are designed. Synthetic unit hydrographs were prepared and tested for about 50 drainage areas in the Houston area.

SICKLE, D.VAN. 1969: "Experience with the evaluation of urban effects for drainage design". In, Effects of watershed changes on streamflow, Section 3, urban watersheds, (eds. W.L. Moore; C.W. Morgan), University of Texas, Austin.

Key words: urbanisation; rainfall-runoff relationships; hydrographs; storm runoff; peak discharge.

An example is given of the adaption of preliminary research data to the development of new drainage system criteria for a major metropolitan area. The new criteria should be closer to the actual needs than the old rational method criteria. The Houston metropolitan area, one of the most rapidly urbanising areas in the United States, was used to establish and test new urban runoff criteria. In order to apply the urbanisation factor data to design, the following procedures are followed: (1) develop the mean basin length and mean basin slope values from topographic maps; (2) estimate the degree of development anticipated in the watershed for the period of design; (3) estimate drainage density for each of the areas of use; (4) multiply the drainage density by the area for each type of land use to get total channel length; (5) determine the basin factor; (6) from the curves, determine the time to peak and the unit hydrograph peak for the degree of development involved; and (7) develop the unit hydrograph. A simpler way to use the criteria is to develop them as empirical curves of drainage area versus discharge, of specific use only in the urban area and for the storm frequencies for which they are designed. Synthetic unit hydrographs were prepared and tested for about 50 drainage areas in the Houston area.

SINGH, R. 1974: "Water quality of urban storm runoff". In, Proceedings of the International Seminar and Exposition on water resources instrumentation; volume 1 - measuring and sensing methods, IWRA, Illinois; p577-589.

Key words: urban runoff; storm runoff; analytical techniques; water pollution sources.

Recent studies indicate that storm runoff from urban areas carries various

pollutants in heavy concentrations. Quality of receiving waters and rivers can be significantly affected by such urban runoff. Hence, determination of pollution load in urban storm runoff is a vital tool for managing the receiving water quality and safeguarding the environment. A practical method for assessing the water quality of storm runoff is presented.

SIRISINHA, K. 1973: "Algal available nitrogen in Madison urban storm water drainage and selected tributaries of Lake Ontario". M.S. Thesis, University of Wisconsin, Madison.

Key words: nitrogen compounds; nutrients; algae; storm runoff.

SKAKAL'SKIY, B.G. 1973: "Effect of urbanisation on the quality of river water". Soviet Hydrology, Selected Papers, No.5; p413-420.

Key words: urbanisation; industrial wastes; detergents; urban runoff; biochemical oxygen demand; nutrients; water pollution.

In our time of rapid economic development and population growth, the effect of human activity on nature has increased sharply and spread to all natural environmental components, leading to their deterioration in some cases. The increase in the utilisation of natural resources not only threatens their exhaustion in some cases, but may be accompanied by pollution because of the increasing amount of waste. One of the most important problems to arise is that of meeting the increasing requirements of the population and various branches of the economy for water resources of adequate quality under conditions of waste water disposal into natural bodies of water. Pollution of the hydrosphere is an undesirable effect of many aspects of economic development, including industrialisation, urbanisation, the development of transportation, and also reclamation and the chemicalisation of agriculture. Some aspects of the effect of urbanisation on the quality of natural surface waters were examined on the basis of Soviet and foreign investigations.

SKAKAL'SKIY, B.G. 1977: "Estimation of the changes in the chemical composition of surface water in urban areas". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p334-338.

Key words: water pollution; chemical analysis; surface runoff; landuse change.

General problems of urban influences on the chemical composition of surface water are discussed. The main factors are described affecting the hydrochemical regime of natural water resources under urban conditions and the general tendency of the changes in the chemical composition of water within the urban

area is analysed.

SKIPWITH, W.E. and MOORE, W.L. 1976: "Evaluation of urban runoff by watershed simulation". Centre for Research in Water Resources, The University of Texas at Austin, Technical Report HYD-14-7601, CRWR-127; 121pp.

Key words: computer models; mathematical models; urban runoff; urbanisation.

Using the University of Texas watershed simulation computer model as the principal investigation tool, the effects and characteristics of urban development in a small watershed were explored. Primary objectives of the research were: (1) to determine the significance and effects on streamflow of lawn irrigation in a small watershed containing a large amount of residential land use; (2) to evaluate the effect of urbanisation on runoff from the watershed and the corresponding change of the parameters in the watershed simulation program; (3) to utilise the comparison of field measurements of soil moisture with simulated soil moisture values as an indication of the validity of the simulation program; and (4) to investigate various ways for determining amounts and distribution of lawn watering data.

SLADE, R.M. and TAYLOR, J.M. 1976: "Hydrologic data for urban studies in the Fort Worth, Texas metropolitan area, 1974". U.S. Geol. Survey open-file report; 100pp.

Key words: hydrologic data; rainfall-runoff relationships; urban runoff; data collection; peak discharge; hydrographs.

This report, which is the sixth in a series of reports published annually for the Fort Worth, Texas area, presents basic hydrologic data collected in four study areas during the 1974 water year (October 1, 1973, to September 30, 1974). The four study areas within the metropolitan area are Sycamore Creek, Sycamore Creek tributary, Dry Branch, and Little Fossil Creek. Each year, storm events are selected for detailed rainfall-runoff analysis. The event during which the annual maximum discharge occurs is usually included in the selection. Summaries of storm rainfall-runoff data for selected individual storms at streamflow stations and crest-stage partial-record stations are given. Detailed storm rainfall and runoff records, hydrographs, and mass curves for each station are shown.

SLADE, R.M. and TAYLOR, J.M. 1977: "Hydrologic data for urban studies in the Fort Worth, Texas metropolitan area, 1975". U.S. Geol. Survey open-file report 77-266; 96pp.

Key words: urban hydrology; rainfall-runoff relationships; storm runoff; urban runoff; hydrologic

data; peak discharge; watershed management.

This report contains rainfall and runoff data collected during the 1975 water year for Sycamore Creek, Sycamore Creek tributary, Dry Branch, and Little Fossil Creek study areas in Fort Worth, Texas. The information will be useful in determining the extent to which progressive urbanisation will affect the yield and mode of occurrence of storm runoff. Detailed rainfall-runoff computations, including hydrographs and mass curves, are presented for nine storm periods during the water year.

SMITH, R.E. and JOHNSON, S.L. 1966: "Urban hydrology, Houston Metropolitan area, Texas, 1964". U.S. Geol. Survey open-file report; 18pp.

Key words: storm runoff; data collection; hydrologic data; rainfall-runoff relationships.

The purpose of this report is to outline the progress made in a cooperative program between the city of Houston, Texas, and the U.S. Geological Survey to determine the changes in magnitude of floodflow and runoff caused by urbanisation at selected stream gauging sites. The records collected will provide data on floodflow magnitude and frequency at the gauging sites and can be used in predicting floodflow from ungauged areas. The network of streamflow and precipitation data collection sites determined to be needed for adequate sampling consists of seven continuous rainfall and runoff sites, 15 flood hydrograph partial record sites, and 6 recording raingauges. Instruments used at flood hydrograph stations will also furnish a continuous record of rainfall of sufficient accuracy to supplement other rainfall records during significant storm periods. The drainage areas selected for sampling range in size from less than 1 square mile to 19.5 square miles. They are well distributed throughout the metropolitan area to obtain data from areas of varying stages of development and from areas of different types of cover, shape, and topography.

SMITH, R.L. 1968: "General observations relating to analytical needs in hydrology". In, Urban water resources research: systematic study and development of long-range programs of urban water resources research, first year report. ASCE, app.A, Chap.1; pA6-A14.

Key words: rainfall-runoff relationships; mathematical models; data collection; model studies.

Urban hydrologic problems can be studied by approaches including: direct field measurements; scale and analog models; and analysis and synthesis utilising electronic computers. System simulation techniques include deterministic methods and stochastic methods. Deterministic models attempt to develop relationships among measured physical parameters and processes involved in the hydrologic cycle. These

relationships are then used to generate or to predict non-recorded hydrologic sequences. The principal input function is rainfall, and the principal output function is runoff. In the case of quality models, the input requires magnitude and location of system loads, and the output is the time distribution of concentration.

SMITH, R.L. 1968: "Application of models in urban hydrology". In, Urban water resources research: systematic study and development of long-range programs of urban water resources research, first year report. ASCE, app.A, Chap.2; pA15-A21.

Key words: rainfall-runoff relationships; mathematical models; data collection; model studies.

Urban hydrology model development should be coordinated with associated basic data and research activities. In order to test the transfer capability of the models, 3 to 5 years of data sufficient to provide an appropriate range of input variables should be collected. Most existing models, owing to limitations in available data, utilise limited climatic input; usually this consists of low density precipitation coverage plus evaporation (or temperature). Similarly, watershed parameters are usually limited to readily identifiable factors such as slope, surface characteristics, and channel conveyance characteristics. Measured output is normally limited to surface flow. Perfection of adequate modeling techniques would be of great assistance to public works administrators in appraising the adequacy of their existing storm drainage systems.

SMITH, R.W. et al. 1977: "Effect of land use management on flood predictions". Virginia Water Resources Research Centre, Blacksburg, Bulletin No.103; 39pp. (NTIS PB-270 645).

Key words: flood forecasting; urbanisation; landuse change; watershed management.

This study investigated the effects of changes in land use practices and hydrologic parameters on flooding in an urbanising area. It adapted modeling techniques developed by the Soil Conservation Service to local computing facilities and applied these models to flooding problems in the South River Watershed in and above Waynesboro, Virginia. (A related research project developed methods to predict runoff from various soil conditions and land uses and, by use of a finite-element technique, to predict total downstream runoff). This study provides comparative data and presents a methodology allowing evaluation of alternative courses of action needed to produce a least-cost flood-management program. In addition to developing computer analysis capability at the local level, the project produced findings that were instrumental in developing flood-management guidelines adopted by the South River Watershed Flood Control

Commission and the Central Shenandoah Planning District Commission.

stalled in several sewer catchment basins throughout the United States.

SMITH, W.H. 1972: "Lead and mercury burden of urban woody plants". Science, Vol.176(4040); p1237-1239.

SNYDER, F.F. 1958: "Synthetic flood frequency". J. Hydraul. Divn., Proc. ASCE, October 1958.

Key words: point sources (pollution); lead; mercury.

Key words: flood discharge; flood forecasting; mathematical models.

For six New Haven woody plant species, the mean lead concentration for tissue produced in the preceding growing season exceeded most lead concentrations determined for trees in areas with geologic lead deposits or adjacent to primary highways. Preliminary estimates indicate that some New Haven plants have slightly higher than normal amounts of mercury. The burden of lead and the difficulty in removing it by washing suggests a potential for pathological significance.

A method is developed for predicting the flood discharge probability associated with a given rainfall-duration frequency pattern. The method can be applied to (1) natural drainage basins, (2) nonchannelised overland flow areas and (3) areas with storm sewer drainage. For urban areas the main variables used are drainage area, length, slope, friction, and shape. The main tool in the study is the rational method, but some consideration is given to the effects of storage existing in all types of channels and conduits and an average rainfall-runoff relation. Data used in this study came from the Washington, D.C. vicinity.

SMOOT, G.F. 1971: "Data collection for real-time systems". In, Treatise on urban water systems, Colorado State University, Fort Collins; p499-508.

Key words: data collection; storm runoff; urbanisation; instrumentation; urban hydrology; rainfall-runoff relationships.

SODERLUND, G. et al. 1971: "Physiochemical and microbiological properties of urban storm water runoff". In, Advances in water pollution research, Proc. Vth Int. Ass. on Water Pollution Research Conf., San Francisco, Hawaii. Pergamon Press, Oxford: Paper I-2; p1-2/1-3.

Existing devices and methods which might be used in data collection systems for metropolitan areas are reviewed and evaluated. The discussion includes devices for measurement of precipitation, surface runoff, sewers, open channels, water quality, and systems for transmitting and logging of data. A data collection system for a metropolitan area must collect data from the network on a common time base. The use of a mixed time base would result in chaos, confusion, and loss of records. A computer based control and data logging system would provide not only the required precise time correlation, but also the real time data required for the urban operational and management service. Such a system would permit programming to record only storm events, thus avoiding an excessive quantity of data that would otherwise result. Real time data collection also provides a means for effective surveillance of the operating condition of instrumentation.

Key words: storm runoff; miscellaneous chemicals; water pollution; urban runoff; suspended solids; lead; snowmelt; nitrogen compounds; phosphorus compounds; oil wastes; heavy metals.

SMOOT, G.F. et al. 1974: "Urban storm rainfall-runoff-quality instrumentation". In, Flash floods: Proc. Paris Symposium, September 1974, IAHS Publication No.112; p44-47.

Key words: instrumentation; urban runoff; hydrologic systems; network design.

In Sweden today a separation of storm and sanitary sewers is usually preferred. This avoids the discharging of mixed storm water and waste water into the streams and inland waters. There is an increasing discussion as to whether the direct discharge of storm water into streams can be justified for the future. A study to collect more information concerning the nature and extent of the pollutional load from highly urbanised areas was made. The results of this study showed that the discharging of snowmelt from heavily trafficated areas into streams and inland waters contributes in a great extent to the pollution of the recipients with oil and heavy metals. Traffic roads give a high degree of contamination as compared with the other test areas. The oil in the storm water is contaminated with oil not only from the traffic but also from the industrial areas. As the use of cutting oils and emulsions, dry cleaning liquids, and industrial cleaning liquids increases the problem of collection and destroying such waste liquids must be solved. Various measurements were taken in areas differing with respect to traffic intensity. The analytical values obtained represent a skewed distribution. Nearly 50 percent of the dry residue obtained from warm water runoff is volatile material, most probably asphalt from the roadway and rubber from the tyres and oil. Other constituents measured in concentration

A project was initiated to develop the necessary instrumentation to study urban runoff and has resulted in an integrated system, including precipitation gauges, a sewer flow measuring device, automatic sampler, clock and recorder. Details of instrumentation are given. Such systems are being in-

versus time were chloride, pH, nitrogen, phosphorus, coliforms, carbohydrates, and BOD."

SODERLUND, G. and LEHTINEN, H. 1972: "The properties of urban storm water". Ytkemiska Institutets Uppdragsforskningslaboratorium. (In Swedish).

Key words: water pollution sources; urban runoff; storm runoff; water pollution.

SODERLUND, G. and LEHTINEN, H. 1973: "Comparison of discharges from urban storm water runoff, mixed storm overflow and treated sewage". In, Advances in water pollution research, Proc. Vth Int. Conf. on Water Pollution Research, Jerusalem, 1972. Pergamon Press, Oxford; p309-325.

Key words: urban runoff; storm runoff; sewage disposal; water pollution control; combined sewers; overflows.

The rapid migration of the Swedish population to a few urban areas is resulting in intense development around the major towns. In these expanded population centres the sewage is collected in separate systems for storm water and domestic sewage. This process of urbanisation leads to a reduction in the natural infiltration capacity, and the volume of storm water runoff is thus increased. As the storm water is conducted through its own sewer system to the nearest discharge point without treatment, its contribution to the water recipients can be considerable. Storm water runoff from heavily trafficked urban areas contains large quantities of pollutants and large numbers of bacteria. Because of the more widespread treatment of domestic sewage, the storm water runoff becomes relatively more important as a source of water pollution and the question is whether this source is important enough to require treatment. The prime purpose of this study was to determine and compare the pollutant content of urban storm water runoff with that of the treated effluents, and also with that of the storm overflow water from combined systems.

SOLIMAN, M.M. 1974: "Urbanisation and the processes of erosion and sedimentation in the River Nile". In, Effects of man on the interface of the hydrological cycle with the physical environment, IAHS Publication No.113; p123-126.

Key words: urbanisation; sediment transport; erosion; channel erosion.

The processes of erosion and sedimentation were in a dynamic state along the River Nile and its small islands during flood times. However after building the High Dam of Aswan, the situation changed and these islands appear to be in a stable position. This paper is mainly concerned with studying the urbanisation process on the islands south of Cairo.

SONNEN, M.B. et al. 1976: "Future direction of urban water models. Final report". Water Resources Engineers Inc., Walnut Creek, California. Environmental Protection Technology Series, EPA-600/2-76-058, Washington, D.C.; 95pp. (NTIS PB-249 049).

Key words: mathematical models; combined sewers; waste water treatment; model studies; analytical techniques; computer models; watershed management.

The state-of-the-art of urban water modeling since 1968 is reviewed. Future urban water models are suggested from the review, and from demonstrated needs for additional problem solving capabilities. A phased model implementation program for the EPA's Storm and Combined Sewer Section is suggested.

SORMAN, A.U. 1977: "Some aspects of the effects of urban development on thunderstorms in the southeast coastal plain of Georgia, USA". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p3-11.

Key words: urbanisation; weather modification; model studies.

This research is intended to show the effect of a newly developed urban area on heavy rainfall distribution as well as to ascertain to what extent the urbanisation of part of an experimental basin effects the temporal and spatial distribution of raincells. The study was carried out from the analysis of storm data collected during the summers of 1968-1970. The Little River Experimental Watershed located near Tifton, Georgia, is monitored by a dense network of raingauges covering an area of 650 sq km. The results obtained from graphical plots indicated that summer thunderstorms with a precipitation depth of 25 mm or more were initiated earlier on an urban area compared to the surrounding rural area. The frequency of storm occurrences from the year of urbanisation and the areal depth of rainfall on the urban area increased with increase of storm depth. Finally, the transformation factor, the mean correlation coefficient, converting point rainfall into areal rainfall was determined in terms of storm area and characteristic distance parameter. The ratio dA/dO increased with an increase of storm centre depths from 5 mm to 50 mm or more on the urban area, but it remained constant over the non-urban area. The results from the model study confirm the findings of similar studies carried out recently in this field of research.

SOUTHEASTERN CONNECTICUT REGIONAL PLANNING AGENCY. 1968: "Storm drainage study, Southeastern Connecticut Region". Report by S.E. Connecticut Regional Planning Agency, Norwich, et al.; 157pp. (NTIS PB-184 565).

Key words: urban drainage; storm runoff.

The report provides an overall program for the development of future storm drainage in southeastern Connecticut and includes a general description of watersheds within the region. Condition of existing structures is studied to identify their capacity to handle current and projected storm water runoff.

SPIEKER, A.M. 1968: "Some observations on streamflow and water quality in the urban environment". Proc. 4th American Water Resources Conference, November 1968, New York. American Water Resources Assoc., Urbana, Illinois; p742-753.

Key words: urbanisation; low flow; dissolved solids; dissolved oxygen; water pollution sources; bacteria; rainfall-runoff relationships; biochemical oxygen demand.

The effects of urbanisation on the hydrologic regime are studied through observation of the Salt Creek basin in Illinois from 1940 to 1965. The effects of urbanisation on low flows may be significant. Discharge of sewage from the local drainage basin by affiliation with the Metropolitan Sanitary District of greater Chicago may reduce flow almost completely during dry periods. Where a community operates its own treatment plant, increased population brings about increased sewage effluent discharge. Where treatment is good, DO (dissolved oxygen) and BOD (biochemical oxygen demand) readings at several locations show favourable conditions during the flooding period. Exceptions result from untreated discharge from combined sewer systems. Dissolved solids concentrations are much higher at low flow. Coliform bacterial counts are higher during high flows in areas with combined sewers or accumulated sludge in streambeds.

SPIEKER, A.M. 1969: "Urbanisation and the water balance". Proc. Symp. on water balance in North America. American Water Resources Assoc., Banff, Canada, Proceedings Series No.7.

Key words: water pollution sources; sediment yield; peak discharge; combined sewers; urbanisation; hydrographs; rainfall-runoff relationships; waste water disposal.

Urbanisation modifies the hydrologic balance by causing changes in the distribution and quality of water in time and place. The overall quantity of water, however, remains essentially unchanged. In extreme cases, the lack of adequate management measures can result in catastrophic events. Several examples are cited. In 1969 floods in southern California were intensified by uncontrolled urban sprawl in alluvial fans and canyons. Sewering of urbanised areas on Long Island has caused an increase in direct runoff and flood peaks, and a lowering of ground water levels. Detailed studies of storm runoff in Fairfax County, Virginia, have shown that urbanisation in small watersheds increases peak flow by 2 to 3

times, and shortens the lag time by about 8 times. Intensive construction in urbanising areas can result in sharply increased sediment loads in streams and lakes. Chemical and bacterial quality of water are also affected by urbanisation. Studies of Salt Creek, a small stream in suburban Chicago, indicate high coliform and BOD levels at both low and high flows. Coliform counts are greater at high flows, resulting from combined sewer overflows.

SPIEKER, A.M. 1970: "Water in urban planning, Salt Creek Basin, Illinois". U.S. Geol. Survey water supply paper No.2002; 147pp.

Key words: watershed management; water pollution sources; flood control.

Water management can be an integral part of urban comprehensive planning in a large metropolitan area. Water both imposes constraints on land use and offers opportunities for coordinated land and water management. Salt Creek basin in Cook and Du Page Counties of the Chicago metropolitan area is typical of rapidly developing suburban areas and has been selected to illustrate some of these constraints and opportunities and to suggest the effects of alternative solutions. The present study concentrates on the related problems of ground water recharge, water quality, management of flood plains, and flood control measures.

STALL, J.B. et al. 1970: "Some effects of urbanisation on floods". Preprint paper presented at the ASCE National Water Resources Meeting, Memphis, Tenn.; 29pp.

Key words: surface runoff; storm runoff; rainfall-runoff relationships; peak discharge; urbanisation; hydrographs; model studies.

The objectives of the study were: (1) to attempt a better definition of the effects of urbanisation on floods by using relatively good information available in Illinois on storm rainfall structure and frequency, and (2) to translate this into the resulting effect on the flood-frequency curve using a set of empirical equations developed in 1965 at the University of Texas Centre For Research in Water Resources. The Texas equations were used as a transfer function from storm rainfall to flood peak. A model two-hour rainstorm, based on recorded precipitation data from East-Central Illinois, was developed for various recurrence intervals and applied to the completely urbanised, 3.5 square mile drainage area of Boneyard Creek at Urbana, Illinois. The specified model storm was applied to the derived unit hydrographs after determining the rainfall excess after losses. The empirical Texas equations seem adequate to produce a 30-minute unit hydrograph for the Boneyard basin and it checks favourably with actual unit hydrographs. The complete transformation of a 3.5 square mile rural basin, in East-Central Illinois, to an

intensely urbanised basin would quadruple the flood peak for the 50-year recurrence interval; and the mean annual flood would increase by about eight times.

STALL, J.B. and SMITH, H.F. 1961: "A comparison of urban and rural runoff". ASCE Hydraulic Conference, Urbana, Illinois, August, 1961.

Key words: rainfall-runoff relationships; landuse change; storm runoff.

This study compares a 4.6 sq mile watershed containing 5 raingauges and a 12.3 sq mile rural watershed containing 1 raingauge. The 11 year records are compared by mass curves of runoff, flow duration curves and unit hydrographs from one storm. Reactions of the basins to periods of drought as well as storms are considered.

STALL, J.B. and TERSTRIEP, M.L. 1972: "Storm sewer design. An evaluation of the RRL method". Environmental protection technology series, Illinois State Water Survey, Urbana; 78pp. (EPA-R2-72-068; NTIS PB-214 402/0).

Key words: surface runoff; rainfall-runoff relationships; mathematical models.

Storm rainfall and runoff data were assembled from 10 urban basins in the U.S.A. ranging in size from 14 acres to 8 sq mls. The British RRL method of storm drainage design was applied to the 10 basins. The RRL method considers the urban basin to be comprised of the paved area of the basin which is directly connected to the artificial storm drainage system. In 3 of the 10 basins the RRL procedure was deemed to be appropriate and suitable for the design of a storm drainage system within the normal range of frequency of design rainfall events, from 2- to 20-year events. For greater storms and for certain cases within this frequency range, the RRL method breaks down because the runoff coming from the grassed area is significant.

STALLINGS, E.A. 1977: "Impact of urbanisation on regional and national water planning and management". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p543-549.

Key words: urbanisation; watershed management; model studies.

There are four major steps in the development of a regional water plan and the corresponding effects due to urbanisation. The first two steps are problem identification and formulation of alternatives with the corresponding development of problem solutions. The next step in the planning process involves the impact assessment which introduces the mathematical modeling process. The final phase is evaluation

which will discuss the effects both with and without the project. Finally, a description of the important trade-off analysis in the planning process and the relationships as affected by urbanisation is described with examples from actual on-going projects.

STANDER, G.J. 1961: "Topographical pollution - the problems of the water and sanitary engineer". In, 40th Annual Conference, Inst. of Municipal Engineers, National Institute for Water Research.

Key words: storm runoff; bacteria; nitrogen compounds; chemical oxygen demand; dissolved solids; biochemical oxygen demand.

Storm water samples from residential, park, school, and sports ground type areas in Pretoria, South Africa, revealed coliform counts of 240,000 per 100 ml; total organic nitrogen, 5.4 mg/l; COD, 29 mg/l; dissolved solids, 228 mg/l; and BOD, 30 mg/l. From a business and flat area, the concentrations were: coliforms, 230,000 per 100 ml; total organic nitrogen, 3.5 mg/l; COD, 28 mg/l; dissolved solids, 154 mg/l; and BOD, 34 mg/l.

STANKOWSKI, S.J. 1974: "Magnitudes and frequencies of floods in New Jersey with effects of urbanisation". State of N.J., Dept. of Environmental Protection, Division of Water Resources, Special Report No.38; 46pp.

Key words: urbanisation; urban hydrology; storm runoff; urban runoff; flood forecasting; rainfall-runoff relationships.

Mathematical and graphical relations are presented to estimate flood-peak magnitudes having selected recurrence intervals ranging from 2 to 100 years for drainage basins larger than one square mile with various degrees of existing or projected urban and suburban development in New Jersey. Four parameters are required for use of the relations. Three of these may be measured from topographic maps; namely, basin size, channel slope, and surface storage within the basin. The fourth is an index of manmade impervious cover, which can be determined for existing and future development conditions from census data and population projections that are readily available from regional, State, and local planning agencies. The relations were developed from an analysis of flood information for 103 sites in New Jersey; they should be useful for design of bridge waterway openings, selection of optimum size for drainage structures, evaluation of flood hazards for alternative land use plans, and for definition of floodway and flood-hazard-area limits. Urban and suburban development increase flood peaks up to 3 times at the 2-year recurrence interval and up to 1.8 times at the 100-year recurrence interval as statewide averages.

STEGER, R.D. 1973: "Annual compilation and analysis of hydrologic data for urban studies in the San Antonio, Texas metropolitan area, 1971". U.S. Geol. survey data report; 109pp.

Key words: urban hydrology; data collection; hydrologic data; water pollution; flood discharge.

The objectives of the San Antonio urban hydrology study are: to provide data showing the effects of various stages of urbanisation on flood discharge and runoff, and to provide water quality data showing chemical constituents, nutrients, biochemical oxygen demand, pesticides, and sediment in surface water runoff from floods of various magnitudes during all seasons of the year with different types of utilisation.

STEGER, R.D. 1974: "Hydrologic data for urban studies in the San Antonio, Texas metropolitan area, 1972". U.S. Geol. Survey open-file report; 102pp.

Key words: data collection; urbanisation; urban hydrology; hydrologic data.

Data were collected to show the effects of various stages of urbanisation on flood discharge and runoff in San Antonio, Texas. Factors considered are time, variation in rainfall patterns and intensity, and size of the drainage area. Total precipitation and rainfall intensities were determined from 19 recording rain gauges distributed throughout the study area. Runoff data from the San Antonio urban study area are based on discharge measurements and stage records at six continuous-record stream-gauging stations, seven crest-stage partial-record stations (flood hydrographs obtained), and water-surface elevations at four flood-profile partial-record stations. Daily discharge records are given for the six continuous-record stations. Annual maximum discharge records were collected in the seven crest-stage partial-record stations.

STEGER, R.D. 1975: "Hydrologic data for urban studies in the San Antonio, Texas metropolitan area, 1973". U.S. Geol. Survey open-file report; 127pp.

Key words: urban hydrology; data collection; hydrologic data; storm runoff; rainfall-runoff relationships; hydrographs.

This report contains rainfall, runoff, and water quality data collected during the 1973 water year for the San Antonio metropolitan area. The information will be useful in determining the effects of various stages of urbanisation on flood discharge and runoff and in determining chemical constituents in surface water runoff from floods of various magnitudes during all seasons of the year from areas with different types of utilisation. Detailed rainfall-runoff computations, including hydrographs and mass curves, are presented for several storms during the 1973

water year.

STONEHAM, S.M. and KIDD, C.H.R. 1977: "Prediction of runoff volume from fully sewered urban catchments". NERC, Institute of Hydrology, Report No.41; 44pp.

Key words: mathematical models; urban runoff; rainfall-runoff relationships.

This report describes the development of a mathematical model to predict the volume of runoff from a given rainfall event on a fully sewered catchment. The model will ultimately be incorporated into a new design method for storm sewer systems. Regression analysis on existing urban catchment data was used in the model development because the translation of rainfall into runoff is a complex physical process. Data from 368 storms on 14 catchments were collated and processed from an archive being established at the Institute. A data set was compiled of rainfall and runoff volumes and pertinent catchment and storm characteristics for each of the 368 events. Analyses performed on the data from individual catchments demonstrated that there was no clear trend from one catchment to another. Analyses on the whole data set identified an additive 3-variable form of regression equation, using percentage runoff as dependent variable, as being the most appropriate. This equation will be updated as further data become available.

STOUT, C.E. and HUFF, F.A. 1962: "Studies of severe rainstorms in Illinois". J. Hydraul. Divn., Proc. ASCE, Vol.88(HY4); p129.

Key words: urban drainage; weather modification.

Study included a network of 10 recording raingauges on a 10 sq. ml. urban area and investigated distribution characteristics of heavy rainstorms over urban watersheds for a 10 year period. It was found: (1) twice as many excessive quantities occur within a 10 sq. ml. area compared with a specific point within the area; (2) the percent of the 10 sq. ml. area experiencing excessive rainfall increases with increasing storm duration; (3) a majority of the excessive quantities of rainfall lasting from 30 min. to 24 hr. occur in the same storm; (4) although a single raingauge records only a portion of the excessive rate occurrences in 10 sq. ml., a point rainfall record is a satisfactory index of frequency distribution of areal mean rainfall; (5) urban influences, if present, are not of practical significance in the distribution of excessive quantities.

STREET, D.W. and RAGAN, R.M. 1974: "Maryland highway drainage study. Volume IV. Overland flow on areas subjected to infiltration losses. Final Report 1967-74". Maryland University, College Park, Department of

Civil Engineering; 115pp.

Key words: computer models; surface runoff; urban drainage.

Describes the results of a series of computer simulations of overland flow on pervious surfaces in urban areas.

STUBCHAER, J.M. 1975: "The Santa Barbara urban hydrograph method". In, proceedings of the national symposium on urban hydrology and sediment control, University of Kentucky, Lexington, Ky.

Key words: mathematical models; hydrographs; storm runoff.

The Santa Barbara Urban Hydrograph (SBUH) method is a simple means of developing runoff hydrographs from urban watersheds using local data. To use the method, the watershed is divided into pervious and hydraulically connected impervious portions. Rain falling on the impervious portion is considered to be 100 percent runoff. Rain falling on or flowing across pervious portions is subjected to infiltration losses, the magnitude of which depend on antecedent rainfall. The resulting rainfall excess for each time period is converted to a rate of flow. The instantaneous hydrograph thus obtained is routed through an imaginary linear reservoir with a routing constant equivalent to the watershed time of concentration to obtain the final hydrograph.

SULLIVAN, R.H. et al. 1977: "Nationwide evaluation of combined sewer overflows and urban storm water discharges. Volume 1: executive summary". American Public Works Association, Chicago, Ill., Report EPA-600/2-77-064a; 95pp. (NTIS PB-273 133).

Key words: storm runoff; urban drainage; water pollution sources; urban runoff; water pollution control; combined sewers; waste water treatment; biochemical oxygen demand; heavy metals; suspended solids.

This study analyses the cost of abating pollution from combined sewer overflows and urban storm water; the impact of these discharges on receiving waters; and the pollution potential of these discharges. Continuous simulation runs using one year of hourly data were made to determine the attainable level of pollution control with a specific availability of storage volume and treatment rate in five cities - Atlanta, Denver, Minneapolis, San Francisco, and Washington, D.C. This procedure was used to derive generalised equations relating pollution control to storage and treatment. These results were combined in a simple optimisation which determined the optimal mix of storage and treatment for any reasonable level of control for any city. The nationwide assessment resulted in specific annual and capital investment cost estimates for given levels of control. These costs can be reduced significantly if storm water pollution control is integrated with best management practices and integrated into a

multi-purpose program. The assessment of pollution potential and resulting impact of urban runoff identified direct connections between parameters such as biochemical oxygen demand (BOD) and suspended solids, and the amount of street refuse. Some parameters appear to be related to more site specific factors. Practical limitations necessitate relating pollution abatement to BOD and suspended solids.

SUMMERS, W.K. and SPIEGEL, Z. 1974: "Ground water pollution: a bibliography". Ann Arbor Science Publishers Inc., Ann Arbor, Mich.; 90pp.

Key words: bibliographies; ground water resources; solid wastes; water pollution sources; oil wastes; nitrates; heavy metals; pesticides; herbicides.

This book contains a partially annotated bibliography of over 400 references on the pollution of ground water resulting from urbanisation and disposal of solid wastes, animal wastes, and petroleum products, with particular reference to contamination of ground water by nitrates, heavy metals, pesticides, and herbicides. Within each section the references are presented alphabetically by author.

SURKAN, A.J. 1973: "Hydra: dynamic model for urban hydrologic systems". Nebraska University, Lincoln. Water Resources Research Inst., Completion Report, 1 June 1971 - 30 June 1973; 157pp.

Key words: computer models; flood routing; storm runoff.

The design and application are described of HYDRA, a new package of computer programs designed for the detailed modeling of the routing of water in converging channel networks. Geometric characteristics of intricate systems consisting of arbitrarily large numbers of channel segments can be considered. Accounted for in the simulation model are the relationships of the channel segments to each other, to surrounding areas, and to the rainfall variations and/or movement of storms. Storms are described as regions enclosed by boundaries approximated by any arbitrary number of polygon sides. The degree of detail with which either the network or storm patterns are defined may be chosen by the user. Results from this modeling package include, for finite storm events, the runoff rate and accumulated rainfall at any specified point on the network.

SURKAN, A.J. and KELTON, P. 1974: "Binary tree model simulation of the behaviour of urban hydrologic systems". Int. Journal Systems Science, Vol.5(7); p639-653.

Key words: hydrographs; mathematical models.

A simulator of urban hydrologic net-

works based primarily on geometric descriptors is described. Its application is demonstrated using data from the Northwood Gauging Installation in Baltimore, Maryland. The simulator incorporates a binary tree model of the network, a polygon representation of the storm geometry, and time-varying rainfall intensity to produce simulated hydrographs of flow. A comparison of the simulated hydrographs with the experimental runoff graphs is made.

SUTHERLAND, R.C. and McCUEN, R.H. 1976: "A mathematical model for estimating pollutional loadings in runoff from urban streets". In, *Mathematical models for environmental problems*, Proc. Int. Conference, Southampton (ed. C.A. Brebbia); p283-297.

Key words: mathematical models; computer models; point sources (pollution); pollution abatement; urban runoff.

A computer planning model that estimates the accumulation of eight pollutants on urban streets, their removal by rainfall, and their removal by street sweeping operations has been developed and presented. Over thirteen years of hourly precipitation data from Washington D.C. were used to demonstrate some of the model's capabilities. This research led to the following conclusions: (1) under good operating procedures and conditions occurring over an extended period of time, street sweepers can remove approximately 50 percent of the pollutants accumulating on urban streets; (2) the amounts of pollutants accumulating on the street over an extended period of time were very significant; and, (3) total rainfall volume was found to be the most important variable in estimating the amount of pollutants removed by a storm event.

SUTHERLAND, R.C. and McCUEN, R.H. 1978: "Simulation of urban nonpoint source pollution". *Water Resources Bulletin*, Vol.14(2); p409-428.

Key words: nonpoint pollution sources; computer models; solid wastes; biochemical oxygen demand; chemical oxygen demand; Kjeldahl nitrogen; nitrates; phosphorus compounds; heavy metals.

Public Law 92-500 has mandated the need for evaluating the impact of nonpoint source pollution on receiving water quality, primarily through Section 208 Arcwide Planning. The Management of Urban Nonpoint Pollution (MUNP) model was developed to estimate the accumulation of eight nonpoint pollutants on urban streets, their removal by both rainfall and street sweeping operations. The model can simulate the following pollutants: total solids or sediment like material, volatile solids, five-day biochemical oxygen demand, chemical oxygen demand, Kjeldahl nitrogen, nitrates, phosphates, and total heavy metals. The simulated results can be used for investigation of nonpoint pollution management alterna-

tives. The model is capable of reflecting variation in such diverse factors as physical and chemical characteristics of accumulated pollutants, land use characteristics, rainfall characteristics, street sweeper characteristics, roadway characteristics, and traffic conditions. By using mean estimates of many input variables for large segments of a city, the MUNP model could be used to define the specific nonpoint source pollution areas within a city. Hypothetical locations and actual rainfall data for Washington, D.C. were used to demonstrate some capabilities of the MUNP model.

SYLVESTER, R.O. 1960: "An engineering and ecological study for the rehabilitation of Green Lake". University of Washington, Seattle, Washington.

Key words: storm runoff; turbidity; lakes; biochemical oxygen demand; waste dilution; bacteria; nutrients.

Storm water samples from Seattle street gutters, in a study made in 1959 and 1960, contained constituent values as follows: turbidities, up to 1,290 units; colour, to 350 units; BOD's, with aerated Green Lake water as the diluent, about 10 mg/l; coliforms, to 16,000 MPN's/100 ml. Nutrient values were: organic nitrogen, up to 2.80 mg/l; and phosphorus, to 784 μ -g/l soluble, and to 1,400 μ -g/l total, as P. The highest constituent concentrations usually were found when antecedent rainfall had been low.

SYLVESTER, R.O. 1961: "Nutrient content of drainage water from forested, urban and agricultural areas". In, *Algae and metropolitan wastes*, U.S. Dept. of HEW SECTR W61-63; p80-87.

Key words: nutrients; urban drainage; eutrophication; landuse change.

Nutrient concentrations are presented from field observations on drainage waters originating in timbered areas of little habitation and land use; from urban street drainage; subsurface and surface drains carrying irrigation return flows; urban streams; a eutrophic lake, and a comparison is made of the nutrient change in a stream of multi-purpose usage. The effect of land and water use on nutrient concentrations is clearly shown. Nutrient loss through sedimentation and incorporation in the bottom sediments and loss to littoral and other attached vegetation is indicated.

SYLVESTER, R.O. and WALLE, F.B.DE. 1972: "Character and significance of highway runoff waters, a preliminary appraisal". Washington University, Seattle, Dept. of Civil Engineering, Final Report May-December 1972, RPR-7.1; 107pp.

Key words: urban runoff; point sources (pollution); heavy metals; oil wastes; nutrients; water pollution control.

A study was conducted on the character and significance of highway runoff waters in the State of Washington. The preliminary appraisal of runoff quality consisted of a literature review and critique plus a limited amount of field sampling on State Highway 520. Although a large amount of information is present in the literature concerning urban runoff, there is very little strictly related to highways and their rights-of-way. Highway runoff is similar to urban area runoff but may be higher in heavy metals and oil. A significant fraction of the heavy metals, oil and nutrients are absorbed to the dust and dirt fractions and then may be removed by sedimentation. Recommendations are made for mitigating runoff effects and for conducting an intensive study of highway runoff water quality and its significance.

they contribute, and the degree of dilution each has to undergo in meeting with United States Public Health Standards requirements for nitrate nitrogen in drinking water supplies.

SYRACUSE UNIVERSITY. 1971: "Street salting - urban water quality workshop". Proceedings, State University College of Forestry, Syracuse, N.Y.

Key words: chlorides; water pollution sources.

SYMADER, W. 1977: "Heavy metals in water, suspended matter and sediment". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p339-343.

Key words: heavy metals; suspended solids; dissolved solids; zinc; analytical techniques.

Using principal component analysis, relationships are investigated between heavy metals in solution, suspended matter and sediment. It can be shown, that especially in former mining areas the heavy metal content in sediment does not reflect the properties of the water body except for Cu and Ni. Mn and Fe show no relationships at all. The heavy metal content of suspended matter is generally more influenced by sediment than by water. Nevertheless it may show quite a different behaviour if special waste waters are discharged, like those containing Cd and Zn. Concerning temporal relationships between dissolved and suspended heavy metal contents, it is strongly suggested that the lack of significant correlations is due to comparison of different dimensions. At least in highly polluted rivers such relationships do exist.

SYMONS, J.M. 1970: "Urban sources of nitrate". Illinois University, Urbana, Bulletin, Vol.68(2); p78-85.

Key words: industrial wastes; urbanisation; storm runoff; nitrates; ammonia; organic compounds; waste dilution.

The urban sources of nitrate nitrogen are dealt with, and data on nitrite nitrogen, ammonia, and organic nitrogen are included in the study since they can be partially or totally biologically oxidised to the nitrate form. The sources of urban nitrogen include human wastes from individual and central sewage systems, runoff from separate and combined storm water systems, rainfall, and industrial wastes. These sources are discussed in terms of the quantities and concentrations of readily biologically oxidisable nitrogen

TAFURI, A.N. 1975: "Pollution from urban land runoff". News of Environmental Research in Cincinnati, Advanced Waste Treatment Research, April 11, 1975; 4pp.

Key words: urban runoff; pollution abatement; waste water treatment.

A study to characterise urban runoff with respect to pollutant concentrations, and to compare the impact of the annual yield of pollutants from urban runoff on water quality with that of domestic waste waters, conducted in a 1.67 square mile drainage basin at Third Fork, Durham, N.C., is reported. The effectiveness of chemical coagulation and sedimentation techniques for treating urban runoff were also determined, and coagulation with alum, with or without coagulant aids, was judged the most effective. Data presented indicate that in urban drainage basins the benefits of improving sewage works efficiency may be uncertain in view of the impact of urban land runoff on receiving water quality.

TASK GROUP REPORT (2610P). 1967: "Sources of nitrogen and phosphorus in water supplies". J. American Water Works Association, Vol.59; p344-366.

Key words: nutrients; urban drainage; phosphorus compounds; nitrogen compounds; detergents; industrial wastes; agricultural pollution.

In this second part of Task Group 2610P of the American Water Works Association the sources from which nitrogen and phosphorus may enter water supplies are reviewed; a bibliography of 63 references is appended. Sources of these nutrients include sewage, synthetic detergents, industrial wastes, compounds used in water treatment, runoff from agricultural and urban areas, wastes from farm animals and wildfowl, and nitrogen fixation. Some figures showing increases in nutrient content of various rivers and lakes in the U.S.A are quoted. From the available data, an attempt has been made to estimate the relative significance of the various sources of nitrogen and phosphorus, and the results are tabulated, showing that agricultural runoff is the greatest single contributor of nitrogen and phosphorus to water supplies. The possibility of controlling the amounts of nutrients contributed by various sources is considered briefly.

TAYLOR, C.H. 1977: "Seasonal variations in the impact of suburban development on runoff response: Peterborough, Ontario". Water Resources Research, Vol.13(2); p464-468.

Key words: urban runoff; storm runoff; urbanisation; rainfall-runoff relationships; hydrographs.

A small basin in Peterborough, Ontario, has been instrumented to investigate the contrasts in runoff response between rural and suburbanised sections of the basin. Data have been collected over three seasons (summer, fall, and

spring) to evaluate seasonal variations in the urban-rural contrast. Results indicate that the effect of the urban development is felt most strongly in the spring under snowmelt conditions and least strongly in the summer. Urban direct runoff volumes exceed rural volumes by factors of 1.2 for summer rainstorms, 2.3 for fall rainstorms, and 7.5 for spring snowmelt and rain-on-snow events. Urban peak discharges exceed rural peaks for the same seasons by factors of 4.5, 2.4, and 7.1. Direct rainfall-runoff ratios (rainfall and snowmelt in the spring case) are fairly consistent in the rural basin, being 0.05 for the summer, 0.07 for the fall, and 0.06 for the spring. The corresponding ratios in the urban basin are 0.06, 0.16, and 0.76. It is believed that seasonal variations in the rural-urban response ratios are caused mainly by seasonal fluctuations in the extent of the runoff contributing area in the urban basin.

TERRY, R.D. and HUGHES, G.M. 1976: "Pollution effects on surface waters and ground waters, (Literature review)". J. Water Pollution Control Federation, Vol.48(6); p1420-1433.

Key words: water pollution; thermal pollution; biochemical oxygen demand; toxicity; chlorides; heavy metals; zinc; phenols; nutrients; pesticides; herbicides; nitrates; turbidity; waste water treatment; leachate; mathematical models; ground water resources; bibliographies; phosphorus compounds; nitrogen compounds.

Surface and ground water quality studies were compiled by the Ministry of the Environment of Canada. The water quality parameters included in these studies were, (1) trace metals in stream and lake sediments, (2) herbicides and pesticides, including DDT, PCB's, phenoxy-acid herbicides, copper sulphate solutions, Fenthion and Dicamba, (3) nutrients including dissolved oxygen, nitrates and phosphates, (4) land use effects, including biochemical oxygen demand (BOD), heavy metals, asbestos, petroleum products, rubber, nitrogen and phosphorus, (5) industrial effects, including contamination by chloride, pickling liquors, phenolic effluent, thermal effluents, and cannery wastes, (6) basin studies and river pollution, (7) water quality models and indices, and (8) contamination of ground water.

TERSTRIEP, M.L. and STALL, J.B. 1969: "Urban runoff by the Road Research Laboratory Method". J. Hydraul. Divn., Proc. ASCE, Vol.95(HY6); p1809-1843.

Key words: mathematical models; urban runoff; hydrographs.

The mathematical model of urban runoff developed by the British Road Research Laboratory is tested on three urban catchments. These are located in Baltimore, Chicago, and Urbana, Ill., and

are of 0.395, 12.5 and 2290 acres respectively. The model produces runoff by applying rainfall to the contiguous impervious area of the basin only. This simplifies the hydraulic conditions allowing a time-area diagram and discharge-storage relationship to be developed by standard equations. The actual and predicted hydrographs for the basins are compared and show reasonable correspondence. The analytical nature of the model allows hydrographs to be produced for proposed drainage schemes.

TERSTRIPP, M.L. and STALL, J.B. 1974: "Illinois urban drainage simulation, ILLUDAS". Illinois State Water Survey, Urbana, Bulletin No.58; 90pp.

Key words: computer models; urban runoff.

The digital computer model described for urban runoff calculations is in essence the same as that described in a report of the Road Research Laboratory, with an allowance for non-paved areas, generally grassed. The model divides an urban basin into sub-basins, computes the storm drainage components from the paved and grassed areas in each, sums them, and passes them to the next downstream design point. Pipe sizes required for conveyance of the runoff are calculated for each site, and detention storage within each sub-basin can be included in the program. Details are given of the verification of the model by trials on 21 existing urban basins and 2 rural basins, in widely divergent parts of the United States; since in these real life situations the existing drainage pipes may have collapsed or been blocked, or have a slope different from that assumed, verification requires considerable personal judgement, and results from only 14 of the 23 basins were regarded as acceptable.

TEXAS A. and M. UNIVERSITY. 1971: "Water for Texas. Urban water resources planning and management". Proc. of the Water Resources Institute Annual Conference (16th) held at San Antonio, Texas, September 1971. (NTIS PB-201 325).

Key words: ground water resources; surface runoff; watershed management.

The theme of the 16th Annual Conference on Water for Texas was urban water resources planning and management. Among the topics discussed are: perspectives in urban water management, systems description for urban water resources, conjunctive use of surface and ground water in urban water supplies, hydrometeorology for urban runoff systems, flood plain planning in urban areas, socio-economic aspects of urban water planning, environmental enhancement and recreation, costs of water reuse, river basin quality simulation, Bureau of Reclamation programs related to urban water resources and comprehensive inter-basin planning and inter-governmental coordination. Most papers use examples in Texas, especial-

ly the San Antonio area.

THELEN, E. et al. 1972: "Investigation of porous pavements for urban runoff control". Franklin Institute Research Laboratories, Pa., Water Pollution Control Research Series; 150pp. (NTIS PB-227 516; EPA-11034DUY03/72).

Key words: flood control; storm runoff.

Laboratory and economic studies have shown the advantages of using porous pavements to allow storm runoff to percolate into the ground, thus reducing the volume of runoff entering the sewers and alleviating pollution by overflows from combined sewers.

THOLIN, A.L. and KEIFER, C.J. 1960: "The hydrology of urban runoff". Trans. ASCE, Vol.125, Part 1; p1308-1355.

Key words: rainfall-runoff relationships; analytical techniques.

A detailed study is presented of rainfall-runoff relationships in urban areas. The "Chicago Hydrograph Method" of storm sewer design is used. Evaluation is made of the rainfall abstractions and flow detentions which intervene between the hyetograph of rainfall, the inlet hydrographs, and storm sewer outlet hydrographs. Several types of uniform land use with various values of ground slope and depression pondage have been studied. Derived storm sewer hydrographs are used to develop a series of design charts for selected interdependent variables. Delineation of the water surface profile and related hydrograph effects are studied for large sewers, and the effect of non-uniform areal distribution of rainfall considered. The paper guides the thinking of the designer to a clearer visualisation of hydrological events following rainfall on heterogeneous land surfaces of a city.

THOMAS, H.E. and SCHNEIDER, W.J. 1970: "Water as an urban resource and nuisance". U.S. Geol. Survey circular No.601-D; 9pp.

Key words: urban hydrology; urbanisation; landuse change.

Water is subject to natural variations in quantity and quality both in time and place. Many urban activities concerned with development and use of land and its resources other than water affect the natural water flow system and are affected by it. In urbanised areas, water as a resource becomes increasingly inadequate to meet requirements; nonconsumptively used waters contribute pollutants to natural water resources. Urbanisation causes some drastic changes in the natural hydrologic system and changes the hydrology of an area profoundly. Urban planners are becoming aware that decisions for today based upon expediency may result in problems for tomorrow that may be cost-

ly or even impossible to solve. The urban water problem is a part of the ever growing national water problem which can be solved only if a complete understanding of the role of water in the urban environment is realised.

THOMPSON, G.B. et al. 1974: "Variation of urban runoff quality and quantity with duration and intensity of storms - Phase III". Water Resources Centre, Texas Tech. University, Lubbock, Completion Report WRC-74-2; 56pp. (NTIS PB-241 406).

Key words: urban runoff; storm runoff; watershed management; water pollution sources; biochemical oxygen demand; low flow; chemical oxygen demand.

In the 1,499 acre watershed in Lubbock, Texas, thirty-five percent of the total precipitation appeared as direct runoff. From storm to storm, runoff pollutant concentrations varied widely in average and extreme values. COD and BOD washoff from the watershed equalled, respectively, 16.7 and 1.75 pounds/acre-inch of rainfall. There was a continuous, though highly variable, discharge during dry weather from the 26th Street storm sewer, totaling approximately two million gallons per year. Quality of the dry weather flow was considerably poorer than that of untreated domestic sewage. The yearly amount of COD in the dry weather discharge was equal to 15 percent of the mean annual COD in storm runoff. Discharges resulting from efforts to fight major fires contained significant quantities of pollutants. A facility should be constructed to provide interception and storage of the storm sewer discharge. Such a holding pond should trap all dry weather flow, and all flows resulting from unusual events.

THOMPSON, J.R. 1970: "Soil erosion in the Detroit metropolitan area". J. Soil and Water Conservation, Vol.25(1); p8-10.

Key words: erosion rates; erosion.

The author used the Universal Soil Loss Equation for computing erosion rates from non-construction areas and a similar equation for construction areas in the Detroit metropolitan area. By sampling 2.1 percent of the area, it was found that 2.1 percent that was under development produced the same amount of eroded soil material as the remaining 97.9 percent. Erosion from the developing areas averaged 69 tons per acre per year compared with the overall average erosion rate for the metropolitan area of about 3.0 tons per acre per year and an overall average erosion rate for southeast Michigan of 2.6 tons per acre per year.

TIMBERMAN, C.W. 1970: "Discussion of some aspects of urban hydrology methodology". In, Seminar on urban hydrology, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre, Paper

No.7; 48pp.

Key words: urban hydrology; hydrographs; rainfall-runoff relationships; storm runoff; urban runoff; model studies; peak discharge; flood forecasting.

The distinctive hydrologic characteristic of urban hydrology is the change in runoff response of an area as a function of its development. The unit hydrograph mathematical modeling procedure appears to be a suitable method of analysing urban area runoff. The unit hydrograph characteristics including time to peak, peak discharge, and recession factor can be correlated to physical basin characteristics such as slope, basin shape, basin storage, and channel and overland flow efficiency. Loss rates, or runoff factors, can be determined with sufficient accuracy and properly related to rainfall duration, season, API, and rainfall intensity. The recommended methodology can be related to specific design criteria, is relatively easy to apply, provides a basis for evaluating basin storage effects, and allows determination of an optimum design discharge and volume for selected design criteria.

TODD, D.K. and McNULTY, D.E. 1974: "Polluted ground water: a review of the significant literature". U.S. EPA Washington, D.C. Office of Water Resources Research, Environmental Monitoring Series, W74-11800; 224pp. (EPA-600/4-74-001; PB-235 556/8).

Key words: ground water resources; aquifers; water pollution sources; industrial wastes; agricultural pollution; bibliographies; pesticides; herbicides.

A selective review is presented of the literature on man-caused ground water pollution, including causes and occurrence, procedures for control, and methods for monitoring. References cited by number in the text are listed in complete bibliographic form at the end of the report together with an author index. With few exceptions, the material reviewed is limited to relatively recent published items in the United States.

TORNO, H.C. 1975: "A model for assessing impact of storm water runoff and combined sewer overflows and evaluating pollution abatement alternatives". Water Research, Vol.9(9); p813-815.

Key words: model studies; pollution abatement; water pollution control; storm runoff; hydrographs; biochemical oxygen demand; suspended solids; dissolved oxygen; bacteria.

Recognising the need for a comprehensive model of urban waste water systems, the EPA contracted for the development of the Storm Water Management Model (SWMM) which uses the rainfall (hyetograph) and system (catchment, conveyance, storage treatment, and receiving water) characteristics as inputs, determines quantity and quality

of runoff, routes this runoff through a combined (or separate) sewer system with specified storage and treatment facilities and operating policies, and thence into receiving waters, where their impacts are identified. The output from the model consists of tables, hydrographs, and "pollutographs" of BOD, suspended solids, DO, and coliforms. The following groups of subroutines make up the SWMM: the executive block which provides control and service functions; the runoff block which computes the storm water runoff and its associated pollution loadings for a given storm for each subcatchment and stores the results in the form of hydrographs and pollutographs at the inlets to the main sewer system; the transport block which routes flows through the sewer system; the storage block which simulates the changes in the hydrographs and pollutographs of the sewage as the sewage flows through one optional special waste water treatment facility; and the receiving water block which takes output from transport or storage and computes the impact of the discharges on the quality of the receiving water. Storm water conveyance and treatment cannot be considered separately from the conveyance and treatment of sanitary sewage.

TOURBIER, J. 1973: "Water resources as a basis for comprehensive planning and development in the Christina River basin". Final Report, Water Resources Centre, Delaware University, Newark; 199pp. (NTIS PB-228 853).

Key words: model studies; landuse change; urban hydrology; nonpoint pollution sources.

The Christina River basin near Wilmington, Delaware was used as a model area to determine methods that could be used by the public sector through its planning and regulatory powers to first assess the impact of land development upon water resources and certain hydrologic phenomena and then to create a responsible land use policy and program. The impact of urban development on the natural pattern of water flow is a function of 2 sets of variables, the natural characteristics of the land and the type and intensity of development. Land areas were classified into categories called site classes on the basis of the properties that influenced the water regimen. Land uses were described in terms of their water-related impact. A computer program then related environmental protection measures, measures that can be incorporated into development while it proceeds, to the variables of site class and land use intensity. The cost distribution of these measures was used to evaluate regional land use policies and to indicate areas of natural resources limitations to development, to allow for guidance of land uses to areas where they would do the least damage. The program is heavily reliant on protection measures and their cost as an indication of problem areas. The selection of measures requires an assessment of the impact of land uses on hydrologic processes, a definition of levels of quality to be achieved, and the quan-

tification of amelioration measures. The costing of protection measures requires specifications for construction.

TOVAR, F.H. 1972: "Annual compilation and analysis of hydrologic data for urban studies in the Bryan, Texas metropolitan area, 1970". U.S. Geol. Survey data report; 43pp.

Key words: urban hydrology; rainfall-runoff relationships; hydrologic data; data collection; peak discharge; hydrographs; urban runoff.

Basic hydrologic data collected during the 1970 water year (October 1, 1969, to September 30, 1970) are presented for the Burton Creek and Hudson Creek watersheds in Bryan, Texas. Rainfall-runoff data for storms are tabulated. Computations with hydrographs and mass curves for each storm are included.

TOVAR, F.H. 1973: "Annual compilation and analysis of hydrologic data for urban studies in the Austin, Texas metropolitan area, 1971". U.S. Geol. Survey open-file report; 73pp.

Key words: hydrologic data; urban hydrology; data collection; urban runoff; rainfall-runoff relationships; peak discharge.

The U.S. Geological Survey, in cooperation with the Texas Water Development Board, began hydrologic studies in the Austin urban area in 1954 to determine the effects of progressive urbanisation on infiltration rates, and rainfall-runoff relations in the Waller Creek watershed; to provide rainfall and runoff data from the rural Wilbarger Creek watershed to be used for comparative purposes in determining the effects of existing and progressive urbanisation in the Waller Creek watershed; and to provide applied research facilities for studies at the University of Texas at Austin. Rainfall and runoff data are presented for the Waller Creek and Wilbarger Creek study areas for the 1971 water year (October 1, 1970, to September 30, 1971). Weighted-mean rainfall was 18.31 inches, 44 percent below the mean annual rainfall for Austin. Mean daily discharge was 0.25 cfs; annual runoff was 0.73 inches, or 4 percent of rainfall. One storm period, October 22-23, 1970, was selected for analysis. A summary of rainfall-runoff data for each storm is tabulated. Computations with hydrographs and mass curves for each storm are included.

TOYOKUNI, E. and HAGIHARA, K. 1974: "Studies on modeling of urban storm water runoff - on the relation between the composition of basin model and the equivalent roughness". Memoirs of the Ehime University, Section III (Engineering), Vol.7(1); p49-64.

Key words: storm runoff; hydrologic data; model studies; urban runoff.

On the basis of observed hydrological data in a research basin, the relation between the composition of the basin model in the homogeneous surface and the equivalent roughness for each model and adaptability of the runoff model are discussed. These are representations of equivalent drainage area for the heterogeneous area composed of roof, asphalt road, or pervious ground surface. Each of three models, one simple and two more complex, are derived theoretically from the elements of composition in the basin model, applying the kinematic wave method.

TRANSPORT AND ROAD RESEARCH LABORATORY.
1976: "A guide for engineers to the design of storm sewer systems". Road Note No.35, D.S.I.R. (2nd edition); 30pp.

Key words: rainfall-runoff relationships; hydrographs; analytical techniques.

In 1962 the Transport and Road Research Laboratory published Technical Paper TP 55, describing what is still the largest program of experimental urban hydrology ever undertaken in Great Britain. This resulted in the development of a new method of urban storm water sewer design which was called the RRL Hydrograph Method. In 1963 the first edition of Road Note 35 was published as a guide for engineers in the use of the method. The research also showed the areas in which the 'rational' (Lloyd-Davis) formula could be satisfactorily applied and also included advice on this method. Since 1963 the RRL Hydrograph Method has become the most commonly applied surface water sewer design method in the United Kingdom. Through experience of its use there have been modifications to the basic method and to the rainfall input, and most recently the units used in the calculation have been metricated. This revised Note incorporates these changes, and also advises on such problems as carrier sewers and cases where natural streams are diverted into surface water sewer systems.

TREXIER, B.D. and RUEDISILI, L.C.
1976: "Stage, discharge and quality changes in a water table aquifer related to urbanisation". Toledo University, Ohio. Dept. of Geology Completion Report; 72pp. (NTIS PB-264 539).

Key words: urbanisation; aquifers; water pollution sources.

This investigation was divided into two major phases. Phase 1 was to establish a hydrologic monitoring system and to collect background data on the hydrology and geology of the Oak Openings area. The second phase involved the study of the area as it was developed into a 'new town' containing residential, business, and industrial areas. From the time-dependent data, a model was developed of water-table responses in the park. Only preliminary data were gathered from 1972 through 1976 because the urbanisation of the 'new town' never materialised. The only ur-

banisation factors affecting the area are the subsurface drains and drainage ditches. Heavy industrial development and large population effects have not developed. The major potential environmental problem in the Oak Openings area is the possibility of polluting the water-table aquifer. The aquifer possesses high infiltration and hydraulic conductivity values. Chemicals, oils and domestic sewage spills or discharges would rapidly move to the water-table and disperse throughout the aquifer. Such pollution would eliminate the aquifer as a supply of potable water and might drastically disturb the vegetation cover in areas where the water-table reaches the root zone.

TRUE, H.A. 1976: "Planning models for non-point runoff assessment". In, Proceedings of the conference on environmental modeling and simulation, Cincinnati, Ohio. Report EPA 600/9-76-016; p74-76.

Key words: computer models; rainfall-runoff relationships; erosion; nonpoint pollution sources.

The main objective in assessing nonpoint runoff is to estimate constituent loads for some representative time period for a defined drainage area. No absolutely accurate answers appear economically feasible now or in the future, and getting a grip on the many facets of the problem is very difficult. Presented are several computer-based planning models; they are generalised tools designed for initial gross assessments with refinement capabilities for decision making. Major benefits can be derived by using these modeling processes to calculate relative numerical measures of effects resulting from changes in treatment level percentages, land use allocation percentages, population densities, loading rates, and rainfall event intensities. The models are not costly to run and are not excessively complex; all computer programming is in the FORTRAN-4 language. The individual models discussed herein are: (1) 'Urban, Commercial, and Industrial Runoff;' (2) 'Erosion, Sedimentation, and Rural Runoff;' and (3) 'Total Loadings from Point and Nonpoint Sources to Waterbodies.' The accuracy of these models is directly related to the quality of the input data supplied by the user.

TRUHLAR, J.F. and REED, L.A.
1975: "Occurrence of pesticide residues in four streams draining different land use areas in Pennsylvania". Water resources investigations (Final), Geological Survey, Harrisburg, Pa., Water Resources Division; 29pp. (NTIS PB-242 770/6ST).

Key words: water pollution; pesticides; herbicides; organic compounds.

Samples of water, bed material, fish, and soil were collected in four small drainage basins in Pennsylvania in 1969-71 and analysed to determine the

concentrations of chlorinated-hydrocarbon insecticides. Water samples only were also analysed for phenoxy-acid herbicides. Each basin studied represents a predominant land use classification - forested, general farming, residential, and orchard farming. All water and fish samples showed pesticide concentrations less than the U.S. Public Health Service's (1969) recommended maximum permissible concentration. However, no fish were found in the orchard area stream at the time collection was attempted. DDT or one of its metabolites was the most frequently occurring insecticide and was detected in all media sampled except the forested area soil. The highest observed combined concentration of DDT and its metabolites in storm runoff samples was 11.4 micrograms per litre in a sample collected from the residential area stream, but the median was higher (0.12 microgram per litre) in the orchard area than in the residential area (0.02 microgram per litre).

TUCKER, C.G.J. 1974: "Storm water pollution - sampling and measurement". J. Institution of Municipal Engineers, Vol.101; p269-273.

Key words: data collection; urban runoff; storm runoff; hydrographs; water pollution sources.

Assessment of the nature of urban runoff pollutants requires the measurement of both flow and composition throughout a storm. It is important that automatic equipment measure the initial flow, where a first flush pollutant often occurs. Various types of automatic control may be used, such as floats, static head transducers and pressure switches. Sampling may be done on a continuous or discrete basis at variable time intervals. Two methods of dilution gauging, constant rate injection and gulp injection, are used for measuring storm water. A lithium tracer is used since rainfall and runoff do not contain natural lithium. Described is the method of gulp injection, controlled by an interval which is activated by an automatic float switch. A mass of tracer solution is added to the flow in a gulp dose. The passage of the resultant pulse is measured downstream. Equipment is detailed; its installation in manholes is simple, so long as space is sufficient for sampler and doser to pass through a 21 inch manhole ring. Results are given by storm hydrographs and concentration-time curves which are plotted to determine the polluting constituents. The integrated or Total Storm Load (TSL) value is found. This TSL is derived from a sum of the sampling intervals and represents the quantity of pollutant which is washed by a storm from the surface water catchment.

TUCKER, C.G.J. 1975: "Polluting loads in runoff from urban areas". Unpublished PhD Thesis, Trent Polytechnic, Dept. of Building and Civil Engineering.

Key words: urban runoff; water pollution.

TUCKER, L.S. 1969: "Availability of rainfall-runoff data for sewered drainage catchments". Tech. Memo. No.8, ASCE Urban Water Resources Research Program, New York; 100pp. (NTIS PB-184 703).

Key words: data collection; mathematical models; rainfall-runoff relationships.

Very few urban sewered drainage catchments have been gauged. As a consequence, little is known about the rainfall-runoff process and still less about rainfall-runoff-quality. Plans are being formulated by the USGS for acquisition of high quality data from a representative sample of sewered drainage catchments. The immediate, most crucial use for this data would be for calibration and verification of appropriate mathematical models that could be used to provide criteria for improved storm drainage design. Presently available models have not been adequately tested in this connection because of a lack of high quality rainfall-runoff-quality data for sewered urban catchments. The purpose of this technical memorandum is to make available to researchers information on the very limited amount of available rainfall-runoff data for sewered drainage catchments. It is hoped that data listed by the ASCE program will meet an immediate need for initial testing of mathematical models developed previously for natural drainage catchments. Although superior, more reliable data is needed for the complex models that must be developed, model development and testing should be in progress in the interim using the limited data available. Thirteen installations for the collection of rainfall and runoff data from completely sewered urban drainage catchments are discussed. Partially sewered urban drainage catchments are not considered. The installations described are additionally limited to those containing either a flume or a weir for measuring runoff.

TUCKER, L.S. 1970: "Availability of rainfall-runoff data for partly sewered urban drainage catchments". Tech. Memo No.13, ASCE Urban Water Resources Research Program, New York; 168pp. (NTIS PB-191 755).

Key words: data collection; hydrologic data; rainfall-runoff relationships.

Available rainfall-runoff data for partially sewered urban drainage catchments are identified to facilitate model development by researchers. Information on the availability of rainfall-runoff data from 64 developed partially sewered urban drainage catchments in the U.S. and 8 in Japan is summarised. The 64 catchments in the U.S. are concentrated in 8 states, and the locations of these instrumented catchments are shown by a map. Rainfall-runoff data for most of the catchments are available from the agen-

cies collecting the data. A summary of information on the 64 instrumented, highly-developed, partially sewered urban drainage catchments in the U.S. is presented. Additional details such as availability of data, how to obtain further information about catchments and data, gauge locations and maps of catchments are presented.

TURK, L.J. 1970: "Hydrology in the urban environment". In, Environmental geology - AGI short course lecture notes, Milwaukee, Wisconsin, 1970. (Washington, D.C. American Geological Inst.); 37pp.

Key words: urbanisation; urban hydrology; hydrographs.

Hydrologic principles of the runoff cycle and flood frequency are discussed. The effects of urbanisation on the hydrologic system are to increase unit yield, peak discharge and sediment yield, and to reduce lag time and recharge to ground water. In order to reduce risks and minimise problems in urban hydrology, it is necessary to institute floodplain zoning and corrective measures to reduce flood hazards. Geologists and geology teachers must educate laymen, lawmakers, and planners on the necessity of floodplain zoning.

TURNER, R.R. et al. 1975: "The effect of urban land use on nutrient and suspended solids export from North Florida watersheds". In, Mineral cycling in Southeastern ecosystems, Proc. of a Symposium, Augusta, Georgia, May 1974. (ed. F.G. Howell. et al.). U.S. Energy Research and Development Administration, Tech. Information Centre, ERDA Symposium Series, CONF-740513; p868-888.

Key words: landuse change; nutrients; suspended solids; dissolved solids; network design.

Two watersheds of similar size, geomorphology, and pedology representing forested-agricultural and residential-commercial (urban) land use were hydrologically instrumented to obtain comparative nutrient and suspended solids export data. Constituents measured included suspended solids, total dissolved solids, dissolved silicon, and dissolved nutrients (nitrogen and phosphorus). Observed differences in exports were related to the changes in hydrology associated with urban development, i.e. in streamflow rate, total volume of stream discharge, and the relative significance of various pathways of water movement, as well as to increased diffuse anthropogenic inputs in the urban watershed. Comparison of material loads exported by storm flow and low flow in each watershed suggested increased significance of storm events in materials export in the urban watershed.

U.S. ARMY CORPS OF ENGINEERS. 1970: "Urban hydrology". Proceedings of a seminar, Davis, Calif. U.S. Army Corps of Engineers, Hydrologic Eng. Centre; 287pp.

Key words: urban hydrology; water pollution sources; storm runoff; urban runoff; model studies; urban drainage; rainfall-runoff relationships.

Problems associated with runoff in urban areas derive not only from the necessity to handle runoff that enters the area from natural watersheds but also from the necessity to evaluate the effects of urbanisation on the actual runoff process. In general, the creation of impervious sections of the drainage area causes an increase in the total volume of runoff and in the peak rates of runoff. Furthermore, the drainage of natural ponding areas, the improvement of natural channels, and the realignment of drainage patterns can greatly increase the peak rates of runoff. Runoff from urban areas has increasingly become a quality problem in the receiving rivers. When rainfall washes the cities and surrounding areas, the resulting runoff can contribute to river pollution. Many cities have combined sewers, and overflows often contribute seriously to river pollution.

U.S. ARMY ENGINEER DIST. 1964: "Hydrologic relations in Hawaii". Engineering Studies, Project ES-182, Project Bulletin No.1, U.S. Army Engineer Dist., Honolulu, Hawaii; 7pp.

Key words: hydrographs; hydrologic data.

The report gives detailed annual and storm rainfall and runoff data on drainage areas of 2.61 and 5.24 sq miles in Kalihi Basin, Oahu Island, Hawaii. The larger area is 40 percent urbanised. Unit hydrographs have been derived for each storm period. The investigations are continuing.

U.S. DEPT. OF AGRICULTURE. 1960: "Urbanisation and changing land uses: a bibliography of selected references 1950-1958". USDA miscellaneous publication No.825, Washington, D.C.; 212pp. (All.38:825).

Key words: bibliographies; abstracts; landuse change; urbanisation.

This annotated bibliography was compiled as one of the early steps in an economic appraisal of impacts of urban growth on rural land use by the Farm Economics Research Division, Agriculture Research Service. Full cooperation was received from the Division of Bibliography, USDA Library. The bibliography was begun as a means of surveying the literature on landuse changes in the urban-rural fringe. The bibliography became a selection of references from many disciplines and the authors provide a sampling of available materials from all parts of the United

States for the years 1950 through 1958, together with selections from Canada, Great Britain, and a few other countries when these items seemed to be applicable to conditions here.

U.S. DEPT. OF AGRICULTURE. 1969: "Standards and specifications for soil erosion and sediment control in urbanising areas". U.S. Dept. of Agriculture, Soil Conservation Service, College Park, Md.

Key words: sediment control; erosion control.

A presentation of standards and specifications for sediment control measures in urban areas including installation and maintenance requirements. Each measure is defined, purpose of use given, application discussed and criteria presented. It is intended as a reference for consulting engineers and others in the design of sediment control features when land is undergoing development.

U.S. DEPT. OF AGRICULTURE. 1970: "Guidelines for the control of erosion and sediment in urban areas of the northeast". U.S. Dept. of Agriculture, Soil Conservation Service, Regional Tech. Service Centre, Upper Darby, Pa.

Key words: erosion control; sediment control.

A technical publication providing information on minimising erosion and sedimentation on land undergoing urban development. The guidelines are regional in scope and are generalised due to the wide variations in climate, topography, geology, soils and plant requirements. Most of the information is geared to SCS personnel assisting local people through soil and water conservation districts. The guidelines contain 134 pages with illustrations, tables and appendix.

U.S. DEPT. OF HEALTH, EDUCATION AND WELFARE. 1961: "Ground water contamination". Proc. Symposium on ground water contamination, April 5-7, 1961, Cincinnati, Ohio. U.S. Dept. of Health and Welfare, Robert A. Taft Sanitary Eng. Centre, Technical Report W61-5; 222pp.

Key words: ground water resources; aquifers; water pollution sources; leachate.

This report comprises the papers and summaries of the discussions presented at the symposium on ground water contamination, Cincinnati, Ohio, 1961, which include sessions on the hydrogeological aspects of ground water contamination, types of contaminants, specific incidents of contaminants in ground water, regulations and their administration and research on ground water contamination.

U.S. DEPT. OF HEALTH, EDUCATION AND WELFARE. 1964: "Pollutional effects of storm water and overflows from combined sewer systems". U.S. Public Health Service, Dept. of Health, Education and Welfare, Publication No.1246; 46pp.

Key words: storm runoff; combined sewers; overflows; pollution abatement.

Tabulated data are given from a preliminary survey of the polluting effects of storm sewage and overflows from combined sewers; most of the information was obtained by means of questionnaires, special agency reports, and interviews with municipal representatives throughout the U.S.A. The results indicate that most existing sewerage systems are inadequate to handle domestic sewage and storm water without excessive overloading of treatment plants, and the resulting overflows from the sewers are responsible for a considerable degree of pollution in the receiving streams; with increasing urbanisation such discharges are likely to increase. Various methods have been suggested for reducing the volume and polluting effects of storm overflows; of these, complete separation of sanitary and storm sewage would be the most effective but would be very expensive and difficult to implement in some areas. It is recommended that more detailed studies should be carried out on this problem.

U.S. DEPT. OF HOUSING AND URBAN DEVELOPMENT. 1969: "Proceedings of the National Conference on sediment control". U.S. Dept. of Housing and Urban Development, Environmental Planning Div., Washington; 54pp.

Key words: erosion; erosion control; sediment control; water pollution sources.

The proceedings contain a number of papers dealing with the sediment problem in urban areas. Case histories are given for several developing areas. Erosion and sediment control methods and technology are discussed for highways and urban areas. Particular emphasis is placed on sediment as a pollutant.

U.S. DEPT. OF THE INTERIOR. 1968: "Considerations for modeling urban rainfall-runoff-quality processes". In, Urban water resources research: systematic study and development of long-range programs of urban water resources research, first year report. Office of Water Resources Research, U.S. Dept of Interior, Washington, D.C.; pA1-A124.

Key words: rainfall-runoff relationships; data collection; mathematical models; storm runoff.

Current assessments of urban drainage construction requirements and current estimates of damage from urban storm water indicate a need for a research effort on urban rainfall-runoff-quality

relationships. Mathematical modeling is the method most useful for defining such relationships. Standard statistical techniques for analysing data are inadequate because of the lack of a data base. There is a considerable body of knowledge available for analysing the hydrology of natural basins. Much of this knowledge is transferable to the urban environment. More urban hydrologic data are needed. Data which exist now or will be collected should be made readily available for calibrating and testing mathematical models of urban hydrology. Research must be conducted both in the fields of model building and model assessment and in the way in which urban conditions affect the natural hydrologic environment.

U.S. DEPT. OF THE INTERIOR. 1970: "Sediment problems in urban areas". U.S. Geol. Survey circular No. 601-E; 7pp.

Key words: erosion; sediment transport; sediment control.

A seven page circular describing urban soil erosion, sediment transport and deposition problems. A few examples of probable solutions are presented.

U.S. DEPT. OF THE INTERIOR. 1971: "A national urban water resources research program". U.S. Govt. Printing Office, Washington, D.C.; 54pp.

Key words: urban hydrology.

On August 1, 1969, the Office of Water Resources Research submitted a proposed program of urban and metropolitan water resources research and recommended convening a conference of water resources practitioners to review the proposed program. A National Urban Water Resources Conference was convened at the Georgia Institute of Technology on March 17, 1970. Sixty one individuals participated in the conference, including academic researchers, consulting engineers, participants from business and industrial firms, and the representatives from federal, State, and local government agencies. The speakers directed the conference to the social, economic, political, legal, ecological, and water resource engineering problems of major significance in urban regions. Most critical needs are at interfaces, linkages, and interrelationships with physical, administrative, financial, social, political, and legal elements of urban systems.

U.S. DEPT. OF THE INTERIOR. 1971: "National conference on urban water research". Georgia Institute of Technology, Atlanta. U.S. Govt. Printing Office, Washington, D.C.; 31pp.

Key words: urban hydrology; watershed management.

This report contains the keynote and plenary session papers presented at the National Conference on Urban Water Re-

search, sponsored by the Office of Water Resources Research. Contents include introductory remarks, keynote address, resource development in the urban environment, the social consequences of natural resource development in urban regions, the economic consequences of natural resource development in urban regions, and engineering alternatives in natural resource development in urban regions.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1972: "Bibliography of water quality research reports, June 1972". Office of Research and Monitoring, U.S. EPA, Washington, D.C.; 45pp.

Key words: water pollution sources; bibliographies; industrial wastes; agricultural pollution; water pollution control; waste water treatment; sewage disposal.

A bibliography which lists publications in EPA Water Pollution Control Research Series. Citations appear under the following categories: municipal pollution, industrial pollution, agricultural pollution, mining pollution, other sources of pollution, water quality control, waste treatment and ultimate disposal, water quality requirements research.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1972: "Subsurface water pollution, a selected annotated bibliography". Parts I - III. Office of Water Programs, Washington, D.C.; 168pp, 174pp, 174pp. (NTIS PB-211 340-2).

Key words: ground water resources; water pollution sources; bibliographies; waste water disposal; leachate; salinity.

These three volumes contain selected annotated references to the literature on pollution of ground water associated with underground waste disposal, intrusion of saline water, and percolation from surface sources. Each volume also contains a significant descriptor index and a comprehensive index.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1973: "Environmental Protection Agency reports bibliography". Distributed by NTIS, U.S. Dept. Commerce, Virginia. (EPA-LIB-73-01; PB-223 693).

Key words: bibliographies; abstracts.

This bibliography contains citations, abstracts and author, corporate source, subject, contract, and title indexes for all U.S. Environmental Protection Agency and its predecessor agencies' reports contained in the NTIS collection as of April 1, 1973. A supplement will be issued in February, 1974 to include older reports which will be identified and included in NTIS during the remainder of the calendar year, as well as all new reports issued by the EPA during this time. The bibliography should provide sufficient information for any user to identify any EPA report

desired.

See also: (a) 1st supplement:- August 1974. (EPA-LIB-74-03; PB-234 215). This bibliography supplements the original one (EPA-LIB-73-01; PB-223 693) dated July 1973. It contains citations, abstracts and author, corporate source, subject, contract, and title indexes for all U.S. Environmental Protection Agency and its predecessor agencies' reports entered into the NTIS collection between April 1, 1973 and December 31, 1973. The original bibliography and this supplement should provide sufficient information for any user to identify any EPA report desired.

(b) 2nd supplement:- December 1974. (NTIS PB-238 800). This bibliography supplements the original one (EPA-LIB-73-01; PB-223 693) dated June 1973 and the first supplement (EPA-LIB-74-03; PB-234 215) dated August 1974. It contains citations, abstracts and author, corporate source, subject, contract, and title indexes for all U.S. Environmental Protection Agency and its predecessor agencies' reports entered into the NTIS collection in 1974. The original bibliography, and the first and second supplements should provide sufficient information for any user to identify any EPA report desired.

(c) 3rd supplement:- March 1975. (EPA 600/9-74-032). This bibliography is a current listing (updated to January 1975) of the Office of Research and Development's final reports on in-house, grant, contract, and interagency projects. Reports are indexed by Title, Program Area (subject), Performing Organisation, Personal Author, Report Number, and Grant, Contract, or Interagency Agreement Number to aid the reader in identifying reports of interest. Instructions on how to order copies are on the inside of the front cover.

U.S. GEOLOGICAL SURVEY. 1964: "Storm runoff from urbanised watersheds in Puerto Rico". Water Resources Division, U.S. Geol. Survey information release PR-9; 2pp.

Key words: flood discharge; flood forecasting; storm runoff.

The article gives determinations of peak flood discharges from the storm of June 5, 1964 at four points in the partially urbanised small drainage area of Quebranda Margarita. The areas varied in size from 0.087 sq mile to 2.42 sq miles.

U.S. GEOLOGICAL SURVEY. 1973: "Selected references, ground water contamination, the United States of America and Puerto Rico". U.S. Geol. Survey open-file report; 103pp.

Key words: bibliographies; water pollution sources; ground water resources; water pollution control; environmental effects.

In 1972 the U.S. Geological Survey, Water Resources Division, made a reconnaissance study of the location and severity of ground water contamination throughout the 50 States and Puerto Rico. During the course of that study a substantial list of references pertaining to ground water contamination was obtained. The references are listed alphabetically and are also indexed according to geographic areas, States, kinds of contamination, sources of contamination, and general discussions.

U.S. OFFICE OF WATER RESEARCH AND TECHNOLOGY. 1975: "Urbanisation and sedimentation: a bibliography, Volume 2". Water Resources Scientific Information Centre, U.S. Office of Water Research and Technology, Washington, D.C. WRSIC-75/207; 156pp.

Key words: urbanisation; bibliographies; abstracts; urban hydrology; erosion control; sediment yield; sediment transport; water pollution sources; watershed management.

This report, containing 96 abstracts, is another in a series of planned bibliographies in water resources produced from the information base comprising Selected Water Resources Abstracts (SWRA). The portion of the data base searched for this volume included 58,593 abstracts covering October 1971 through October 15, 1975 (Volume 8, Number 20). Author and subject indexes are included.

U.S. SOIL CONSERVATION SERVICE. 1970: "Controlling erosion on construction sites". U.S. Dept. of Agriculture, Soil Conservation Service, Agriculture Inf. Bulletin No.347; 31pp.

Key words: erosion control; sediment yield; erosion; landuse change.

Each year more than a million acres of land in the United States are converted from agricultural use to urban use. Erosion on land going into urban uses is about 10 times greater than on land in row crops, 200 times greater than on land in pasture, and 2,000 times greater than on land in timber. The trend towards large developments has left large cleared and graded areas exposed to erosion for long periods. Erosion and sedimentation can be controlled effectively and at reasonable cost. The principles of erosion control are: using soils that are suited for development; leaving the soil bare for the shortest possible time; reducing the velocity and flow of runoff; detaining runoff on the site to trap sediment; and releasing runoff safely. In applying these principles, the following practices are effective: selecting land favourable for the intended use; fitting the development to the site and providing for erosion control; using for open space and recreation those areas not well suited for urban development; developing large tracts in small units so that large areas are not left bare; grading at a minimum and removing few trees; controlling

runoff; protecting soil with mulch, crop covers, and with mechanical measures; constructing sediment basins; and establishing permanent vegetation and erosion control structures.

U.S. SOIL CONSERVATION SERVICE. 1975: "Urban hydrology for small watersheds". U.S. Soil Conservation Service, Technical Release No.55; 98pp. (NTIS PB-244 531).

Key words: landuse change; storm runoff; peak discharge; urbanisation.

A guide is presented for estimating the effects of landuse changes and structural measures on hydraulic and hydrologic parameters, runoff volume and peak rates of discharge.

U.S. WATER RESOURCES SCIENTIFIC INFORMATION CENTRE. 1972: "Subsurface water pollution: a selective annotated bibliography, Part II, saline water intrusion. Part III, percolation from surface sources". U.S. Office of Water Resources Research, Washington, D.C; p104-107, 161-162.

Key words: bibliographies; abstracts; ground water resources; leachate; salinity; water pollution sources; pollution abatement.

Subsurface Water Pollution is a selective bibliography produced by the Environmental Protection Agency from the computerised data base of the Water Resources Scientific Information Centre, U.S. Department of the Interior. This bibliography represents published research and development in water resources as abstracted and indexed in the semi-monthly journal, Selected Water Resources Abstracts (SWRA). This bibliography represents a search of a 33,980 item data base, covering SWRA from October 1968 through December 1971, and is published in three parts. The bibliography contains references to technology dealing with the prevention or abatement of pollution, litigation pertaining to incidences of pollution, and laws and regulations pertaining to the construction and operation of subsurface waste disposal facilities. The index is made up of a fraction of the descriptors and identifiers by which each paper in the bibliography has been indexed, and represents weighted terms that best describe the information content.

UNIVERSITY OF CINCINNATI. 1970: "Urban runoff characteristics". University of Cincinnati, Cincinnati. (NTIS PB-202 865; EPA-11024 DQU 10/70).

Key words: storm runoff; overflows; hydrographs; model studies.

This is an interim report on investigations for the development of a comprehensive storm water management model. Detailed information on the watershed characteristics and data on runoff quantity and quality have been compiled from a one-year study of a combined

sewer watershed of approximately 2380 acres in Cincinnati, Ohio. Collection of these data is planned to continue over a several year period. The information collected will be used to test and develop practical storm water management models.

UTTORMARK, P.D. et al. 1974: "Estimating nutrient loadings of lakes from nonpoint sources". Ecological Research Series, EPA, Washington, D.C. EPA-660/3-74-020; 121pp. (NTIS PB-238 355).

Key words: lakes; nutrients; water pollution sources; phosphorus compounds; nitrates; surface runoff; eutrophication.

Data describing nutrient contributions from nonpoint sources were compiled from the literature, converted to kg/ha/yr, and tabulated in a format convenient for estimating nutrient loadings of lakes. Contributing areas are subdivided according to general use categories, including agricultural, urban, forested, and wetland. Data describing nutrient transport by ground water seepage and bulk precipitation are given along with data for nutrient contributions from manure handling, septic tanks, and agricultural fertilisers. Nutrient content of urban runoff was the highest; forested areas were lowest.

VALLE, P.D.LA. 1975: "Domestic sources of stream phosphates in urban streams". Water Research, Vol.9(10); p913-915.

Key words: phosphorus compounds; water pollution sources; nutrients; detergents; water pollution; urbanisation; chemical analysis; data collection.

To assess the relationships between stream orthophosphate, stream polyphosphate concentrations, and possible domestic sources, a random sample of 24 drainage basins dominated by residential land use activities was studied. Stream orthophosphate and polyphosphate data were then correlated with the following variables: (1) mean garden fertiliser use (kg/yr), (2) mean phosphate detergent use (kg/month), (3) percent watershed households connected to city sewers, (4) precipitation phosphate concentration. When a multiple regression analysis was run on the phosphate data, 76 percent of the variation in stream orthophosphate concentrations were accounted for by the percentage of watershed households connected to city sewers parameter, while garden fertiliser use and precipitation phosphate content accounted for 4 to 2 percent of the variation respectively. In a similar analysis of stream polyphosphate concentrations, a combination of detergent use and the percentage of watershed households connected to city sewers accounted for 48 percent of the total variation of stream polyphosphate concentrations.

VICE, R.B. et al. 1969: "Sediment movement in an area of suburban highway construction, Scott Run basin, Fairfax County, Virginia, 1961-64". U.S. Geol. Survey water supply paper No.1591-E; 41pp.

Key words: sediment yield; erosion.

Movement of sediment during a period of intensive highway construction was studied in the Scott Run basin, Fairfax County, Va., from 1961 to 1964. The 4.54 square mile drainage basin, which empties into the Potomac River about 6 miles above the head of the Potomac Estuary, was the scene of highway construction covering 11 percent of the basin; other types of urban construction in the basin during this time are minor.

Sediment that moved with the flow was measured at the gauging station by a system of representative samples. These samples made it possible to document the sediment yield for 88 storm events representing the overland runoff. Analysis of streamflow and sediment transport during the period showed that: (1) the 88 events accounted for 37 percent of the runoff and 99 percent of the sediment movement in 3 percent of the time; (2) the highway construction areas, varying from less than 1 to more than 10 percent of the basin at a given time, contributed 85 percent of the sediment; (3) 38 percent of the sediment movement occurred during April, May, and June, and only 11 percent occurred during July, August, and September; and (4) on the basis of re-

sidual soil and stream sediment particle sizes, the amount of sediment eroded from areas of construction was about twice that transported from the basin.

Precipitation during the study was about 12 percent less than the long-term average. If normal precipitation had prevailed, the estimated gross erosion in the construction area would have been about 20 percent more than actually occurred, giving an average of 151 tons per acre per year, about 76 tons of which would be transported from the basin. This amount is about 10 times that normally expected from cultivated land, 200 times that expected from grassland, and 2,000 times that expected from forest land.

VICIAN, E.B. 1966: "Hydrologic study of an urban watershed in West Lafayette, Indiana". MSCE Thesis, Purdue University, June, 1966.

Key words: flood forecasting; peak discharge; data collection; analytical techniques; instrumentation.

Recently new scientific methods for predicting storm runoff from urban watersheds have been proposed to replace the inadequate rational formula. However, because of a lack of sufficiently accurate hydrologic data, the new methods have not been adequately tested to receive the confidence of practicing engineers. The first objective of this study, therefore, was the collection of hydrologic data and the evaluation of some of these new methods. The second objective of the research was the evaluation of the hydrologic measuring instruments in order that better instrumentation may be installed in other urban basins which may be used in future studies.

VISSMAN, W. 1966: "The hydrology of small impervious areas". Water Resources Research, Vol.2(3); p405-412.

Key words: storm runoff; hydrographs; urban drainage; rainfall-runoff relationships; peak discharge.

The rainfall-runoff relationships on several impervious urban drainage areas varying in size from about 0.4 to 1.0 acre were investigated. The effective storm pattern, divided into a sequence of 1-minute inputs, provided the basis for generation of a corresponding sequence of runoff outputs, which were combined to produce the total runoff hydrograph. The basic output is a unit hydrograph resulting from an effective rainfall input of 1 minute's duration.

VISSMAN, W. 1968: "Modeling of water quality inputs from urbanised areas". In, Urban water resources research: systematic study and development of long-range programs of urban water resources research, first year report. ASCE, app.A; pA79-103.

Key words: water pollution sources;

storm runoff; sediment yield; data collection; hydrologic data.

As a result of the neglect of water quality considerations, only a few efforts have been made to identify the water quality constituents of urban runoff. This paper summarises the data which have been obtained, the outlook for future data collection, the water quality models which have been used on large water courses and which could be adapted to urban drainage areas, the manner in which the urban drainage system relates to the larger regional drainage complex, the kinds of quality components which need to be considered in a generalised urban runoff water quality model, and a general orientation for developing useful water quality models for urban drainage systems.

VIESSMAN, W. 1968: "Runoff estimation for very small drainage areas". Water Resources Research, Vol.4(1); p87-93.

Key words: hydrographs; urban hydrology; storm runoff; rainfall-runoff relationships.

Analyses of hydrologic data from high-intensity short-duration storms on very small drainage areas having varying physical characteristics indicated that a 1 minute unit hydrograph could be used as the basis for generating runoff from an effective rainstorm input. The single parameter of the unit hydrograph (time constant K) was shown to be related to the physical characteristics of the drainage area. No evidence of the correlation between K and storm pattern was discovered. Procedures are given for estimating net storm inputs.

VIESSMAN, W. 1969: "Assessing the quality of urban drainage". Public Works, Vol.100(10); p89-92.

Key words: urban drainage; urbanisation; storm runoff; water pollution sources.

Recommendations are made for further study in the area of identifying sources and constituents of urban runoff through the development and testing of urban water quality models and through the national collection of urban water quality data. Possible sources of pollutants and constituents of storm water runoff are described with emphasis on a primary pollutant, sediment. Approaches to the development of water quality models are discussed.

VIESSMAN, W. et al. 1968: "The hydrology of an urban residential area". Paper presented at 7th National Fall Meeting of AGU, December 1968. Surface Water Hydrology. (See Trans. AGU, Vol.49(4); p677).

Key words: computer models; model studies; storm runoff; hydrographs.

A conceptual model incorporating the hydrologic and hydraulic phases of

storm water flows is used to estimate the runoff from a 23 acre residential area. The hydrologic model is designed to accept a variety of loss functions. Three of these are applied and the resulting hydrographs are compared. A study of the fraction of the total area contributing flow to the drainage system is discussed. This points out the need to identify more carefully the runoff producing elements of an urban drainage area. Prediction errors using the hydrologic model are generally less than 10 percent.

VIESSMAN, W. et al. 1968: "Urban hydrologic relationships". Publication No.6, Water Resources Centre, University of Maine, Orono; p1-17.

Key words: rainfall-runoff relationships; urban hydrology.

VIESSMAN, W. et al. 1970: "Urban storm runoff relations". Water Resources Research, Vol.6(1); p275-279.

Key words: storm runoff; model studies; data collection; rainfall-runoff relationships; urban hydrology.

A model incorporating the hydrologic and hydraulic phases of storm water flows to estimate the runoff from a 23-acre residential area has prediction errors that are generally less than 10 percent when the peak flow is used as the criterion for comparison.

VIESSMAN, W. and ABDEL-RAZAQ, A.Y. 1954: "Time lag for urban inlet areas". Technical Report No.19, Engineering Experiment Station, New Mexico State University, University Park, New Mexico.

Key words: model studies; storm runoff.

VIESSMAN, W. and GEYER, J.C. 1962: "Characteristics of the inlet hydrograph". J. Hydraul. Divn., Proc. ASCE, Vol.88(HY5); p245-268.

Key words: rainfall-runoff relationships; analytical techniques.

A relationship between rainfall and runoff for impervious areas is obtained. The significant variables included in the relationship are antecedent rainfall, storm intensity and pattern, and size, and shape and roughness of the inlet areas. Also, equations are obtained which can predict the peak rates of runoff and time of rise of the hydrograph. Also proposed is a method which may be used to predict the shape of a simple hydrograph. Data in the study came essentially from the Storm Drainage Research Project of the John Hopkins University, Baltimore, Maryland.

VISSMAN, W. and KEATING, W.R. 1968: "A runoff model for a composite urban area". Trans. AGU, Vol.49(1); p163.

Key words: mathematical models; flood forecasting; flood routing; hydrographs.

A linear storage model is used to estimate the runoff from a 23 acre residential urban area of approximately 50 percent imperviousness. Depression storage and infiltration are primary components of the model. Surface flows to seventeen individual collection points are computed and subsequently routed through an underground drainage system to the storm drainage outfall. The hydraulic system is represented by a linear channel. Actual and computed hydrographs are compared.

VIRGINIA WATER RESOURCES RESEARCH CENTRE. 1975: "Nonpoint sources of water pollution". Proceedings of a conference, Blacksburg, Virginia, May 1975, Virginia Polytechnic Institute and State University; 314pp.

Key words: water pollution control; turbidity; urban runoff; water pollution sources; erosion; combined sewers; bacteria; pesticides; agricultural pollution; nutrients; heavy metals; sediment yield; biochemical oxygen demand; nonpoint pollution sources.

The declared U.S. Congressional aim of zero polluting discharge of pollutants to navigable waterways by 1985 embraces nonpoint sources, whose control will present totally different problems from the upgrading of sewage treatment works. The 21 papers given at this conference considered 4 broad aspects of activity - agriculture, forestry, mining and construction. Some of the speakers drew attention to the considerable contribution from what they call 'natural pollution' (e.g. salt spray from the sea, sulphur and ashes from volcanic eruptions) and they conclude that nothing can be done about these.

VITALE, A.M. and SPREY, P.M. 1974: "Total urban water pollution loads: the impact of storm water". Report to the Council on Environmental Quality, Washington D.C., 1974; 183pp. (NTIS PB-231 730).

Key words: storm runoff; water pollution sources; surface runoff; urban runoff; combined sewers; solid wastes; nutrients; heavy metals; bacteria; dissolved oxygen; pollution abatement.

This analysis of engineer survey data from eight cities on the effects of storm events on water quality in the Delaware River estuary, estimates the quantities of pollutants entering receiving waters from cities, determines the proportions that can be attributed to other than sewage treatment plants, especially storm water related sources, compares the cost and effectiveness of alternative methods of reducing pollution from storm water, and discusses

the implication for policy decisions. Major findings of the study included: a large part of the water pollution load created by urban areas results from storm associated surface runoff, storm sewer discharges, sewer overflows, sewer leaks and treatment plant bypasses; pollutant materials include oxygen demanding material, settleable solids, nutrients, heavy metals and other toxic substances, and pathogens and bacteria; urban storm water has a severe impact on dissolved oxygen content in the receiving water; the pattern of storm events is such that the oxygen demand from urban runoff occurs both infrequently and intensely; and the average oxygen depletion due to typical storm events reaches 2 ppm, and the depletion lasts for substantial periods of time - from 8 to 12 days. Policy implications of this study include: both water quality planning and water pollution abatement programs need to be based on an analysis of the total need more federal incentive to identify and perform the comparatively inexpensive and cost effective sewer inspection, cleaning, and maintenance programs which could significantly reduce the discharge of pollutants; and, sewer separation is not a cost effective approach to the storm water problem.

VITTANDS, J.P. 1974: "Three case studies on the application of the storm water management model". In, Proceedings Short Course on the applications of storm water management models, University of Massachusetts, Amherst; p280-332.

Key words: model studies; overflows; water pollution sources; pollution abatement; combined sewers; waste water treatment; analytical techniques.

Three case studies are presented which employ the Storm Water Management Model. These involved sewer system modeling and improvements in Cleveland, Ohio; combined sewer overflow regulation in Middletown, Ohio; and combined sewer overflow regulation in metropolitan Boston, Massachusetts. For the purpose of the first study, only parameters needed to be added in order to use the model as an aid in determining alternative remedies for combined sewer overflows. The technique used was design by analysis with computer simulation employed to determine conditions in a sewer system during a storm. For the second study, dry-weather flows, wet-weather flows, and other data were combined to conduct a comprehensive engineering evaluation of pollution abatement relative to combined sewer overflows to the Great Miami River within Middletown. The model was used in the metropolitan Boston area to assess the combined sewer overflow problem and to determine possible means for pollution abatement during the planning process for sewer development during the next 80 years. About 24,000 acres of combined and separate sewer areas were modeled to quantify combined sewer overflow pollution in terms of quality

of discharge and amount of pollutants represented by BOD, suspended solids, and coliform bacteria.

WAANANEN, A.O. 1961: "Hydrologic effects of urban growth - some characteristics of urban runoff". U.S. Geol. Survey prof. paper No.424-C; pC353-6.

Key words: surface runoff; urban runoff; peak discharge.

Presents comparative runoff data from gauging stations with drainage areas of 88.9 square miles and 103 square miles on Onandaga Creek in Syracuse, New York, where the intervening area is city development. Also presents double mass curve of flows in Permanente Creek basin at Los Altos and Mountain View, California. Notes that urban development may affect flood flow substantially. Available records from urbanised areas in New Jersey, Michigan, Pennsylvania, and Virginia indicate that peak flows from developed areas average three to four times those from adjacent undeveloped areas. Analysis of mean annual flows in Connecticut indicates a two-fold increase in total runoff from drainage areas.

WAANANEN, A.O. 1964: "Urban development and hydrology". U.S. Geol. Survey open-file report; 12pp.

Key words: urban runoff; storm runoff; hydrographs.

Qualitative discussion of general effects of urban development on runoff and summary of quantitative findings by various investigators. Presents comparative runoff data for three basins ranging in area from 170 to 300 acres at Menlo Park, California, and selected storm runoff hydrographs.

WAANANEN, A.O. 1969: "Urban effects on water yield". In, Effects of watershed changes on streamflow. (eds. W.L. Moore; C.W. Morgan), Water Resources Symposium No.2, Centre for Research in Water Resources, University of Texas Press, Austin; p169-182.

Key words: urbanisation; streamflow; hydrographs.

The results of several studies are used to illustrate the progressive effects of urbanisation on water yield. Precipitation may increase with development, while decrease in concentration times and increase in impervious area will decrease infiltration and ground water recharge. The effects may be most marked during dry periods when flows are maintained by waste waters which may have been imported into the basin. Computer simulation may be useful in studying and estimating the effects of urbanisation over longer periods than of the records normally available.

WAITE, T.D. and GREENFIELD, L.J. 1975: "Storm water runoff characteristics and impact on urban waterways". EED-ASCE Speciality Conference, Gainesville, Florida, July 1975; 3pp.

Key words: nutrients; bacteria;

storm runoff; algae.

Land use forms in metropolitan Miami, Florida, were related to storm water runoff characteristics, and resulting water quality impact on the Coral Gables waterway. A 1-acre parking lot area and a 1-acre residential campus area showed much higher coliform counts and nutrient analyses (orthophosphate, ammonia-N, nitrite-N, and nitrate-N) than did a 251-acre residential and light industry area. Levels of most contaminants in the waterway increased with increased frequency of rainfall. Certain zones of the canal maintained much lower algal diversities than others, implying that only certain parts of the waterway are severely affected by runoff water.

WAKEHAM, S.G. 1977: "Hydrocarbon budgets for Lake Washington". *Limnology and Oceanography*, Vol.22(5); p952-957. —

Key words: organic compounds; urban runoff; water pollution sources; oil wastes; lakes.

Fluxes of hydrocarbons through Lake Washington showed that urban storm water runoff and river runoff were the major sources of petroleum hydrocarbons to the lake. Sedimentation was the primary removal process for these hydrocarbons.

WALESH, S.G. and VIDEKOVICH, R.M. 1978: "Urbanisation: hydrologic - hydraulic - damage effects". *J. Hydraul. Div., Proc. ASCE*, Vol.104(HY2); p141-155.

Key words: landuse change; flood discharge; model studies.

An effective conceptual approach to determining the consequences of landuse changes on flood flows, stages, and damage involves partitioning the watershed land surface into floodland and nonfloodland areas. A hydrologic - hydraulic - flood damage model consisting of a combination of continuous process and steady-state computer programs is presented as a potentially effective analytic tool. The model is used to assess the impact of seven combinations of floodland and nonfloodland development on a 136 sq mile (352 sq km) urbanising watershed in southeastern Wisconsin. Under conditions of complete urbanisation of the presently undeveloped floodland and nonfloodland areas in the watershed the 100-year flood discharge may be expected to increase, relative to existing conditions, by a median factor of 1.9; the predicted median increase in 100-year flood stages is 4.5 ft (1.4 m); and average annual flood damage for four flood-prone reaches may be expected to increase by factors of 2.4 to 8.5.

WALLACE, J.R. 1971: "The effects of landuse changes on the hydrology of an urban watershed". Georgia Institute of Technology, School of Civil Engineering, Report ERC-0871; 79pp. (NTIS

PB-206 426).

Key words: landuse change; flood discharge; rainfall-runoff relationships; storm runoff; low flow.

Historical changes in the pattern of land use and the effect of these changes on floods along Peachtree and Nancy Creeks, streams flowing through metropolitan Atlanta, Georgia, are analysed and discussed. Land use patterns in the watershed were determined at several points in time. Rainfall and runoff data were analysed to determine the changes in hydrologic characteristics of the watershed effected by the changes in land use. Clearly, urbanisation was found to affect the seasonal distribution of runoff. Overall, the study shows that urbanisation of the watershed has increased storm runoff in the dry months, decreased base flow in the wet months and significantly increased the peak runoff from summer storms.

WALLER, D.H. 1971: "Pollution attributable to surface runoff and overflows from combined sewerage systems". Final Report to Central Mortgage and Housing Corporation, Ottawa, Ontario; 168pp.

Key words: water pollution sources; combined sewers; overflows.

WALLER, D.H. 1972: "Factors that influence variations in the composition of urban surface runoff". *Water Pollution Res. in Canada*, Vol.7; p68-95.

Key words: waste storage; urban runoff; water pollution; surface runoff; leaves; sediment yield.

Variations in the composition of urban surface runoff in relation to rate of flow, time from start of storm, dry-period lengths, season, land use, leaves and litter, sediment, dustfall, city works practices, and roof runoff composition, are discussed. Effects of catch basins on storm water composition are considered. Results indicate that mean concentrations of urban runoff constituents do not provide an adequate description of runoff composition.

WALLER, D.H. 1975: "Urban drainage problems and possibilities". In, Annual Conference Proceedings of the Ontario Section of the AWWA, Pollution Control Assoc. of Ontario, and Ontario Municipal Water Assoc., Toronto, Ontario; p136-153.

Key words: urban drainage; urban runoff; surface runoff; turbidity; water pollution control; industrial wastes; mathematical models.

Problems associated with urban drainage are reviewed along with some proposed solutions. Changes in ground cover and surface topography that occur as a result of urban development are associated with a drop in ground water level, decreased streamflows during dry weather, and increased soil erosion which

results in surface water turbidity and sediment accumulation in lakes, storage basins, and sewage plants. Drainage problems associated with already developed urban areas include those associated with overloaded drainage systems and pollution problems due to combined sewer overflows, urban surface runoff, and municipal and industrial effluents. Solutions proposed for such problems include: careful land development which takes advantage of natural storage, combined sewer separation, source and collection system controls, storage systems which are capable of holding wet flow for treatment following storm periods, and treatment systems that are designed to handle wet weather flows. The value of using urban drainage system models for solving the above problems is also discussed.

WALLER, D.H. 1977: "Effects of urbanisation on phosphorus flows in a residential area". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p52-58.

Key words: model studies; nutrients; streamflow; phosphorus compounds.

A model represents, on an annual basis, water and nutrient flows into and through a residential system. Changing model parameters to represent alternative development patterns helps to illustrate the dramatic effects of urbanisation on nutrient flows. Analysis of sources and magnitudes of phosphorus discharges from a 1-ha residential area suggests that vegetation is the principal source of phosphorus, and that explicit consideration of individual sources may be a useful approach to prediction of phosphorus loads from urban areas.

WALLER, D.H. et al. 1974: "A comparative evaluation of two urban runoff models". Report to Urban Drainage Subcommittee, Toronto, Ontario; 40pp.

Key words: model studies; mathematical models; urban runoff.

WALLER, D.H. et al. 1976: "Urban drainage model comparison for a catchment in Halifax, Nova Scotia". Canada-Ontario Agreement on the Great Lakes Water Quality, Research Report No.43, Environmental Protection Service, Environment Canada, Ottawa, Canada; 35pp.

Key words: urban runoff; data collection; model studies; storm runoff; hydrographs; urban drainage; watershed management.

Rainfall-runoff data were collected for a 167.2 acre combined sewer drainage area at Halifax, Nova Scotia. These data were used to compare the performance of the U.K. Road Research Laboratory (RRL) runoff model and the RU-NOFF block of the U.S. Environmental Protection Agency Storm Water Management Model. Both models were capable

of producing creditable results for a sewerage system that included surcharged pipes and yielded runoff from pervious areas in major storms. Calculated peaks were generally earlier and higher than observed values. Agreement improved with the magnitude of storm events. Hydrographs from the models were more similar than were calculated and observed results, especially in larger storm events. The EPA RU-NOFF block required more computer time than the RRL model.

WALLER, D.H. and COULTER, W.A. 1976: "Winter runoff from an urban catchment (January to March 1974)". Environment Canada Research Program for the abatement of municipal pollution, Research Report No.41; 60pp.

Key words: urban runoff; suspended solids; snowmelt; hydrologic data.

Results are given of studies on winter runoff and snowmelt carried out from January to March 1974 in an area of Halifax, N.S., served by a combined sewerage system. Data are included on precipitation, dustfall, quantity and quality of snow, amount and composition of street solids accumulation and of sand used for ice control, composition of runoff, and composition and flow rate of dry weather flow and combined sewerage. The application of the data to development or testing of runoff models is discussed.

WALLING, D.E. 1974: "Suspended sediment production and building activity in a small British basin". In, Effects of man on the interface of the hydrological cycle with the physical environment. IAHS Publication No.113; p137-144.

Key words: urbanisation; sediment yield; suspended solids; hydrographs.

A study is being carried out on the influence of building activity on suspended sediment production from a small basin on the margins of Exeter. Records from the period August 1968 to March 1971, when the basin was essentially undisturbed, have been used to calibrate its response and to assess the changes that occurred during 1973 when 25 percent of its area was influenced by building activity. On average, sediment concentrations have increased 5 fold and sediment loads 5 to 10 fold.

WALLING, D.E. 1976: "Modification of hydrological processes consequent upon suburbanisation". In, IGU/IHP Symposium on man made transformations of the water balance, Leningrad, July 1976.

Key words: rainfall-runoff relationships; urbanisation.

WALLING, D.E. and GREGORY, K.J. 1978: "The measurement of the effects of building construction on drainage

basin dynamics". J. Hydrology, Vol.11(2); p129-144.

Key words: suspended solids; landuse change; sediment yield; erosion; analytical techniques.

The magnitude of the impact of building activity upon suspended sediment concentrations may be assessed by comparing samples obtained simultaneously at different points within one catchment or by comparing samples derived from two adjacent small watersheds, one of which serves as a control. In each case the suspended sediment concentrations are between 2 and 10 times, and occasionally up to 100 times, greater than the concentration obtained from undisturbed conditions. The form of the relationships obtained demonstrates the importance of variable source areas within the catchments. To assess the yields over time streamflow and sediment records are required and a small catchment has been instrumented for this purpose on the margin of Exeter, Devon. The catchment has been calibrated for a period of 17 months prior to building activity by deriving multiple regression equations relating peak flow, runoff amount and runoff percentage to precipitation characteristics at different times of the year, by evaluating unit hydrographs, by establishing suspended sediment rating curves, and by using two adjacent catchments as controls.

WANIELISTA, M.P. et al. 1977: "Nonpoint source effects on water quality". J. Water Pollution Control Federation, Vol.49; p441-451.

Key words: nonpoint pollution sources; point sources (pollution).

Results of a project to define the nature and extent of nonpoint source water quality responses are reported. Included are some details of a procedure to construct instrumentation that can automatically collect water samples in a way that reflects field conditions, water quality response curves related to point and nonpoint sources, and development of loading rates from nonpoint sources for urban and non-urban basins. A pollutant mass standard is proposed where appropriate, in addition to concentration standards. The work is useful as an aid to establish field measuring programs to determine the characteristics and extent of nonpoint and point source pollution. Results for two basins in central Florida are presented. A comparison of these results considered with other data indicates the necessity of site-specific studies.

WARD, M.A. (ed). 1970: "Man and his environment: Volume 1". Proc. 1st Banff Joint Conference on Pollution. The University of Calgary and the Engineering Institute of Canada, Pergamon Press; 196pp.

Key words: water pollution; air pollution effects; environmental effects; water pollution sources; industrial

wastes; pollution abatement; water pollution control.

The purpose of the first Banff, Canada Conference was to bring together all parties who have an interest in environmental pollution but at different levels; the politicians, the planners, the industrialists, the engineering profession, the biologists and the medical profession. It was hoped that the interchange of ideas between the various groups would lead to a clearer understanding of the whole problem by all and thus assist in its solution, in any given circumstances. Seventeen technical papers covering the political, legal, medical and some general aspects of the overall problem of pollution were submitted by prominent and concerned men from throughout Canada and the United States. These proceedings document the formal program of the conference. The main topics for the four sessions were as follows: (1) general; (2) water pollution, (3) and (4) air pollution and urban waste.

WARK, J.W. and KELLER, F.J. 1963: "Preliminary study of sediment sources and transport in the Potomac River basin". Interstate Comm. on the Potomac River basin, Washington, D.C., Tech. Bulletin 1963-11; 11pp.

Key words: sediment yield; erosion; water pollution sources.

A 2-year sediment study was made on the Potomac River basin to determine the magnitude of sediment loads of streams and the sources of sediment. Also studied were environmental factors affecting sediment yield. Computed average annual sediment discharge varies from 21 to 2,300 tons per square mile and can be attributed chiefly to variations in land use. Drainage basins with a high percentage of forest cover have low sediment yields. Areas undergoing urbanisation near Washington, D.C., have the highest yields.

WARNER, R.F. et al. 1977: "Changes in an urban water resource, an example from Sydney, Australia". Earth Surface Processes, Vol.2(1); p29-38.

Key words: urbanisation; waste water disposal; urban runoff; turbidity; flood discharge; bank erosion.

This paper examines present and future utilisation in the tidal section of the Georges River in the southern part of Sydney. Over the last 30 years, the physical characteristics of the river have changed as a result of urbanisation, changed hydraulic regime and sand dredging. Urbanisation has resulted in an increase in population from 190,000 in 1947 to 550,000. This has resulted in an increase in runoff, sediment input to the river and waste disposal. The change in hydrologic regime has resulted in a substantial increase in the magnitude and frequency of flooding which has increased erosion. Sand dredging has increased the channel capacity, enlarged the tidal prism and increased water turbidity. It has also

resulted in extensive bank erosion in the upper part of the river and extension deposition lower down as tailings are deposited. Although most of these changes have resulted in the deterioration of environmental quality, use of the river for recreation and as an urban amenity has increased.

WARNOCK, R.G. 1971: "A study of pollutional loadings from urban storm runoff". In, Proceedings of the 6th Canadian Symposium on Water Pollution Research, Toronto, Ontario.

Key words: storm runoff; water pollution.

WARNOCK, R.G. and LAGOKE, R.G. 1974: "Suspended sediments from urban development". In, Effects of man on the interface of the hydrological cycle with the physical environment, IAHS Publication No.113; p117-122.

Key words: erosion; suspended solids; sediment yield.

Urban development is accompanied by construction activity. The vegetative ground cover may be removed and the soil may be exposed to erosion as a result. Precipitation is an active agent of erosion and it may cause increased erosion in areas under urban development. In this study, some preliminary results are given for research on the increase in suspended sediments in streams draining lands on which urban development is taking place. The location of the study is in Quebec in the drainage basin of the River Ottawa. Suspended sediment loads in two streams after storm precipitation are correlated to storm precipitation amounts. One of the streams drains a rural area, the other drains an area which is being developed; both of the streams drain approximately the same size area and are near one another. The stream draining the developing area shows two to five times as large a suspended sediment load. Data from both streams show correlation of suspended sediment load with amount of storm precipitation, with the data from the developing area showing a considerably better correlation.

WASSON, B.E. 1972: "Effects of urbanisation on timing of flood peaks on Town Creek in Jackson, Mississippi". U.S. Geol. Survey open-file report; 3pp.

Key words: urbanisation; storm runoff; peak discharge; hydrographs; watershed management.

The abnormal sequence of flood peaks observed during two low-order floods on Town Creek in Jackson, Miss., is attributed to spot urbanisation. Flooding after general rains in March and April 1969 crested at downtown Gallatin Street before crests occurred at upstream measuring sites. Heavy urbanisation in the downstream part of the basin caused an abnormal flood peak sequence. Floodflow at Gallatin Street

is spread over a greater time span than flows in the lightly urbanised area upstream in the northwest parts of the city. Rapid runoff from the lower heavily urbanised part of the basin flows past the gauge before runoff from the lightly urbanised parts of the basin arrives. During floods caused by rainfall of longer duration than those described, the effects of nonuniform urbanisation probably will be less pronounced.

WATER RESOURCES SCIENTIFIC INFORMATION CENTRE. 1971: "Urbanisation and sedimentation: a bibliography". Water Resources Scientific Information Centre, Washington, D.C. Report No.WRSIC-71-203; 120pp. (NTIS PB-203 188).

Key words: urbanisation; bibliographies; abstracts; erosion; erosion control; sediment yield; storm runoff; water pollution sources; surface runoff; water pollution control.

The bibliography is a compilation of 116 abstracts of current and earlier pertinent reports, journal articles and other publications on urbanisation and sediment problems. The abstracts include full bibliographic citations and a set of descriptors from the water resources thesaurus. The bibliography was produced by computer retrieval from the information base of Selected Water Resources Abstracts (SWRA), which had 31,244 abstracts at the time of the retrieval. The Kwic method of indexing is used in which each significant word in the title is filed in alphabetical place. Using a few key words describing the subject matter of interest, one scans the middle rank for their presence, then the remainder of the title to determine relevance. The bibliography is arranged in ascending WRSIC accession number sequence.

WATER RESOURCES SCIENTIFIC INFORMATION CENTRE. 1977: "Heavy metals in water (excluding mercury), a bibliography". Office of Water Research and Technology, Washington, D.C. Volume 1: Report OWRT/WRSIC 77-201; 438pp. (NTIS PB-269 427). Volume 2: Report OWRT/WRSIC 77-205; 479pp. Volume 3: Report OWRT/WRSIC 77-206; 371pp. (NTIS PB-269 429). Volume 4: Report OWRT/WRSIC 77-207; 351pp. (NTIS PB-269 430). Volume 5: Report OWRT/WRSIC 77-208; 361pp. (NTIS PB-269 431).

Key words: heavy metals; bibliographies; analytical techniques; industrial wastes; metals; lead; toxicity; waste water treatment; zinc.

These reports are another in a series of planned bibliographies in water resources produced from the information base comprising Selected Water Resources Abstracts (SWRA). Author and subject indexes are included. Volume 1 contains 499 abstracts, Volume 2, 500, Volume 3, 419, Volume 4, 430, and Volume 5, 419 abstracts.

WATER RESOURCES SCIENTIFIC INFORMATION CENTRE. 1977: "Urban water planning, a bibliography, Volume 2". Office of Water Research and Technology, Washington, D.C. Report OWRT/WRSIC 77-269; 189pp. (NTIS PB-269 510).

Key words: abstracts; bibliographies; urban hydrology; urbanisation.

This report, containing 181 abstracts, is another in a series of planned bibliographies in water resources produced from the information base comprising Selected Water Resources Abstracts (SWRA). At the time of search for this bibliography, the data base had 104,878 abstracts covering SWRA through February 1977 (Volume 10, Number 4). Author and subject indexes are included.

WATKINS, L.H. 1956: "Rainfall and runoff". J. of the Inst. of Municipal Engineers, Vol.82(8); p305-316.

Key words: rainfall-runoff relationships.

This is an early report on a study of the effects of urbanisation on rainfall-runoff relations. Three years of record are analysed on a 5270 acre catchment near Harlow New Town in England which contains a stream gauge and three recording raingauges. The area was rural at the start of the study (1951), had 100 acres of paved area by 1953, and is expected to have 670 acres paved when complete.

WATKINS, L.H. 1962: "The design of urban sewer systems". Road Research Tech. Paper No.55, London (HMSO).

Key words: rainfall-runoff relationships; instrumentation; hydrographs; urban drainage.

A detailed report on research into the relation between rate of rainfall and rate of flow in sewers. A method (R.R.L. hydrograph method) was developed for the design of urban storm drains based on the study of 286 storms at 12 locations in England. Comparisons of results between the R.R.L., the rational, the tangent, and the unit hydrograph methods are presented. The 12 study areas and some new instrumentation are described. A computer program for case of solution is mentioned but not presented.

WATKINS, L.H. 1963: "The design of storm sewer systems". J. Inst. of Municipal Engineers (Britain), Vol.90; p337.

Key words: rainfall-runoff relationships; computer models; urban drainage.

This paper gives an account of research carried out by the Road Research Laboratory, in collaboration with the Hydraulics Road Research Station, and the Meteorological Office, into the relation between the rate of rainfall and the rate of runoff from urban areas. A

new method of calculating sewer sizes using a digital computer is described. Rainfall and runoff were recorded in 12 areas varying in type and size of development for 286 storms. The Lloyd-Davis formula, tangent method, and unit hydrograph method of calculating runoff are compared with the results obtained. At the present time programs exist for a Ferranti Pegasus computer, and computations can be carried out by the Road Research Laboratory.

WATKINS, L.H. 1966: "Runoff from combined rural and urban areas". In, River engineering and water conservation works, (ed. R.B. Thorn), Butterworths; p111-121.

Key words: urban runoff; analytical techniques; hydrographs.

Runoff from urban areas was formerly calculated by the rational formula (the Lloyd Davies formula). This has now been superseded by the R.R.L. Hydrograph method, similar to the U.H. method. This method is described together with a discussion of practical applications.

WATKINS, L.H. and YOUNG, C.P. 1965: "Developments in urban hydrology in Great Britain". Conference on urban hydrology research at Proctor Academy, New Hampshire, August 1965; 18pp. (See also as: DSIR RRL Note No.IN/885, HMSO, London, July 1965).

Key words: rainfall-runoff relationships; storm runoff; mathematical models; urban drainage.

This paper has been prepared for the Conference on Urban Hydrology Research at Proctor Academy, New Hampshire, U.S.A. in August, 1965. It describes research carried out by the Road Research Laboratory into the relation between the rate of rainfall and the rate of runoff from urban areas. The principal objective of the research was to produce a method of calculating the rate of storm runoff in sewer systems that would be accurate and reliable under as wide a range of conditions as possible. The work formed part of a larger program of research, in which the Hydraulics Research Station and the Meteorological Office took part, into the whole problem of designing surface drainage systems for urban areas. A method has been devised by the Road Research Laboratory to overcome the deficiencies in existing methods. It was found to be accurate and reliable for the calculation of runoff hydrographs and is based on broadly the same principle as the unit hydrograph method. A program for the electronic computer has been developed to enable this method to be used simply and economically for designing sewer systems. This program is now being widely used in Great Britain.

WATT, W.E. and KIDD, C.H.R. 1975: "QUORM - a realistic urban runoff model". J. Hydrology, Vol.27; p225-235.

Key words: urban runoff; mathematical models; computer models; hydrographs; flood routing. . .

QUURM, a mathematical model which simulates urban storm runoff for any given rainfall pattern, is described. A realistic and design oriented model QUURM employs the n-linear reservoir model to generate inlet hydrographs from the rainfall excess for each area type for each subcatchment. These inlet hydrographs are combined and routed through the sewer system using a modified time offset or progressive - average - lag method. The model has been applied successfully to an urban catchment in Kingston, Ontario, Canada.

WAUGH, J.R. 1975: "Review of the effects of urbanisation on hydrological characteristics of streams". Presented at N.Z. Hydrological Society Annual Symposium 1975, Auckland; 12pp.

Key words: urbanisation; urban runoff; water pollution sources; hydrographs; bibliographies.

In recent years a large number of reports have been published dealing with the effects of urbanisation on streamflow. In 1968 Leopold reviewed existing data and synthesised the data into a form useful for planning and design purposes. More recently, Hollis (1975) has extended the synthesis of reported results from U.S.A., Japan and Britain to provide further valuable information. The present paper summarises the more important effects of urbanisation, as reported in the literature, and also includes a comprehensive selected list of references.

WAUGH, J.R. 1975: "Magnitude and frequency of floods in the Northland - Auckland area and their application to urban flood design". Presented at N.Z. Hydrological Society Annual Symposium 1975, Auckland; 23pp. (See also as N.Z. Ministry of Works and Development, Water and Soil Technical Publication No.8, 1978; 14pp.).

Key words: storm runoff; flood discharge; flood forecasting; analytical techniques.

A considerable body of data on the effect of urbanisation on streamflow is now available from overseas. Reports by Leopold (1968) and Hollis (1975) synthesise the data from numerous sources to provide information in a usable form for planners and design engineers. This report is based on the notion that knowledge of rural flood frequency can be combined with the known effects of urbanisation on streamflow to produce useful design information for part of New Zealand.

Flood discharge-frequency-area curves have been derived for the Northland - Auckland area. These curves are based on actual streamflow data from 13 catchments in the region, supplemented with U.S. Geological Survey data for 13 streams in north coastal California. The curves are based on actual stream-

flow data, and hence do not involve the assumption that the rain-storm frequency is the same as the flood frequency. The information provided in this report is an initial summary of the available flood frequency data for the northern part of New Zealand. The author recommends in his conclusion that: (1) use be made of the extensive research results already available from overseas to avoid repetition of the costly flooding problems already becoming apparent in urban areas in New Zealand; and (2) limited research into the effects of urbanisation on streamflow is needed in New Zealand.

WEHMEYER, E.E. 1974: "Hydrologic data for urban studies in the Austin, Texas metropolitan area, 1972". U.S. Geol. Survey open-file report; 49pp.

Key words: urban hydrology; data collection; rainfall-runoff relationships; hydrologic data; urbanisation; storm runoff.

Hydrologic studies in the Austin urban area, Texas are made to determine the effects of progressive urbanisation on infiltration rates of peak discharge, and rainfall-runoff relations in the Waller Creek watershed. Rainfall and runoff data from the rural Wilbarger Creek watershed are used for comparative purposes in determining the effect of existing and progressive urbanisation in the Waller Creek watershed. Rainfall and runoff data are presented for the Waller Creek and Wilbarger Creek study areas for the 1972 water year (October 1, 1971, to September 30, 1972).

WEIBEL, S.R. 1969: "Urban drainage as a factor in eutrophication". In, Eutrophication: causes, consequences, corrections. National Acad. Science, Washington, D.C.; p383-403.

Key words: eutrophication; storm runoff; overflows; water pollution sources; nutrients; sewage treatment; combined sewers; urban drainage; urbanisation.

Storm water runoff and combined sewer overflows as sources of water pollution, including nutrient distributions are discussed. Maps show future urbanisation patterns and present distribution of states and their communities served by combined sewer systems. Tables showing average concentrations and computed annual amounts of constituents, including nutrients, produced per square mile by the several sources such as rainfall, community sewage, urban storm water runoff and combined sewer overflows, are presented. These indicate that all are significantly concentrated in some respect as to warrant consideration in appraising sources of pollution, particularly nutrients. In terms of relative production of nutrients per unit of area, community sewage heads the group, followed in order of decreasing unit production by combined sewer overflow, storm water runoff from a residential-commercial area and rain-

fall. Urban storm water runoff as a water resource is discussed. Comments on studies and practices representing the variety of efforts to control pollution from storm water runoff or combined sewer overflows are presented. Treatment of extraneous flows in sanitary sewers is also discussed. Government research contract and demonstration grant programs to provide assistance to qualified workers interested in contributing to methods for control of storm and combined sewer sources of pollution are outlined.

WEIBEL, S.R. et al. 1964: "Urban land runoff as a factor in stream pollution". J. Water Pollution Control Federation, Vol.36(7); p914-924.

Key words: flood control; water pollution control; urban runoff.

This paper is concerned with streamflow regulation for water quality control, particularly with the study of urban land runoff as a factor in stream pollution. This report is in the nature of an announcement of such a study by the Division of Water Supply and Pollution Control at the Robert A. Taft Sanitary Engineering Centre and a progress report on the status of this study.

WEIBEL, S.R. et al. 1966: "Characterisation, treatment and disposal of urban storm water". Third International Conference on Water Pollution Research, Munich: Paper No.15, Section 1; p329-343.

Key words: waste water disposal; waste water treatment; water pollution sources; storm runoff.

Field studies being conducted by the Robert A. Taft Sanitary Engineering Centre are directed to characterisation of rainfall and of urban storm water runoff in terms of quality and quantity for various urban environments. Concurrent studies in the Taft Sanitary Engineering Centre laboratory are under way to test the efficiency of sedimentation and chlorine disinfection on urban storm water runoff. Studies on hydrology, sewer system design improvements, and exploration of disposal methods will be undertaken. The present article summarises results from studies made thus far by the Sanitary Engineering Centre.

WEIBEL, S.R. et al. 1966: "Pesticides and other contaminants in rainfall and runoff". J. Amer. Water Works Association, Vol.58(8); p1075-1084.

Key words: agricultural pollution; nutrients; pesticides; bacteria; biochemical oxygen demand; water pollution sources.

Tabulated results are given of studies on the composition of rainfall and runoff from an urban area in Cincinnati, Ohio, and from a rural area near Coshocton, Ohio. Runoff from a field cul-

tivated with winter wheat was found to contain nutrients in concentrations much greater than the threshold values associated with algal nuisance, and also contained coliform organisms. However, faecal streptococci outnumbered faecal coliform organisms, indicating that the pollution sources were predominantly warm-blooded animals other than humans. A graph is given showing the hypothetical effects of crude sewage, sewage effluent after different degrees of treatment, and runoff from urban areas on the BOD of receiving streams; this indicates that while crude sewage has the greatest polluting effect at low flows, storm runoff becomes increasingly important as the degree of sewage treatment increases, emphasising the need to consider the effects of rainfall and runoff in pollution control programs.

WEISS, L.A. 1975: "Floodflow formulas for urbanised and nonurbanised areas of Connecticut". In, Symposium on watershed management held by the ASCE Irrigation and Drainage Divn., Logan, Utah; p658-675.

Key words: flood control; urban hydrology; flood forecasting; peak discharge; urbanisation.

Data from 28 precipitation-gauging stations and 105 stream-gauging stations, which measure streamflow from drainage basins ranging in size from 1 to 1,500 sq miles are used to analyse flood frequencies in urbanised and nonurbanised areas of Connecticut. The precipitation data are used to analyse rainfall frequency for 1-, 4-, 6-, 8-, 12-, and 24-hour storm durations in the State. They also form the base for preliminary magnitude and frequency isopleth maps of the rainfall intensities used as input for a regression analysis of flood flows. Regression analyses rating the 2-year and 100-year flood-flow frequencies for nonurbanised areas to geometric parameters of the drainage basin and to rainfall magnitude and frequency are based on data for 98 stream-gauging stations. The regression equations for nonurbanised areas are applied to urbanised areas by means of an adjustment for lag time based on the percentage of drainage area that is storm sewered.

WELLS, D.M. et al. 1971: "Variation of urban runoff with duration and intensity of storms". Water Resources Centre, Texas Technical University, Lubbock, Project Completion Report WRC-71-5 W72-00816; 161pp.

Key words: urban runoff; mathematical models; hydrographs.

A simulation model describes the quantitative and qualitative regimes of storm water runoff from urban watersheds. The urban runoff system consists of three basic subsystems: precipitation, runoff, and quality. Each of the three subsystems is mathematically modelled using probability and statistical techniques. Major flooding in the high plains of Texas is

associated with short-duration high-intensity convective storms. The model assumes these short-duration precipitation events are random and governed by a stationary probability distribution function. A bivariate log-normal distribution function fits the observed rainfall depths and durations for Lubbock, Texas. The runoff process is modelled by using the British Road Research Laboratory method, which assumes that all runoff is derived from interconnected impervious areas. Rainfall inputs are simulated by the Monte Carlo method. The outflow hydrograph is generated by single step reservoir routing. The total pollutant load is predicted by a multiple regression involving the storm characteristics and the antecedent conditions.

WELLS, D.M. et al. 1973: "Variation of the urban runoff quality with duration intensity of storms. Phase II". Water Resources Research Centre, Texas Technical University, Lubbock, Project completion report; 96pp.

Key words: urban runoff; mathematical models; bacteria; faecal coliforms; chemical oxygen demand; biochemical oxygen demand; solid wastes; suspended solids; nitrates; nutrients.

The variation of urban runoff quality was investigated with the duration and intensity of storms. The data obtained were analysed using stepwise linear regression to determine significant trends in how storm characteristics and antecedent conditions affect runoff quality. The project utilised a 223-acre watershed located within south-central Lubbock, Texas although the results should be applicable to other areas. Samples were analysed for total and faecal coliform, chemical oxygen demand, biochemical oxygen demand, total residue, volatile residue, total suspended solids, volatile suspended solids, pH, alkalinity, nitrate, nitrogen, and orthophosphate.

WELLS, D.M. et al. 1975: "Variation of urban runoff quality and quantity with duration and intensity of storms. Phase III. Volume 4. Project summary. Final report". Water Resources Research Centre, Texas University, Lubbock; 56pp.

Key words: urban runoff; mathematical models; hydrographs; storm runoff.

The three phases of the study during this period are reviewed and the major findings are discussed.

WENSTER, P. et al. 1975: "Diffuse communal pollution loads. Examples from Motala and Uppsala". Vatten, Vol.3; p274 (in Swedish).

Key words: water pollution.

environmental impacts and means of control". 8th Annual Henry M. Shaw Lecture Series in Civil Engineering, North Carolina State University; p14-19.

Key words: watershed management; environmental effects; water pollution control.

The importance of water pollution control and proper planning are examined, with the North Atlantic regional framework for the Hudson River/New York City water pollution problem as an illustration. Problems with assessment of environmental impacts, analysis of unrecorded pollution, and environmental research for water pollution control are discussed. Secondary waste treatment generally will not be sufficient to achieve satisfactory water quality in metropolitan area rivers. If these rivers are intrastate, the states should deploy sufficient resources to have real water quality plans prepared, either through a central state planning authority or a basin authority. Where intrastate basins are involved, the planning should be conducted by the EPA or some alternative agency.

WHIPPLE, W. (ed). 1975: "Urbanisation and water quality control". Proc. Symposium of American Water Resources Assoc., at Rutgers University, June 1975; 286pp.

Key words: urban runoff; watershed management; water pollution control; suspended solids; biochemical oxygen demand; nutrients; bacteria; heavy metals; organic compounds.

This is the report of a conference held at Rutgers University, as the annual symposium of the American Water Resources Association, with co-sponsorship of the Urban Water Resources Research Council, American Society of Civil Engineers. The program had a well defined technical objective, the developing technology of estimating the character and quantity of pollution from urban runoff. This goal is particularly urgent in view of the current initiation by the U.S. Environmental Protection Agency of planning for area wide studies of waste water management in many parts of the country, planning which by law must include consideration of nonpoint sources. Many participants, including the chairman and others from Rutgers University, have devoted a major effort over several years past to developing an understanding of this subject. In many of the papers, data were presented explaining the great variability of pollution during typical storm hydrographs, using experiences from various parts of the country, and indicating pollution loadings not only of suspended solids and biochemical oxygen demand, but also nutrients, hydrocarbons, heavy metals and coliforms. Various papers treated some broader approaches to water quality control.

WHIPPLE, W. et al. 1972: "Unrecorded pollution sources and optimum water quality systems". In, Proceedings of a National Water & soil technical publication no. 15 (1979)

WHIPPLE, W. 1973: "Water pollution:

tional symposium on costs of water pollution control, North Carolina Research Triangle Universities and EPA, Raleigh, North Carolina; p101-113.

Key words: organic compounds; urban runoff; water pollution sources; biochemical oxygen demand; industrial wastes; nonpoint pollution sources.

It is coming to be generally known that there are very large waste loadings in rivers in developed areas, over and above the recorded treatment plant effluents. The origins of unrecorded pollution in developed areas, the policy implications for regional water quality planning, and the method of modeling organic pollution by means of BOD mass balance analysis are discussed. Some 'background' waste loading occurs even in totally undeveloped areas. In level cropped areas and areas of individual family housing in New Jersey, BOD concentrations in dry weather averaged less than 2.0 mg/l and in wet weather less than 3.0 mg/l. In a residential area which has considerable industry, unrecorded dry weather BOD concentrations averaged 9 mg/l and wet weather BOD 17. Mass balance analysis will usually be required in order to determine unrecorded BOD in urban areas, unless the entire watershed is urban. The process is basically simple, but, for accuracy, account should be taken of the deviations of the BOD rate from the usually assumed first order reaction.

WHIPPLE, W. et al. 1974: "Unrecorded pollution and dynamics of biochemical oxygen demand". OWRR Project A-0259N.J., Water Resources Research Institute, Rutgers University, March 1974.

Key words: water pollution sources; biochemical oxygen demand; urban runoff; nutrients; model studies; nonpoint pollution sources.

Results are presented of a four year investigation of the dynamics of biochemical oxygen demand in polluted streams, and of unrecorded origins of such pollution. Data were obtained from watersheds of differing characteristics, including undeveloped woodlands, row crops, single family suburban housing and urban areas. Samples were taken over about a 2 1/2 year period, and analysed for both 5 day and longer period of BOD. It was found that single family suburban housing and row crops in flat land provide only a moderate increase of organic pollution over the undeveloped areas; but that urban watersheds tested are major pollution sources. Very large increases in pollution loading were found for days of rainfall as compared to dry days. A special study of Morristown, N.J. provided a provisional measure of per capita organic pollution to be expected in a clean urban area without major industrial activities. Frequency distributions of the BOD concentrations were prepared. Also, seasonal variations of the BOD loadings indicate that loadings much higher than annual average values could be expected for spring and early summer months. Studies were made of the variation of biochemical

oxygen with time, in order to apply to the water quality modeling of polluted streams. The classic first order model was found not to represent the actual situation very adequately. Other equations which have been suggested were also tested. Finally a new equation was derived which proved to be statistically more satisfactory, and relatively simple to apply. Certain new concepts are suggested for the application of BOD data to water quality modeling of polluted streams.

WHIPPLE, W. et al. 1974: "Unrecorded pollution from urban runoff". J. Water Pollution Control Federation, Vol.46(5); p873-885.

Key words: urban runoff; water pollution; biochemical oxygen demand.

Now that secondary treatment of recorded effluents is becoming widespread, more attention must be given to unrecorded pollution. Although runoff from sparsely occupied areas carries a certain waste load, much higher unrecorded pollution loadings originate as urban runoff. For relatively clean urban areas, largely residential with associated shopping and service facilities, an unrecorded biochemical oxygen demand loading of 0.02 to 0.03 lb/day/person (9 to 13.6 g/day/person) may be expected, with higher loadings from industrial and heavy commercial activities. Runoff from urban areas also contributes heavily to loadings of other pollutants. Grossly uneconomic plans may result when unrecorded pollution aspects are ignored.

WHIPPLE, W. et al. 1976: "Re-orientation of urban water resources research: executive summary". Proceedings of a workshop published by Water Resources Research Institute, Rutgers University; 15pp. (NTIS PB-251 908).

Key words: water pollution control; watershed management; urbanisation; urban runoff.

This is an abbreviated report of the findings of a workshop sponsored by the Universities Council on Water Resources and the Urban Water Resources Research Council of the American Society of Civil Engineers, held at Quail Roost, N.C. in July 1975. Recommendations for urban related research related to water quality propose development of strategy and methodology to contribute to remedying the various deficiencies, including those in the basic planning goals and approaches, better methods of measuring and evaluating pollution from urban runoff, methods of determining the environmental effects of pollution, alternative water quality enhancement approaches (other than effluent treatment), and a better institutional framework for areawide planning. There is no unified national policy for flood plain management. Goals of economic efficiency, of avoidance of social disruption, of financial aid after a disaster, and of better land use of flood plains are expressed implicitly in various Federal programs; but they

need analysis and interpretation in relevant and consistent terms. Much state legislation needs modernising to keep pace with new developments.

WHIPPLE, W. et al. 1976: "Re-orientation of urban water resources research: final report". Proceedings of a workshop published by Water Resources Research Institute, Rutgers University; 52pp. (NTIS PB-251 907).

Key words: water pollution control; watershed management; urban runoff.

This is a report of a workshop held at Quail Roost, N.C. and of final conclusions by an editing and steering committee, to develop an improved program of water resources research related primarily to problems in urban and urbanising areas. The workshop participants were widely representative of different disciplines, different regions, and of agencies and professional consultants as well as the academic community. The consensus was that the Federal approach to water resources has generally neglected the problems of metropolitan areas. Hydrological, water quality and ecological data are insufficient, technology to meet many problems is lacking, and existing institutions are ill adapted to the problems now being encountered. Particular emphasis in urban related research needs to be given to fields of water quality, flood plain management, and interfaces with land use planning and control. Strategies and basic objectives should be re-examined as well as the problems of planning to meet environmental objectives at reasonable cost. Programs of urban related water resources research are recommended.

WHIPPLE, W. et al. 1976: "Characterisation of urban runoff, New Jersey". Water Resources Research Institute, Rutgers University, New Brunswick, N.J.; 94pp.

Key words: water pollution sources; heavy metals; phosphorus compounds; urban hydrology; urban runoff; biochemical oxygen demand; nutrients; sediment yield; suspended solids; organic compounds; nonpoint pollution sources.

Pollution from urban runoff in the Saddle River, N.J., was determined. Specifically heavy metals, BOD, phosphates and suspended solids were measured. Techniques include use of single samples taken at short intervals throughout storm events. Results are compared to different types of land use, showing more pollution of all types from urban and industrial runoff than from residential area runoff.

WHIPPLE, W. et al. 1976: "Characterisation of urban runoff. Summary report". Water Resources Research Institute, Rutgers University, New Brunswick, N.J.; 25pp.

Key words: water pollution; heavy me-

tals; nutrients; suspended solids; urban hydrology; biochemical oxygen demand; urban runoff; organic compounds.

A joint effort to characterise urban runoff was conducted by five universities. The project objective was to contribute to improved technology for analysis of undesirable effects of unrecorded pollution in heavily developed areas, including heavy metals, nutrients, suspended solids and BOD. Use was made of individual examples and of continuous sampling throughout storm hydrographs.

WHIPPLE, W. et al. 1978: "Runoff pollution from multiple family housing". Water Resources Bulletin, Vol.14(2); p288-301.

Key words: urbanisation; urban runoff; storm runoff; heavy metals; ammonia; nutrients; lead; biochemical oxygen demand; water pollution sources; nonpoint pollution sources; phosphorus compounds.

Increasingly, residential development in urbanising areas is accomplished by large housing projects, composed of clusters of townhouses or garden apartments. It is hypothesised that the runoff from such developments should carry more pollution than that from the same number of housing units on separate plots, because the runoff is conveyed directly to drainage channels rather than being drained across lawns and gardens, which may absorb part of the pollutants. In order to evaluate this effect, storm event data were obtained from a planned unit development near Hightstown, N.J., using samples taken every 10 minutes throughout the storm at two different storm sewers. Results show heavy metals pollution about what had been anticipated, in accordance with the hypothesis given above, and BOD, ammonia and phosphates higher than predicted. The results are significant for areawide water quality planning in metropolitan areas, where projections of future pollution loadings depends upon the land use.

WHIPPLE, W. et al. 1978: "Characterisation of urban runoff". Water Resources Research, Vol.14(2); p370-372.

Key words: urban runoff; nonpoint pollution sources; point sources (pollution); water pollution sources.

Unrecorded pollution and nonpoint sources are too important to be neglected in water quality analysis, but the findings in the literature have been too scattered in place and time, too diversely reported, to have been fully accepted. Such pollution is usually referred to as nonpoint source pollution, or in developed areas as urban runoff, in spite of the fact that considerable parts of it are delivered by large storm sewers and may originate partly from unrecorded urban point sources. For convenience, this terminology is employed in this paper. The

work of each of five participating institutes was designed to evaluate urban runoff pollution from areas within that state and to relate those findings to differences in land use. Results have been reported in detail in the separate reports by the respective investigators. This report summarises these findings and then draws conclusions which the five principal investigators agreed upon.

WHIPPLE, W. and HUNTER, J.V. 1977: "Nonpoint sources and planning for water pollution control". J. Water Pollution Control Federation, Vol.49; p15-23.

Key words: biochemical oxygen demand; heavy metals; nonpoint pollution sources; water pollution control; urban runoff; water pollution; urban drainage; nutrients; organic compounds.

Nonpoint sources and urban runoff must be considered in the planning of water pollution control, but data are lacking and necessary technology is deficient. Shock loads of organic material from urban storm runoff can depress dissolved oxygen levels in receiving waters. Urban runoff is also high in sediment, phosphates, coliform count, and heavy metals. Frequent samplings throughout the storm are required to estimate pollution loadings. Methods are required to derive biochemical oxygen demand loadings during design storms, and also annual or seasonal averages, based upon discharge or rainfall frequencies. Some irregularities in pollutant occurrence are caused by illegal dumping. Heavy metals in storm runoff largely occur as particulate matter. This polluted sediment may settle into the bed of streams where it is taken up by benthic macroinvertebrates. Control of urban runoff pollution is apt to be very expensive. Planning approaches must be flexible, and not rely on any single, arbitrary standard.

WHITE, C.S. 1976: "Factors influencing natural water quality and changes resulting from land use practices". Water, Air and Soil Pollution, Vol.6(1); p53-69.

Key words: water pollution sources; dissolved solids; landuse change.

Samples of surface water and precipitation from Mount Taylor, New Mexico, were analysed for various chemical constituents, and it was found that the natural water quality was determined mainly by the contact with different geological formations. Water originating on or from basaltic terrain was of better quality and contained fewer dissolved solids than water from sedimentary terrain. Studies on the effects of various land use practices (grazing, irrigation, impoundment, clearing of vegetation, and road construction) showed that road construction had the greatest impact on water quality, but all had a significant effect on at least one dissolved constituent.

WIBBEN, H.C. 1976: "Effects of urbanisation on flood characteristics in Nashville-Davidson County, Tennessee. Water resources investigations (Final)". U.S. Geol. Survey, Nashville, Tenn., Water Resources Divn., USGS/WRD/WRI-77/026, WRI-76-121; 41pp.

Key words: computer models; flood discharge; urbanisation.

Streamflow data from 14 basins in Davidson County were extended in time by use of a digital model of the hydrologic system. The basins ranged in size from 1.58 to 64.0 square miles, and ranged in extent of manmade impervious cover from 3 to 37 percent. The flood-frequency characteristics were defined by weighting frequency curves based on simulated discharges with those based on observed discharges.

WIITALA, S.W. 1961: "Some aspects of the effect of urban and suburban development upon runoff". U.S. Geol. Survey open-file report; 28pp.

Key words: landuse change; storm runoff; hydrographs; flood discharge.

This paper consists of a hydrologic comparison between a 36.5 sq mile urban watershed and a 22.9 sq mile rural watershed. The lag times were found to be about 3 hr and 12 hr respectively while the urban flood peaks were about 3 times that of the rural. Total volume of runoff between the two basins was essentially the same.

WIITALA, S.W. et al. 1961: "Hydraulic and hydrologic aspects of flood plain planning". U.S. Geol. Survey water supply paper No.1526; 69pp.

Key words: flood forecasting; watershed management; urban hydrology; analytical techniques.

The valid incentives compelling occupation of the flood plain, up to and even into the stream channel, undoubtedly have contributed greatly to the development of the country. But the result has been a heritage of flood disaster, suffering, and enormous costs.

Flood destruction awakened a consciousness toward reduction and elimination of flood hazards, originally manifested in the protection of existing development. More recently, increased knowledge of the problem has shown the impracticability of permitting development that requires costly flood protection. The idea of flood zoning, or flood-plain planning, has received greater impetus as a result of this realisation.

This study shows how hydraulic and hydrologic data concerning the flood regimen of a stream can be used in appraising its flood potential and the risk inherent in occupation of its flood plain. The approach involves the study of flood magnitudes as recorded or computed; flood frequencies based on experience shown by many years of gauging station records; use of exist-

ing or computed stage-discharge relations and flood profiles; and, where required, the preparation of flood-zone maps to show the areas inundated by floods of several magnitudes and frequencies.

The planner can delineate areas subject to inundation by floods of specific recurrence intervals for three conditions: (a) for the immediate vicinity of a gauging station; (b) for a gauged stream at a considerable distance from a gauging station; and (c) for an ungauged stream. The average depth for a flood of specific frequency can be estimated on the basis of simple measurements of area of drainage basin, width of channel, and slope of streambed. This simplified approach should be useful in the initial stages of flood-plain planning.

Brief discussions are included on various types of flood hazards, the effects of urbanisation on flood runoff, and zoning considerations.

WILBER, W.G. and HUNTER, J.V. 1975: "Contributions of metals resulting from storm water runoff and precipitation in Lodi, New Jersey". In, Urbanisation and water quality control. Proc. Symposium American Water Resources Association, No.20; p45-54.

Key words: heavy metals; storm runoff; lead; zinc; water pollution sources.

The primary objective of this research was the evaluation and comparison of heavy metal loadings in storm water runoff with those associated with precipitation and secondary treatment plant effluents. Seven individual storm hydrographs were manually sampled at the storm sewer outfall during the project period. Heavy metal concentrations were found to vary significantly throughout runoff events and from storm to storm. In most cases, metal concentrations during the rising limb of the hydrograph were typically higher than those during the descending limb, suggesting a 'first flush' effect. Lead, zinc, and sometimes copper were the major contributors of heavy metals in the storm water runoff examined. Together these accounted for approximately 90 to 98 percent of the metals observed. Of this, lead and zinc were found to account for 84 percent of the total. The effect of variation of land use on storm water loadings was not evident during this sampling period and needs to be investigated further. The distribution of metals in precipitation samples collected in this study was found to be similar to the distribution in runoff, with lead and zinc predominating. It was noted that the lead:zinc ratio in precipitation was similar to the lead:zinc ratio in runoff for the same area, possibly suggesting similarity in origin of these metals. The annual metals yield resulting from storm water runoff, precipitation, and secondary treatment plant effluents was evaluated for the community of Lodi. On the basis of these calculations, storm water runoff was calculated to account for as much

as 86 percent of the total annual load of metals resulting from the 2.2 square mile area studied.

WILBUR, W.G. and HUNTER, J.V. 1977: "Aquatic transport of heavy metals in the urban environment". Water Resources Bulletin, Vol.13(4); p721-734.

Key words: heavy metals; urban runoff; water pollution; storm runoff; urbanisation; lead; zinc; metals.

A study has been conducted for the past two years on a 4.6 mile stretch of the Saddle River near Lodi, New Jersey. The primary objectives of this study were two fold; initially, the amounts of heavy metals being contributed to the Saddle River by storm water runoff, rainfall, and individual tributaries, etc., were investigated to better delineate the distribution of various sources of heavy metals to the aquatic environment. Secondly, a series of benthic deposits from the Saddle River were analysed to determine the fate of these metals once introduced into the receiving stream. A mass balance analysis of heavy metals in the Saddle River was performed to determine the amount of these materials contributed from unrecorded sources. The results of this study seemed to demonstrate the importance of considering the potential scouring of river sediments as a secondary source of metals in determinations of this type. The distribution of metals in precipitation samples collected in this study was found to be similar to that in runoff, with lead and zinc predominating. Relative concentrations of metals in precipitation as compared to those of storm water were relatively insignificant. Metal concentrations of bottom sediments were found to vary considerably from sample to sample.

WILDRICK, J.T. et al. 1976: "Urban water runoff and water quality control". Virginia Polytechnic Inst. and State University, Blacksburg. Water Resources Research Centre, Completion Report; 37pp. (NTIS PB-269 411).

Key words: urban runoff; pollution abatement; erosion control; storm runoff; water pollution sources; nonpoint pollution sources.

The 1972 Amendments to FWPCA specifically require that nonpoint sources of water pollution be considered in the development of water quality management plans for both local and areawide planning. Urban runoff often accounts for a major portion of the nonpoint pollution load. The purpose of this manual is to explore the possibilities available to urban areas for reducing levels of pollution from urban runoff. The manual contains an assessment of the seriousness of urban nonpoint pollution, a survey of the control methods available for combating nonpoint urban pollution, and some planning guidelines for developing an integrated strategy of controls. It is not a technical manual but rather was designed as a

general knowledge brochure.

WILKINSON, R. 1956: "The quality of rainfall runoff water from a housing estate". J. Inst. Public Health Engineering, Vol.55(2), Part 1; p70-84.

Key words: surface runoff; urban runoff; biochemical oxygen demand; suspended solids.

In 1954, a study of surface runoff from a 611 acre estate with separate sewers at Oxney, England, indicated BOD's up to 100 mg/l and suspended solids contents up to 2,045 mg/l. BOD's tended to increase with the length of the antecedent dry weather period up to 8 to 10 days, after which little further change developed. Computations were made to compare discharges to the river from the separate system with a hypothetical combined system wherein all flow would receive treatment. On the basis of assumed treatment plant effluent levels of 20 mg/l for BOD and 30 mg/l for suspended solids, it was concluded that the separate system reduced the BOD loading on the stream, but increased the suspended solids loading by 6 to 7 times. First flushes were not much more polluting than subsequent flows, except after long antecedent dry periods.

WILLEKE, G.E. 1962: "The prediction of runoff hydrographs for urban watersheds from precipitation data and watershed characteristics". Presented at the annual meeting, AGU, Washington, D.C. (See JGR Vol.69(9), 1962; p3610).

Key words: hydrographs; mathematical models; flood forecasting; peak discharge.

A method is presented by which the runoff hydrograph from an urban watershed can be computed from hyetograph and topographic characteristics of the watershed. The phi-index is used to obtain excess precipitation from total precipitation. The Muskingum method is adopted for routing excess rainfall through storage, with time of travel in the sewer a variable. The nine watersheds tested show that rainfall pattern, storage, and abstractions from rainfall are the principal determinants of the runoff hydrograph, and that good predictions can be obtained for both the peak and the total hydrograph.

WILLEKE, G.E. 1966: "Time in urban hydrology". J. Hydraul. Divn., Proc. ASCE, Vol.92(HY1); p13-29.

Key words: mathematical models; hydrographs.

This is a detailed study of runoff from urban areas less than two acres in size. The paper describes a method of hydrograph synthesis which uses a storage routing method to reproduce storm hydrographs on small watersheds.

WILLIAMS, P.W. 1976: "Impact of urbanisation on the hydrology of Wairau Creek, North Shore, Auckland". J. of Hydrology(NZ), Vol.15(2); p81-99.

Key words: urbanisation; landuse change; streamflow; watershed management.

Hydrological changes that have occurred as a consequence of the urbanisation of a small catchment of 11.4 sq km on the North Shore of Auckland are examined. The catchment is mainly developed on relatively impermeable siltstones and fine sandstones. It originally had a cover of subtropical evergreen rain forest but by 1940 was predominantly grassland and scrub. In 1959 almost three-quarters of the catchment was covered in bush, scrub and grassland, but by 1975 almost three-quarters of the basin was in urban uses. Hydrological records that commenced in 1962 indicate that up to the present the number of small floods contained within the channel have increased five times and that the number of larger floods has also increased, especially since the channel was lined with concrete. In general there appears to be an inverse relationship between flood frequency increase and flood magnitude. Flood hydrographs have also changed over the period, becoming much more peaked. Floods now strike more swiftly, rise higher and run off more rapidly than before urbanisation. Sedimentation has also increased. Suspended sediment concentration in storm drainage from a neighbouring East Coast Bays residential subdivision attained 59,000 mg/l, which is as high as any concentration ever recorded in New Zealand. In the Wairau Creek catchment, preliminary sediment rating curves were constructed for tributary streams draining areas of different land use. It was concluded that, even when residential areas become established, sediment yield remains unexpectedly high. Silt discharge from the Wairau basin contributes to sediment of the estuary at Milford and incurs considerable costs for de-silting the marina. Environmental costs arising from flooding and siltation are estimated, and it is concluded that the costs are not being borne by those that produce them, but are being transferred to the community.

WILSON, K.V. 1964: "Effect of urbanisation on floods at Jackson, Mississippi". U.S. Geol. Survey prof. paper No.501-A; p68.

Key words: peak discharge; analytical techniques; urbanisation.

Preliminary analysis of 10 years of record on streams draining the city of Jackson reveals that some flood crests are increased appreciably by urbanisation. K.V. Wilson and others have found that the increase ranges from 200 percent to 300 percent, depending upon the degree of development and the relative magnitude of the flood. The study reveals that the degree of the effect decreases with increasing flood magnitude.

WILSON, K.V. 1967: "A preliminary study of the effects of urbanisation on floods in Jackson, Mississippi". U.S. Geol. Survey prof. paper No.575-D; p259-261.

Key words: analytical techniques; flood discharge.

Comparison of flood frequency curves for three streams near Jackson, Miss., based on annual maximum floods for the period 1953-66, and for another stream for a shorter period, indicates that the mean annual flood for a totally urbanised basin is about 4 1/2 times that of a similar rural stream. It further indicates that the 50 year flood for such an urbanised basin is about three times that of a rural stream.

WISEMAN, R. and MIKOLS, D. 1975: "Flood plains and urban development: an annotated bibliography". Council of Planning Librarians, Exchange bibliography, No.893; 24pp.

Key words: storm runoff; urban runoff; bibliographies; abstracts; watershed management.

The large amount of research published in the civil engineering and hydrology journals and by various governmental agencies dealing with flooding is narrowed in scope so that inclusions represent only urban related studies. The literature from planning, geography, and other fields of urban study are treated in a similar manner, i.e. only those references concerned with flood plains are reported. The bibliography is partially annotated, arranged alphabetically by author and divided into seven subject headings: management; land use development; damage and insurance; human occupation and perception; techniques; hydrology; and, effects of urban development on flooding.

WISCHMEIER, W.H. et al. 1971: "A soil erodibility nomograph for farmland and construction sites". J. of Soil and Water Conservation, Vol.26(5); p189-192.

Key words: erosion; sediment yield.

A new soil particle-size parameter was found that permitted a drastic reduction in the number of soil parameters and interactive terms previously needed for soil erodibility determination. A simple nomograph provides a convenient technique for calculating the universal erosion equation's factor K for successive subsoil horizons as well as surface soil. Only five soil parameters need be known: percent silt and very fine sand, percent sand to 0.10mm, organic matter content, structure, and permeability.

WISNER, P.E. et al. 1975: "Interfacing of urban runoff models". In, Second Annual National Conference on Environmental Engineering Research, Development and Design; 1p.

Key words: storm runoff; mathematical models; computer models; model studies; urban runoff.

Since a detailed continuous simulation for urban planning is expensive, a simple continuous simulation model in conjunction with a detailed single-event model is used. The package consists of a data processing model, a modified ACE STORM model, and the EPA Storm Water Management Model (SWMM). The data processing model abstracts the required information from the Canadian Climatological Data Banks and generates input data for the modified STORM model, which then identifies critical events and their probability of occurrence. The modification consisted in adding a new snowmelt subroutine. The SWMM is then applied, resulting in good definition of critical storms and antecedent conditions. The SWMM offers a more detailed and exact simulation and makes possible evaluation of various pollution abatement alternatives. The results of simulations are presented and compared with field measurements. Recommendations for the interfacing of models are offered.

WISNER, P.E. et al. 1976: "Application of STORM and SWMM for assessment of urban development alternatives in Canada". In, EPA Conference on Environmental Modeling and Simulation; p79-80.

Key words: urban runoff; urban drainage; model studies; computer models; flood control; hydrologic data; water pollution control.

STORM was employed to simulate quality of runoff involving a continuous analysis of the accumulation and washoff of pollutants within a watershed in a typical developing community in Ontario. FROUT was used to study the runoff peaks for the 25-, 50-, and 100-year storms. This first stage of the study was used for preliminary screening of a number of development alternatives and to demonstrate the effects of storage and treatment on the reduction of pollutant loading on the receiving water. Lumped SWMM was applied to demonstrate the first flush effects of pollutant loading during critical storm events.

WISNOVSZKY, I. 1972: "Assessment of models suited for the hydrologic analysis of urban storm drainage". Hidrológiai Közlemény, Vol.52(10); p443 (In Hungarian).

Key words: model studies; urban runoff; storm runoff.

Models for the analysis of urban storm water runoff are evaluated. In its present state, the Rational Formula is not adaptable to urban runoff conditions and must be modified for this specific use. The Tholin-Keifer model, developed originally for Chicago redevelopment programs, can be adapted to other urban conditions since the dimensioning of the drainage system is based on the most probable form of precipitation distribution with respect to time. Finally, the computerised

Narayana-Riley model, operating with regression analysis for the determination of relationships between area characteristics and specific runoff load, constitutes a generally acceptable design procedure.

WITTENBURG, H. 1975: "A model to predict the effects of urbanisation on watershed response". Paper in proceedings of the National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Ky.

Key words: storm runoff; rainfall-runoff relationships; computer models.

Storm runoff from partially urbanised catchments cannot be a homogeneous event. In general it is the response of two different systems, i.e. pervious and impervious areas, to rainfall input. A model for the separation and simulation of these components was developed on the basis of two parallel cascades of linear reservoirs. Optimum model parameters were found by a search technique for about 230 flood events in 4 catchments over a period of 21 years with increasing urbanisation (Ruhr District in West Germany). It is shown by the analysis of the parameters that the method is able to predict urbanisation effects on watershed responses.

WOLMAN, M.G. 1964: "Problems posed by sediment derived from construction activities in Maryland". Report to the Maryland Water Pollution Control Commission, Annapolis, Md; 125pp.

Key words: sediment yield; erosion; sediment control.

WOLMAN, M.G. 1967: "A cycle of sedimentation and erosion in urban river channels". Geografiska Annaler, Vol.49A; p385-395.

Key words: erosion; landuse change; sediment yield.

Historical evidence and contemporary measurements in the Piedmont of Maryland show successive changes in land use accompanied by changes in sediment yield and in the behaviour of river channels. Sediment yields from forested areas in the pre-farming area appear to have been less than 100 tons per square mile per year. Yields from agricultural lands in the same region at a later time range from 300 to 800 tons per square mile on large drainage areas. Areas exposed during construction can produce sediment loads in excess of 100,000 tons per square mile per year. Increased runoff from urban areas, coupled with a decline in sediment yields to values on the order of 50 to 100 tons per square mile, promote continued bank erosion and channel widening. Raw banks adjacent to coarse cobble bars and widespread deposits of flotsam and debris attest to the flood regime of urban rivers. Canalisation in concrete does not eliminate such debris nor does it eliminate deposition

of sediment.

WOLMAN, M.G. 1975: "Erosion in the urban environment". Hydrol. Sciences Bulletin, IAHS, Vol.20(1); pl17-125.

Key words: erosion rates; streamflow; sediment yield; channel erosion.

Urbanisation and accompanying construction increase erosion rates from five to 200 times or more in the eastern United States, and sediment yields in streams by comparable amounts. Data from the United Kingdom, Japan, Canada, and Mexico suggest roughly similar ranges. Increased discharge from urban areas combined with increases in sediment concentration on the order of 2 to 50 fold are demonstrated in individual storms and in seasonal and annual variations in the UK. Potential for erosion below dams parallels a similar potential from urbanised areas after construction. Nomograms relating area under construction, basin area, and erosion rates provide useful tools for management. Additional information is needed on sediment transport by storm rainfalls of varying frequency and magnitude, on accumulation and movement of sediment in channels and recovery of stream biota, and on channel enlargement resulting from urbanisation.

WOLMAN, M.G. and SCHICK, A.P. 1967: "Effects of construction on fluvial sediment: urban and suburban areas of Maryland". Water Resources Research, Vol.3(2); p451-464.

Key words: erosion; sediment yield; erosion rates; waste dilution; waste storage; sediment control; urbanisation.

The equivalent of many decades of natural or even agricultural erosion may take place during a single year from areas cleared for construction. Areas undergoing rapid development near Baltimore, Maryland, and Washington, D.C., lie on the coastal plain and piedmont, with slopes generally of 1-10 percent but sometimes of 20 percent and more. Soil is deep, and the annual precipitation of 42 inches (1100 mm) is evenly distributed, with high summer intensities. Average sediment yield is 200-500 t/sq km/yr (80-200 t/sq km/yr), with predominantly wooded watersheds supplying sometimes even less. Intensive farming 50-80 years ago caused yields of up to 1000 t/sq km/yr (400 t/sq km/yr), but such high yields are no longer present owing to the continuous decline of farm acreage in the metropolitan periphery. Sediment concentrations from areas undergoing construction ranged from 3000 to over 150,000 ppm, whereas in natural or agricultural catchments the highest comparative concentration was 2000 ppm. In terms of annual values, yields from construction areas range from several thousand to a maximum of 140,000 t/sq km/yr (i.e., up to 55,000 t/sq km/yr) from a small area. Sediment yield is roughly 700-1800 tons per 1000 increase in population. Progressive urbanisation effects an initial rise in the

total sediment, soon followed by a steady decline. Total yield also declines with increasing drainage area as a result of dilution from waters draining urban and other land not actually under construction. Observations demonstrate that sediment storage occurs on construction sites as well as in valley bottomlands.

WOOD, S.R. 1975: "A catchment simulation model developed for urban and urbanising catchments with particular reference to the use of automatic optimisation techniques". In, Modeling and simulation of water resources systems (ed. G.C. Van Steenkiste), North Holland Publ. Co.; p209-217.

Key words: urban hydrology; urban runoff; mathematical models.

Hydrological design techniques for use in an urban environment have developed relatively little since the introduction of the "rational" method nearly a century ago. This paper describes the structure and development of a simulation model for use in an urban environment, with particular reference to the use of automatic techniques for the optimisation of the model parameters. Several of the shortcomings of the optimisation methods have been outlined, and ways of overcoming them tried. Results of the use of the optimised model on two British catchments have been briefly shown.

WOODS, M.B. 1975: "Urban runoff characteristics in Waynesboro and Blacksburg, Virginia". MSc Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Va.; 110pp.

Key words: urban runoff; rainfall-runoff relationships.

WOOLRIDGE, D.D. et al. 1975: "Urban storm runoff, Puget Sound region, Washington". Washington Water Research Centre, Pullman, Completion Report; 182pp. (NTIS PB-242 304).

Key words: flood forecasting; urban runoff; storm runoff; peak discharge.

Peak storm discharge had the flood flow of a 225-year storm on an intensely developed small urban watershed when other streams with lesser urbanisation had usual winter runoff. Mathematical relationships which predict mean daily discharge from precipitation show storm flow yields have increased from 130 to 185 percent over the past decade. These increases in flow range from 0.5 to 0.9 cubic feet per second per square mile per year, based on current trends. In area-inches these range from 0.6 to 1.86 inches of increased runoff from small basins. Common law of surface water rights of the State of Washington has established that owners of lower land have the right to prevent upper land owners from burdening a natural watercourse with a quantity or velocity of water beyond its capacity. Governmental entities are subject to

the same rights and liabilities in their public works. Governmental entities may constitutionally exercise regulatory or policy powers to impose burdens on land ownership and on construction of improvements where such regulation preserves or promotes public health, safety or general welfare. Counties and cities have statutory and constitutional power relating to both flood and surface waters. Considerable progress has been made in recent years in regulation and assessment of responsibilities for control of storm runoff. Improved control of storm runoff could be achieved by requirements for clearing and grading permits accompanied by an environmental assessment of the impacts of the proposed action on quantity, quality, and timing of storm flow. On site storage of storm water in excess of natural flow must be provided in all developments.

WOOTTON, R.M. and MEIN, R.G. 1976: "Development of a continuous urban rainfall-runoff model". In, Inst. of Engineers Hydrology Symposium, Sydney; p88-92.

Key words: urban runoff; mathematical models; urban hydrology; rainfall-runoff relationships.

In order to overcome the limitations of discontinuous models of the rainfall-runoff process caused by the assumption of average antecedent conditions, a continuous model has been developed and tested using data from Yaralumba Creek catchment (Australian Capital Territory). This model simulates the soil moisture movement between storms and thus enables reasonable estimates of the antecedent conditions for any event. The infiltration component uses the Green-Ampt model, extended to simulate redistribution, and uses the Road Research Laboratory method for routing from pervious and impervious areas.

WORLD METEOROLOGICAL ORGANISATION. 1970: "Urban climates". Proc. WMO Symposium on urban climates and building climatology, Brussels. Tech. Note 108, WMO-No.254. T.P.141; 390pp.

Key words: weather modification; air pollution effects.

In 1968 a symposium was held on urban climates and building climatology. Mesoscale airflow systems above urban areas are important not only in themselves but also in other aspects of urban climatology, such as to the temperature and pollution fields. Sharp marginal temperature gradients, especially on the leeward side of towns, may be partly owing to centripetal winds. Urban temperatures, like other measures, are clearly closely related to very local conditions, especially on calm, clear nights. In highly polluted areas adsorption by gasses and aerosols can probably result in heating rates in excess of 5 degrees centigrade per day which could not be compensated by stronger infrared cooling. In consequence, there could be a loss, beneath

polluted city atmospheres, of up to one half of all visible radiation and two thirds of ultraviolet radiation. Three main factors may thus be the cause of urban changes in precipitation. These are additional condensation nuclei, increased turbulence because of increased surface roughness, and thermal convection resulting from higher temperatures. Because of these influences, a number of cities have more rain days, more thunderstorms, and more total precipitation than the country areas around them.

WRIGHT, K.R. 1969: "Multi-means effort for urban flood control". Paper presented at the International Conference on Floods: their protection and defense of the soil, held by the Academia Nazionale dei Lincei, Rome, Italy.

Key words: flood control; storm runoff.

An effective way to deal with this problem is by a multiple means effort based on a basic urban drainage policy. Such a policy should be formulated in lieu of various inputs, principles of urban drainage, hydrology and hydraulics of small urban basins, and accurate knowledge of urban drainage law. Urban drainage policy must also recognise that urban drainage is directly related to the total urban system. The planning process is based on the concept of two urban drainage systems. The initial drainage system, typically storm sewers, is designed to handle storm runoff expected to occur once every 2-10 years. The major drainage system is the area which must accommodate the 100-year runoff and includes both natural and artificial elements. Other specific aspects of urban drainage planning discussed are functions of storm sewers and streets, hydraulic structures, inlets and culverts, storage and floodproofing.

WU, J.S. and AHLERT, R.C. 1978: "Assessment of methods for computing storm runoff loads". Water Resources Bulletin, Vol.14(2), p429-439.

Key words: nonpoint pollution sources; storm runoff; analytical techniques.

Nonpoint source pollution has been characterised, in magnitude and in concentration of pollutants, by intermittent and impulse-type discharges into receiving waters, causing shock loading problems for the ecosystems of these water bodies. The quality of storm runoff appears random and complex in nature. There are not yet universally acceptable assessment tools for analysis and evaluation of the impacts and contributions of pollutant loads to receiving waters. This paper reviews and recommends methods for predicting storm runoff loads. The state-of-the-art for storm runoff pollution prediction includes: zero-order, direct, statistical and descriptive methods. For transient water quality analysis of individual storm events, it is essential to have an efficient sampling program for data collection and a technically sound

method of data analysis. Intensive sampling is considered necessary to a detailed time history of runoff flows and loadings within a storm and for a limited number of storms. Homogeneous-land use and statistical-synthetic approaches are recommended as accurate and practical methods for storm-runoff-load prediction. These two approaches are event-oriented, predicting time-varying runoff loads for transient water quality analysis, utilising data collected from intensive sampling programs.

WULKOWICZ, G.M. and SALEEM, Z.A. 1974: "Chloride balance of an urban basin in the Chicago area". Water Resources Research, Vol.10(5); p974-982.

Key words: chlorides; waste dilution; model studies; point sources (pollution).

During the relatively mild winter of 1972-1973, 20,260 t (metric tons) of NaCl and 40 t of CaCl₂ were spread on the roads within the Salt Creek basin of the Chicago metropolitan area. Over 600 water samples were collected from 11 creek sites within the basin during the salting season. Chloride concentration in the water varied from 35 to 1530 mg/l during the sampling period. Road salt chloride content of the water at any time is dependent on (1) temperature and colligative properties of NaCl, (2) duration of precipitation events, and (3) dilution capacity of the stream. Models are presented for three subsections of the basin based on the relationship between chloride concentration and discharge of the creek during nonsalting periods. A fourth subsection could not be modelled because of insufficient data. Monthly chloride budgets for all four subsections from November 1 through April 30 show that between 55 and 75 percent of the road salt chloride was removed by the creek from the various subsections. Changes in the percentage of chloride removed correlate well with the following indicators of the degree of urbanisation: (1) percentage of area as streets, (2) highway density, (3) population density, and (4) road salt application per unit area. Sixty-two percent of the chloride was removed by the creek from the basin during the first 6 months of the study period. Further sampling after April 30 but before salting commenced in December 1973 indicates that an additional 10 percent of road salt chloride was removed from the basin by the creek during the second 6-month period. A portion of the remaining chloride was removed through the ground water, and the rest was retained in the basin because of lag mechanisms.

WULLSCHLEGER, R.E. et al. 1975: "Methodology for the study of urban storm generated pollution and control". EPA, Cincinnati, Ohio, Draft Report, Contract No.68-03-0335.

Key words: water pollution control; storm runoff; analytical techniques.

YAMAMOTO, S. and HIDA, N. 1974: "A preliminary study on ground water pollution in the western suburb of Tokyo metropolis". Science Reports of the Tokyo Kyōiku Daigaku, Section C, Vol.12(115); p63-73.

Key words: ground water resources; aquifers; leachate; heavy metals; sewage disposal.

The paper discusses contamination of ground water by domestic sewage, landfill and heavy minerals. Results are summarised as: (1) an exponential rise of chloride content and conductivity of ground water, and a slow rise of sulphate were observed in the western suburbs of Tokyo metropolis, indicating contamination of this area; (2) the ground water basin was checked for location and size and the historical landuse changes determined from aerial photographs; (3) pollution of ground water was caused by increasing urbanisation of the area, with delayed sewage treatment systems.

YEH, T.C. and SALEEM, Z.A. 1978: "Effects of urban development patterns and seasonal variations on runoff". Paper presented at Annual Spring Meeting of the AGU, Washington, D.C. EOS, Vol.59(4); p272.

Key words: mathematical models; hydrographs; storm runoff; flood discharge; low flow; landuse change.

A watershed simulation model was validated by applying it to the Upper Salt Creek basin in the Chicago Metropolitan area. Effects of urbanisation and seasonal variations on runoff were studied by synthesising a series of hydrographs representing a variety of urban development conditions in a basin with an area of 50.5 sq km. Urbanisation of the downstream part of the basin increases the magnitude and frequency of floods as compared to the case when the upstream part of the basin is urbanised. Lag times of flood peaks are reduced by three times and the magnitude of flood peaks increased by a factor ranging from 1.1 to 1.6. Flow-duration curves show that the probability of occurrence of high flows when the downstream area is urbanised is about twice as much as when the upstream area is urbanised, and that of low flows is reduced from 5 to 10 times. These differences result from changes in the channel-system storage. The seasonal variations in the ratios of urban to rural direct runoff volumes are 1.32, 1.83, 2.4, 2.2 for summer, fall, winter and spring, respectively. The direct runoff-rainfall ratios for the same seasons are 0.23, 0.16, 0.92, and 0.59 for the urban area, but 0.17, 0.09, 0.39 and 0.29, respectively, for the rural area. During the winter, urban peak discharge is 19.5 times the rural peak discharge. The seasonal variations in the urban-rural response ratios are attributed to the differences in the seasonally fluctuating soil moisture conditions.

YEN, B.C. 1973: "Methodologies for flow

prediction in urban storm drainage systems. Final report September 1969 - January 1973". Water Resources Centre, Illinois University, Urbana, Report RR-72; 163pp.

Key words: flood forecasting; urban drainage; model studies; analytical techniques; flood routing.

An urban storm drainage system can be considered as an integrated system of components of urban surface, gutters, inlets, sewer branches, junctions, manholes, and other facilities. In this study the flow equations that can be used to solve storm drainage problems are critically reviewed and the mathematical methods for solving the St. Venant equations are compared. A method for routing the unsteady flow due to rainfall and other inputs through land surface and gutter is proposed. A mathematical simulation model for tree-type sewer networks is developed for flow prediction and design by using the St. Venant equations to route the inlet hydrographs through the network. An overlapping segment scheme is used to account for the backwater effects and mutual influences of the unsteady flow in the sewers.

YEN, B.C. et al. 1974: "Designing storm sewers using the Rational Method". Water and sewerage Works, Vol.121(10); p92-95.

Key words: analytical techniques; flood forecasting; urban runoff.

Three techniques for design of storm sewers using the rational formula are discussed in this article. They are the standard rational method, risk-based rational method, and risk-based optimal-cost rational method. Two different versions are introduced for each of the latter two methods. The purpose of this paper is to present the computational procedure of design of storm sewers using the rational method with and without considering the risks and costs. The theory of the rational method can be found in standard textbooks and manuals and the theory of the risk-based cost optimisation can be found in a recent paper by the authors.

YEN, B.C. et al. 1976: "Advanced methodologies for design of storm sewer systems". Water Resources Centre, University of Illinois, Urbana, Research Report 112; 238pp.

Key words: computer models; storm runoff; flood routing; urban drainage; model studies.

The development of a series of computer models capable of determining the diameter, slope, and crown elevations of each sewer in a storm drainage system in which the layout and manhole locations are predetermined is described. The criterion for design decisions is the generation of a least-cost system. The basis for all the models is the application of discrete differential dynamic programming (DDDP) as the optimi-

sation tool. The concepts of hydrograph routing and risks and uncertainties in designs are optimal model components. Three routing procedures, each with its own advantages, are adopted; expected flood damage costs are evaluated through the analysis of numerous risks and uncertainties associated with the design. This analysis permits the estimation of the probability of exceeding the capacity and the corresponding assessed damage of any sewer in the system. The expected damage cost is added to the installation cost to obtain the total cost which is then minimised in the DDDP procedure. Two example sewer systems are used to illustrate different aspects of the various least-cost design models and to develop user guidelines.

YEN, B.C. and SEVUK, A.S. 1975: "Design of storm sewer networks". J. Environmental Engineering Divn., Proc. ASCE, Vol.101(EE4); p535-553.

Key words: urban drainage; urban hydrology; model studies; computer models; urbanisation; storm runoff; urban runoff.

Five methods for design of storm and combined sewers were compared by determining the size of the sewers of an example network. The Illinois Storm Sewer System Simulation (ISS) Model appears to be the most accurate method suitable for large expensive networks, and can also be used to study on-line retention storage. The conventionally used steady flow routing method with shifting of hydrographs due to sewer flow time is simple and does not need the use of a computer; thus it can be used for small networks and when high accuracy is not required. The version of steady flow routing method without time shifting of hydrographs is not recommended because it consistently gives overdesign. The Chicago method provides no improvement in design and yet is more complicated than the time shifting version of steady flow routing method. The EPA Storm Water Management Model and the kinematic wave model are improvements over the steady flow routing method. They can be used for large networks but presumably are less accurate than the ISS Model.

YEN, C.L. and SAKHLEH, S.N. 1974: "Sensitivity of surface runoff to variations of watershed parameters in small urban areas". Dept. of Civil Engineering, Howard University, Washington, D.C., C.E. Report 74-02.

Key words: urban runoff; mathematical models; flood discharge; landuse change.

The continuing growth of urban areas that replace farm lands and forests with paved areas and structures inevitably brings about changes in watershed physical parameters such as surface slope, roughness and infiltration rates. The effects of these changes, which result in increased volume and peak rate of runoff that often cause tremendous damage to life and proper-

ties, needs to be better understood. The present study proposed a mathematical model, based on kinematic wave theory, to evaluate the effects of urbanisation on peak flows for small areas. This model takes into account the spatial variations of slope, roughness, slope-length, rain-excess intensity and duration. Computer programs for watershed profiles having two and three sections with different parameters were written for computing peak overland flow under various conditions. The effects of varying infiltration rate, slope, roughness, slope-length and rainfall durations have been investigated using the model proposed. Results are: (i) high infiltration (pervious) portion located at the lower end of watershed profile reduces peak flow more effectively than at the upper end, (ii) increasing roughness-slope parameter beyond certain value will bring about little additional reduction in peak flow, and (iii) for a given rainfall duration, an optimum slope-length for managing peak flow can be found. These results need to be verified by laboratory or field observations.

YORKE, T.H. 1975: "Effects of sediment control on sediment transport in the northwest branch Anacostia River basin, Montgomery County, Maryland". J. of Research of the USGS, Vol.3(4); p487-494.

Key words: sediment transport; sediment control; urbanisation; data collection; sediment yield; landuse change.

Streamflow and sediment were monitored in an urbanising drainage basin in southeastern Montgomery County, Md., from 1962 to 1972. During this period, urban construction areas averaged about 3 percent of the 21.1 sq mi basin. Urban land increased from 3.5 percent in 1959 to 20 percent in 1971. Virtually all the suspended sediment was transported during storms; three-fourths of it, during large storms. High sediment yields were observed in February, March, June, and August; and low yields generally from September through January. The decrease in sediment discharge in the latter half of the study period is attributed to a sediment-control program. Sediment discharge decreased 35 percent between 1967 and 1972, when effective control measures were installed on about half the construction sites.

YORKE, T.H. and DAVIS, W.J. 1971: "Effects of urbanisation on sediment transport in Bel Pre Creek basin, Maryland". U.S. Geol. Survey prof. paper No.750-B; p218-223.

Key words: landuse change; sediment yield; storm runoff; urbanisation.

The effect of urban expansion on the sediment yield of a 1.7 square mile drainage basin is described. Streamflow and sediment data were collected at a gauging station on Bel Pre Creek in Montgomery County, Md., between 1963 and 1967. Prior to March

1965, the drainage area was used for pasture and woodland; however, between March 1965 and August 1967, part of the basin was developed for garden apartments and town houses. A graphical regression analysis indicated that the storm runoff increased 30 percent and the sediment yield was 14 times greater as a result of urban construction on about 15 percent of the drainage basin. The sediment yield from the construction sites was 90 times greater than the yield expected from the area with the original land use conditions.

YORKE, T.H. and DAVIS, W.J. 1972: "Sediment yields of urban construction sources, Montgomery County, Maryland". U.S. Geol. Survey open-file report; 39pp.

Key words: sediment yield; urban hydrology; urbanisation; urban runoff; storm runoff; erosion; sediment control; erosion control; suspended solids.

In three urbanising streams in the Rock Creek-Anacostia River basin, Md., sediment load increases significantly as urban construction increases. In Bel Pre Creek, suspended sediment discharge increased 14-fold as a result of urban construction on about 15 percent of the basin, during the first 30-month period of the study. Sediment-water discharge curves and graphic regression analysis indicate that a direct relation exists between the sediment yield of a basin and the area of land under construction, the season of year, slope of land at construction sites, and proximity of construction sites to stream channels.

YORK T.H. and HERB, W.J. 1976: "Urban area sediment yield - effects of construction site conditions and sediment control methods". Preprint, Proceedings 3rd Federal Inter-Agency Sedimentation Conference, Denver, Colorado; p2.52-2.64. (NTIS PB-245 100/3GI).

Key words: sediment yield; urbanisation; sediment control; data collection; sediment transport.

Suspended sediment discharge and land use were monitored in eight small drainage basins in Montgomery County, Maryland, between 1963 and 1974. Five of these basins, located on the fringe of the rapidly expanding Washington, D.C., metropolitan area, were subjected to continuous construction activity as woodlots, pastures, and cultivated fields were replaced by houses, apartments and shopping centres. Construction site sediment yields ranged from 16 to 226 tonnes per hectare per year (7 to 101 tons per acre per year). The degree of sediment control and the slope conditions on construction sites were the most significant factors affecting sediment yields; the proximity of construction to stream channels and the length of time that the soil surfaces were unprotected affected yields to a lesser extent. As a result of improvements in grading practices and control measures, construction site sediment yields were reduced

60 to 80 percent between 1966 and 1974.

YOUNG, C.P. 1974: "Urban drainage in the United Kingdom". In, Proceedings CIRIA/Bristol University research colloquium on rainfall, runoff and surface water drainage of urban catchments, Bristol, April 1973; p1-1-1-10.

Key words: rainfall-runoff relationships; mathematical models; urban drainage.

There are quite a large number of methods of designing surface water sewer systems but there are only two in general use in the UK (i.e. the TRRL hydrograph method and the rational or 'Lloyd-Davis' method). The latter method has a number of variations but as they do not introduce any additional concepts they are not considered separately. The processes involved in the transition from rainfall to runoff are summarised and simplifying approximations are made.

YOUNG, C.P. 1974: "A critique of the TRRL hydrograph method". In, Proceedings CIRIA/Bristol University research colloquium on rainfall, runoff and surface water drainage of urban catchments, Bristol, April 1973; p11-1-11-7.

Key words: urban drainage; analytical techniques.

The TRRL hydrograph method is now in wide use and has been the subject of independent assessments. These comment favourably on the method and advocate its use where conditions are appropriate. However, experience in the UK has shown that further research is desirable to check some aspects of the method and its use. Consequently, this paper attempts to group possible improvements into two categories: (1) those which are economically desirable; and (2) those which are desirable in that they will increase knowledge of the drainage processes but may not produce much benefit.

YOUNG, G.K. 1976: "Decision perspectives on urban storm water pollution". Water Resources Research, Vol.12(1); p94-100.

Key words: watershed management; water pollution control; pollution abatement; combined sewers; overflows.

The objectives of this study are to develop and use a simple method of analysis for the urban combined sewer and overflow problem. An aggregated method is presented which relates a few significant variables to produce a scalar that describes the severity of pollution for an urban area. The method as applied to typical values leads to the following conclusions: (1) the method has utility for first-level screening of alternatives at the national or state decision making level; (2) hydrologic variables, with the exception of receiving water streamflow at the

start of a storm, do not enter into the assessment of the maximum pollutional impacts of storms; (3) a relatively small set of variables, several relating to water use and the sewer treatment system and the others defining the quality of receiving waters, storm wash and raw sewage, are used to conduct the analysis; and (4) the maximum storm-induced water quality is several times the water quality associated with the dry weather engineering design limits of sewage treatment performance.

YOUNG, K.K. 1976: "Erosion potential of soils". In, Proceedings of the 3rd Federal Inter-Agency sedimentation conference, Denver, Colorado. Water Resources Council, Washington; pl.1-1.10.

Key words: erosion; urbanisation.

Erosion and sediment from farmland remains a serious problem in the United States. Gaining national concern is the erosion and sediment resulting from urban development. Predicting the erosion potential of soils is one of the first steps used by the Soil Conservation Service in planning conservation systems that control soil erosion on farmland and urban developments alike. This paper described the application of research to produce a practical field procedure for determining the erosion potential of soils. Special emphasis was given to the soil factors that influence erosion and to how soil surveys are used to predict the areas of potential erosion.

YOUNG, R.H.F. 1974: "Pollution effects on surface and ground waters, (literature review)". J. Water Pollution Control Federation, Vol.46(6); p1419-1429.

Key words: water pollution sources; aquifers; nutrients; agricultural pollution; miscellaneous chemicals; heavy metals; sewage disposal; industrial wastes; urban runoff.

Literature concerning the pollution effects of various substances on surface and ground water is reviewed. Among the substances covered are nutrients, agricultural wastes, chemicals, heavy metals and radionuclids, and biological contamination. Nutrient enrichment sources cited were sewage treatment effluents, industrial wastes, urban runoff, and agricultural runoff.

YPERIAAN, G.J. 1977: "Statistical evidence of the influence of urbanisation on precipitation in the Rijnmond area". In, Symposium on effects of urbanisation and industrialisation on the hydrological regime and on water quality. IAHS Publication No.123; p23-30.

Key words: mathematical models; weather modification.

In a statistical study, days with precipitation, as measured at 41 stations, were grouped by season, wind direction and precipitation type. The precipita-

tion amounts within each group were tested for systematic differences and areal clustering. Evidence was found of an increase in precipitation near Rotterdam.

YU, S.L. et al. 1971: "Assessing organic pollution from agricultural, urban, and wooded lands". Paper presented at the National Fall Meeting, AGU, San Francisco, December, 1971; 5pp.

Key words: water pollution sources; biochemical oxygen demand; water pollution; organic compounds; urbanisation; agricultural pollution.

Organic pollution concentrations and loadings were investigated for six small New Jersey watersheds representing agricultural, urban, and wooded lands. Data averaged separately for dry and rainy days showed considerably higher BOD concentrations and much higher loadings for the wet days. Data vary significantly with land use. These results are of particular value for evaluating future unrecorded pollution loadings in rapidly developing metropolitan areas.

YU, S.L. et al. 1975: "Assessing unrecorded organic pollution from agricultural, urban and wooded lands". Water Research, Vol.9(10); p849-852.

Key words: organic compounds; agricultural pollution; water pollution sources; biochemical oxygen demand; nonpoint pollution sources.

An investigation was conducted of the organic pollution for seven small New Jersey watersheds representing agricultural, urban and wooded lands. The 5-day biochemical oxygen demand (BOD) was used as a main index of organic pollution. Data obtained for a 2.5 year period indicate background BOD concentrations averaging from 0.5 to 2.0 mg/l in all streams, except that a value of 9.0 mg/l was obtained for a residential-commercial-industrial area. During or after rainstorms, the BOD loadings, in pounds per day per unit area, averagely became more than ten times greater than the background amount for all streams. No significant correlation was found between BOD concentration and flow rate, but good correlations were obtained between BOD loadings and flows. The seasonal pattern of BOD loading distribution was examined. Also the frequency distribution of BOD concentrations and loadings were examined.

YU, S.L. et al. 1977: "Methodology of predicting storm runoff pollution loadings". Paper presented at Annual Spring Meeting of the AGU, Washington, D.C., EOS, Vol.58(6); p389.

Key words: mathematical models; storm runoff; water pollution.

One of the major tasks in evaluating the impacts of urbanisation on water quality is the estimation of pollution

loadings in storm runoff from urban areas. This is an uneasy task in view of the fact that normally only discrete grab sampling data are available, and that only a finite number of storm events are sampled. Furthermore, the mass loadings of pollutants from urban runoff are affected by not only the basin characteristics, such as land use, imperviousness, etc., but also by various hydro-meteorological factors, such as rainfall intensity and duration, flow rate, antecedent conditions, etc. In this paper various methods of pollution loading estimation available in the literature are reviewed. Several 'desktop' methods are discussed. Case studies of the application of these methods are given, using data obtained in connection with studies on characterising urban runoff pollution in several urban areas in New Jersey. Also a discussion on the 'design storm' concept for the analysis of storm runoff pollution is presented.

YU, S.L. and McKNOWN, J.S. 1963: "Runoff from impervious surfaces". Kansas Univ., Lawrence, Contract Research Report; 17pp. (Also published in J. of Hydraulic Research, Vol.2(1); p3-24).

Key words: rainfall-runoff relationships; analytical techniques.

Runoff of rain falling on an impervious surface can be predicted by means of numerical computations. For the small slopes and depths which occur on highways or airstrips, the nonuniform flow is quasi-steady. The calculation proceeds by steps in the direction of flow, beginning at the upstream end of the reach and at the onset of rainfall; repeated computations provide predictions of depths and velocities at subsequent times. Because most of the rain falling is stored on the surface initially, the flow approaches equilibrium quite rapidly. The anomalous increase in discharge which often follows the cessation of rain in field tests is a consequence of turbulent flow becoming laminar when the battering of rain ceases.

YUCEL, V. 1974: "Effects of development in an urban watershed: a case study in simulation". Hydrocomp Simulation Network Newsletter, Palo Alto, Calif., Vol.6(2); 8pp.

Key words: mathematical models; urbanisation.

ZABIK, M.J. 1971: "The contribution of urban and agricultural pesticide use to the contamination of the Red Ceder River". Institute of Water Research, Michigan State University, East Lansing, Final Report, W71-10035, OWRR-A-012-MICH(2); 35pp.

Key words: pesticides; suspended solids; waste water treatment; agricultural pollution; water pollution sources.

Analysis of 1,549 water samples shows that the Red Ceder River, Michigan, is highly contaminated with DDT and DDT metabolites (TDE and DDE). The river becomes progressively more contaminated in a downstream direction and shows seasonal variations. Pesticides in bottom samples show the amount of long-term contamination, whereas those in the suspended matter (that retained by a 5 micron filter) show the amount of pesticide being carried on a short term basis. The largest amount of pesticide contamination entering the Red Ceder River comes through waste water treatment plants.

ZABIK, M.J. et al. 1971: "Effect of urban and agricultural pesticide use on residue levels in the Red Ceder River". Pesticide Monit. J., Vol.5; p301-308.

Key words: pesticides; sediment yield; water pollution sources.

Studies have shown the presence of high concentrations of DDT and its metabolites in water and bottom sediments of the Red Ceder River, Mich.; contamination increases in a downstream direction and shows seasonal variations. The greatest amounts of pesticides enter the river from sewage treatment plants. The studies showed that the concentrations of pesticides in bottom samples give a good indication of long-term contamination, while concentrations associated with suspended matter indicate short-term contamination.

ZANDT, J.K.VAN. 1972: "Annual compilation and analysis of hydrologic data for urban studies in the Austin, Texas metropolitan area, 1970". U.S. Geol. Survey open-file report; 70pp.

Key words: rainfall-runoff relationships; streamflow; urban hydrology; data collection; hydrologic data; urban runoff; storm runoff; watershed management.

Rainfall and runoff data are presented for Waller Creek (Austin, Texas area) for the 1970 water year. The Waller Creek drainage area lies entirely within the city of Austin, with the headwaters originating in the northern part of the city. The creek flows south for 6.6 miles to the Colorado River. Storm sewers and street gutters divert runoff both into and out of the natural drainage area. The headwaters of Wilbarger Creek originate in Travis County near the Williamson County line and flow southeasterly about 40 miles to the Colorado River. The Wilbarger Creek

study area is about 15 miles north of the city of Austin. The weighted mean rainfall upstream from 38th Street was 35.82 inches, 10 percent above the mean annual rainfall for Austin of 32.58 inches. Mean daily discharge was 1.65 cfs; annual runoff was 9.68 inches, or 27 percent of rainfall. The weighted mean rainfall upstream from 23rd Street was 34.95 inches, 7 percent above the mean annual rainfall for Austin. Mean daily discharge was 3.24 cfs; annual runoff was 10.66 inches, or 30 percent of rainfall. Rainfall-runoff data for four storms are summarised.

ZANONI, A.E. 1972: "Ground water pollution and sanitary landfills - a critical review". *Ground Water*, Vol.10(1); p3-13.

Key words: water pollution sources; ground water resources; leachate; aquifers.

Studies concerned with the ground water pollution potential from sanitary landfills and dump grounds were conducted in California, South Dakota, Illinois, and England. These studies all demonstrate that leachates are highly pollutive, but once they pass into the surrounding soil regime, the attenuation mechanisms of dilution, adsorption, and microbial degradation tend to reduce their impact on ground water. A survey of practice in 21 States in the United States regarding ground water pollution from landfill operation shows that not much new research is under way; there is much variation in the code and laws dealing with ground water pollution; and distances from landfills to water wells varied from 50 to 1,000 feet. Based on the literature finding plus the result of State surveys, recommendations are offered to minimise ground water pollution problems stemming from landfill operations.

ZAYO, R. 1973: "The influence of urbanisation and industrialisation on the hydrological cycle". *Wasser Boden*, Vol.25(1); p1-6.

Key words: watershed management; data collection; urbanisation.

After a survey of population development and dispersal, the various influences of conglomerated areas on the hydrological cycle are dealt with. Its overtaxing locally through a high water demand, the extensive influx of sewage - the harmful effect of which is further augmented by the heated cooling waters - and the change in the catchment process generally, call in future for an extended development of the observation network in congested areas and for far reaching comprehensive planning.

ZOGORSKI, J.S. 1975: "Temporal characteristics of storm water runoff: an overview". In, *Urbanisation and water quality control*. Proc. Symposium American Water Resources Association, No.20; p100-109.

Key words: storm runoff; water pollution control; bioindicators; metals; nutrients; organic compounds; solid wastes; oil wastes; pesticides; phenols; bacteria; viral factors.

Very little information is currently available on the temporal characteristics of water quality parameters in storm water runoff. A majority of the projects which have been completed were conducted in urbanised areas. These studies were for the most part fragmentary because the scope of these projects was directed towards evaluating a specific water quality problem rather than toward a comprehensive evaluation. One exception is the investigation recently reported for a small urbanised watershed in Durham, North Carolina, in which the temporal characteristics of indicator bacteria, metals, nutrients, solids, and organics were studied. Little or nothing is currently known concerning the temporal characteristics of oils, pesticides, other refractory organics, viruses, and pathogenic bacteria in storm water runoff. Current investigations, such as that being conducted at Woodlands, Texas, will provide additional information in the immediate future. Additional comprehensive studies of the temporal characteristics of surface runoff should be initiated at other locations in the United States. With a clear understanding of the characteristics of storm water runoff, water management officials will be better able to formulate comprehensive policies and plans for managing surface runoff.

ZOLAN, W.J. et al. 1978: "Urban runoff quality in northern Guam". Guam University, Agana. Water Resources Research Centre, Technical Report No.5; 168pp. (NTIS PB-278 564).

Key words: storm runoff; surface runoff; urban runoff; bacteria; nitrates; water pollution sources.

The purpose was to obtain qualitative information on urban runoff in northern Guam. Runoff was collected over an 18 month period from ponding basins and storm drains and analysed for common water quality parameters. Results indicate that pollutant concentrations in ponding basins are relatively low in comparison to levels measured in other communities in the United States. Moderate to high concentrations of oil and grease and soaps are occasionally measured at storm drain outlets emptying into ponding basins. Coliform bacteria levels are generally low with geometric means of 900 total coliform per 100 ml and 215 faecal coliform per 100 ml. However, counts range from near zero to several hundred thousand (total coliform) per 100 ml depending on rainfall occurrence and basin sampled. Urban runoff being discharged into coastal waters is generally low in pollutants with the exception of nitrate-nitrogen and coliform bacteria. Counts of bacteria in excess of the Guam Water Quality Standards established for Agana Bay shore waters were observed on most samplings. Ground water seepage and tap water sources are the suspected source of the high ni-

trate-nitrogen concentrations (ranging up to 3.4 mg/l) which also exceed the Guam Water Quality Standards.

ZUIDEMA, F.C. 1977: "Urban hydrological modeling and catchment research in the Netherlands". ASCE, New York, Urban Water Resources Research Council, Technical Memo., TM-IHP-10; 52pp.

Key words: urban runoff; computer models; mathematical models.

Modeling and catchment research for drainage systems in the Netherlands is emphasised. Model applications are stressed. Special features include discussions of road runoff hydrology and regional and national total urban water resource modeling.

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