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A procedure for characterising river channels

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The evaluation of the potential impacts of water resource development upon instream uses such as recreation and fisheries requires in the first instance a large amount of information on the character and environment of the river channels involved. A review of the various methods already in use for evaluating instream flow needs indicates, that, despite a wide diversity of approaches, there are many data requirements in common. Indeed, it is apparent that the intrinsic characteristics of a river may be described independently of the particular human use of concern; in principle, description of the physical appearance of a river is a relatively simple, though time-consuming, matter.

A data collection procedure is proposed which will provide all the data needed by a specialist to assess the value of a given channel for instream uses. Data fall into the following groups; (i) Geographic location; (ii) Channel environment and setting; (iii) Channel hydraulic geometry; (iv) Sediment characteristics; (v) Streamflow and water quality; (vi) Riparian vegetation. As an example the procedure is applied to the Ashley River, Canterbury.

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Introduction

Use of New Zealand's water resources for irrigation, hydro-electricity generation, dilution of pollutants and other purposes may modify the hydrologic regime of and sediment transport along a river, and hence cause changes in the form and behaviour of the channel. This in turn may affect the value of a river for such instream uses as water-based recreation and fishing, as well as modifying the aesthetic quality of the river environment.

As part of the process of planning for water resource development, it is necessary to have full information on the characteristics of a river channel in its undisturbed state, its value for any instream uses, and the likely impact of development on these. In the past, efforts to provide this type of information have usually been inadequate, primarily because of a lack of awareness of the precise information required. Those personnel who have been involved in data collection are not trained in specific disciplines such as fisheries biology and recreation resource management, and cannot be expected to intuitively know what parmeters are of importance and should be measured; even the specialists are not always certain what to measure, nor how to measure it.

An alternative to collecting information needed by specific user groups is to collect data that will characterise a river's present form and environment, its instream values, and its likely response to development independently of these uses, and which will provide all the information that will be needed by any user group. A review of existing literature in a wide range of disciplines indicates that there is in fact a substantial overlap in information needs, and that a properly designed general procedure for data collection will provide the information required by all. For example, information on the appearance and condition of a river bank will provide data needed by a fish biologist to assess the amount of cover available to fish, by a recreation resource manager to assess the aesthetic quality of a riverscape as seen by a canoeist, or by a wildlife biologist to assess the amount of habitat available for terrestrial birds, mammals, and other animals. Looked at in another way, it seems that the characteristics of a river which control its suitability for a variety of instream uses are intrinsic to the river, and may be measured or defined whether or not those uses actually occur. In essence, a river may be viewed as a three-dimensional body of water whose dimensions (length, widths, depths) and other characteristics (velocities, temperature, chemical characteristics) can be measured, just as for a block of wood. The surfaces of the body of water (between the water and atmosphere above it and between the water and the stream bed sediment below it) and the edges where those surfaces join (the stream bank) can similarly be measured and described, just as for the block of wood. Of course, a river is a very complex entity, far more so than a block of wood, so that its description is by no means a simple problem of geometry. Nevertheless, there seems no reason why a procedure cannot be developed for measuring, independently of the uses to which it is put, the characteristics of a river, in the same way that the character of a block of wood can be measured, whether it be used as firewood or turned into a piece of furniture.

Purpose

The purpose of the present guidelines is to propose a general procedure for data collection that can be applied to any river that is under consideration for water resource development. The procedure is intended to describe in some detail the appearance and other characteristics of the river and its environment, so that the present and potential value of the river for any instream use may be defined, and changes in its characteristics and instream values resulting from development may be predicted.

Because specialists in the relevant scientific disciplines such as fish biology are limited in number, data collection must be by technical staff, such as staff of catchment authorities or the Ministry of Works and Development, who are untrained in these specific fields. The data will be used by the specialists and other user groups such as canoe clubs to make estimates of the value of the river for their own areas of concern; the data must therefore be in a comprehensible and readily used form, and must provide all the information needed by the specialists and user groups. The procedure is not intended, however, to provide the type of detailed information on the hydrologic characteristics of a river that is required for water resource planning; where this is needed, as for example for preparation of a water allocation plan, much additional data will have to be collected.

The procedure is based partly upon consideration of the best way of describing and measuring a three-dimensional body of water and its boundaries, and partly upon a synthesis of procedures already developed by workers in several disciplines, particularly fish biology, recreation resource management, and geomorphology. Because information needs in these areas have been defined in most detail, the procedure may show some bias towards them, and characteristics of river channels that are significant for other possible uses may not yet have been recognised. These guidelines are therefore exactly that; the procedure will undoubtedly require future modification.

A general data collection procedure like the one proposed herein may provide some information that is redundant for specific, immediate purposes. It is possible to omit those parts that are clearly irrelevant in a given circumstance, but on the other hand use of the whole procedure will ensure that a body of compatible, consistent data is built up which will permit future analysis for other purposes. While this is not the immediate aim, such analyses would immensely enhance our ability to manage New Zealand's rivers in the most efficient way.

Review

Data to describe river channels have been collected by workers in a wide variety of fields, and for many different purposes. To arrive at a basis for a general data collection procedure it has been necessary to carry out an extensive review of the type of data collected and the uses to which they have been put. The major points are brought out in this review.

Factors to be Considered

River engineers and geomorphologists have for many years routinely measured the physical characteristics of river channels. A number of variables have been used (Hey 1978; Leopold *et al.* 1964); in a study of rivers in the South Island of New Zealand, Mosley (1981a) considered the following variables as descriptors of the morphologic and hydrologic character of river channels:

Cross-section

Cross-sectional area A
Wetted perimeter (≃ width) P
Hydraulic radius (≃ mean depth) R = A/P
Maximum depth DX
Width-depth ratio P/R
Shape factor DX/R
Relative roughness R/d_{75}

Reach

Sinuosity
Water surface slope
Braiding index
Meander wavelength

Sediment in channel perimeter

Mean diameter of bed surface sediment
Median diameter of bed surface sediment d_{50}
Representative diameter of bed surface sediment d_{75}
(size at which 75% is finer)
Standard deviation of bed sediment diameter
Silt-clay percentage of bank sediment

Flood discharge variables

Mean annual flood
Standard deviation of annual floods
Maximum recorded flood
Bankfull discharge

Instantaneous flow variables

Mean discharge
Standard deviation of instantaneous flows
Median flow
Minimum recorded flow
Variability index $VI = \left(\frac{\ln(Q_{16}) - \ln(Q_{84})}{4} + \frac{\ln(Q_5) - \ln(Q_{95})}{6.6} \right)$

(where Q_{16} is the discharge equalled or exceeded 16% of the time, etc.)

Canonical correlation analysis indicated that, for the sample of 72 rivers, nearly 70% of variation in channel morphology, as indexed by the cross-section and reach variables, was accounted for by cross-sectional area, slope, and cross-section shape, even though measurements were generally obtained for only the bankfull channel at a single representative cross-section.

Although this type of data may adequately describe a river channel for the purpose of analysing the relationship between channel morphology and the controlling factors of water and sediment discharge, it does not provide sufficient information for such purposes as fish habitat evaluation. A recent workshop (Smith 1979) on the US Fish and Wildlife Service Instream Flow Group (IFG) methodology for evaluating instream flow requirements concluded that thirteen factors must be considered in evaluating a stream ecosystem. These were (in order of importance), depth, velocity, temperature, food supply, riparian cover, and competition, and (of lesser, unranked, importance) predation, substrate (bed material), dissolved oxygen, instream cover, nutrients, stream morphology, and sediment load. The precise ranking of these factors would not receive universal agreement, but they do appear to be sufficient to effectively characterise a given reach of river, at least for ecological/biological purposes. Recent work by Canadian hydrologists has gone some way to characterising river channels at a more detailed level than had formerly been attempted by hydrologists and geomorphologists. For example, in a report documenting channel characteristics at 108 gauging stations in Alberta, Kellerhals *et al.* (1972) assembled the following data:

1. cross-sections in the gauging station reach (3–4 cross-sections up and downstream, over a reach length of up to 50 channel widths);
2. water surface levels at each cross-section;
3. longitudinal profile of the streambed and water surface along the thalweg;
4. bed material samples;
5. descriptive notes on bank materials, vegetation, etc., and photographs of the reach.

Tabulated data included discharge, cross-sectional area, width, depth and mean velocity for the surveyed and bankfull discharge, descriptions of the character of the surrounding terrain, the valley, the stream channel itself (particularly channel pattern and bed and bank materials), and the relationship of the channel to its valley. In addition, extensive hydrologic data were tabulated to provide estimates of long-term, minimum and maximum flows, and flood frequency estimates. Neill and Galay (1967) and Kellerhals *et al.* (1976) have presented checklists of data requirements for characterising in a simple, qualitative fashion, a river channel and its associated valley and surrounding terrain.

Nevertheless, even this level of detail may be inadequate for evaluation of suitability for instream uses, because it excludes many less obvious factors which have been shown to be important (Stalnaker and Arnette 1976; Cortell and Associates 1977). Fisheries biologists in particular have examined the relationships between a variety of river channel characteristics and the suitability of those rivers for use by a large number of fish species, particularly salmonids and other sport fish, at different life stages. The knowledge thus gained has been incorporated into methods for predicting fish population abundance under a variety of conditions, and hence for predicting changes in fish populations in response to changes in flow regime due to water resource development. The most sophisticated approaches so far developed are the "incremental method" of the US Fish and Wildlife Service Instream Flow Group (Bovee 1978a) and the "Habitat Quality Index" (HQI) work of Binns and Eisermann (1979).

In the IFG method, the likelihood of a fish being present at a given point in a stream channel is considered to be a function of the water depth, mean velocity, water temperature, and bed sediment character (Bovee 1978b). The mean water depth, velocity and sediment type in a channel reach are therefore of little relevance to the total fish population in that reach, which is controlled by the precise distribution of depths, velocities and sediment types throughout. Bovee (1978b) provides tables of probability of use by a number of species and life stages of habitats with given values of depth, velocity and sediment type. By estimating the amount of habitat having different combinations of depth, velocity and sediment at a range of discharges, the user of the incremental method may estimate the total fish population in a reach at each discharge, and hence assess the effect of changing discharge on the population. This concentration upon only a small number of factors has been strongly criticised (Smith 1979); other studies that are closely related to the HQI work demonstrate that other factors such as the availability of cover (undercut banks, overhanging trees, aquatic vegetation, submerged logs and roots) (Nickelson 1976; Wesche 1976) or the minimum depth of a riffle (Thompson 1972; White 1976) are also important factors controlling fish populations. Binns and Eisermann (1979) measured, for a sample of 36 Wyoming streams, the following variables:

Physical

*Late summer streamflow
*Annual streamflow variation
*Maximum summer stream temperature
*Water velocity (mean in section)
Turbidity
*Percent cover
*Stream width
Stream depth
Stream morphology (?)
*Proportion of eroding banks
*Bed sediment character

Chemical

*Nitrate nitrogen
Total alkalinity
Total phosphorus
Total dissolved solids
pH

Biological

Stream bank vegetation
*Fish food abundance, diversity, type

Those marked with an asterisk were found to be significantly correlated with trout standing crop, and were combined into a habitat quality index which explained 96% of the variability in standing crop. Lewis (1969) determined that most of the variation in numbers of brown trout in 19 selected pools in a Montana stream was accounted for by current velocity and cover, and Glova and Mosley (in preparation) have found that the standing crops of a number of salmonid and native New Zealand fish species in a sample of riffles in the Ashley and Hurunui rivers also are related to the presence of instream cover (patches of "white water"), among other things.

Less work has been done on the requirements for other instream uses, but Cortell and Associates (1977) have provided a valuable review of the optimum conditions for a variety of water-based recreational activities, such as angling (wading and from the bank), boating (including tranquil water canoeing, white water kayaking, power boating, etc), swimming, rafting and tubing, and so on. Although water depths and velocities and channel widths are of fundamental importance for many activities a variety of other factors must also be considered when evaluating the suitability of a given river reach for recreation. For example, the height, stability and vegetation cover along streambanks influence a river's suitability for bank angling and swimming or diving, while the occurrence of riffles and rapids, overhanging vegetation and obstructions in the channel controls suitability for various types of boating.

In addition, the aesthetic quality of the riverscape has received some consideration (Hamill 1974; Leopold 1969; Morisawa 1971). Hamill (1974) presented a matrix of factors to be considered and rankings to be assigned to each at a given study site:

Physical factors

Low flow water surface width
Low flow depth
Velocity
River pattern
Bed material
Bed slope
Drainage area
Stream order
Width of valley flat
Height of nearby hills

Water Quality factors

Water colour
Turbidity
Water condition (?)
Amount of algae
River fauna
Pollution evidence
Litter

Human use and interest factors

Land flora diversity and condition
Presence of artificial control
Accessibility

Diversity of local scene
Confinement of view and presence of vistas
Land use, degree of urban and industrial development
Presence of special views or historic features

Apart from the physical factors, which can be readily placed into classes on the basis of simple measurement, the other factors are all ranked subjectively; the rankings may then be combined into a overall "evaluation number" for a given site. Morisawa (1971) showed that the results of this type of objective evaluation were closely related to subjective assessments of scenic quality by members of the public.

Site Selection

The type and location of site selected for data collection has varied from study to study, depending on the specific objectives, but three general approaches are commonly followed.

Selection of a specific site of interest

Kellerhals *et al.* (1972) collected data along river reaches in Alberta in which stream flow gauging stations had been established, while Drage and Carlson (1977) considered locations in northern Canada at which pipeline river crossings were planned. Data might be required at a specific location because, for example, a dam, reservoir, irrigation offtake, bridge or other structure is planned.

Selection of a representative reach

Where information is required for a whole river, data may be collected for a reach that is regarded as being representative of the "average" character of the river. This procedure has been followed by, among others, Cochnauer (1976), Collings *et al.* (1972), Dooley (1976) and Waters (1976). An alternative to subjectively selecting a representative reach is to randomly select study sites from aerial photographs (Platts 1979) or to make measurements at sites located at some pre-determined regular interval along the river—¼ mile in the case of Herrington and Dunham (1967). Such sites are considered to be an unbiassed sample of all possible sites in the river, and therefore are representative of the average condition and the range of conditions found therein.

Selection of a critical reach

A number of studies have collected data at locations that are in some way critical controls on the instream use under consideration. For example, White (1976) collected data on a shallow, diagonal riffle to evaluate changes in ease of passage for sturgeon with changing discharge, Lewis (1969) and Cooper (1976) made measurements in pools used by adult trout for resting and feeding, and Swank and Phillips (1976) concentrated on locations regarded as good habitat for fish spawning, rearing, and food production. Use of the IFG computer-based method for predicting water surface profiles at a range of flows requires at least one cross-section to be at a critical hydraulic control point at which the depth-discharge rating curve can be established (Dooley 1976; Jowett and Wing 1980).

Basis for Data Collection

Most studies have relied upon cross-sections or transects as a basis for data collection, but detailed procedures vary widely. Herrington and Dunham (1967) collected data for a single cross-section at each site. Platts (1979) used five cross-sections spaced 15 m apart at each site, while at the other end of the scale, Jowett (1980) used 23 cross-sections at 25 m intervals in an application of the IFG incremental method to the Clutha River. Other studies have used a varying number of cross-sections, commonly between 4 and 10 (Cochnauer 1976; Dooley 1976; Waters 1976; White 1976). Collings *et al.* (1972) used their four measured cross-sections as a basis for drawing maps of their study reaches, while other workers have taken this procedure to its logical conclusion and have prepared highly detailed maps of their study reaches (Keller and Tally 1979; Mosley 1981b; Swanson and Leinkaemper 1978).

Uses of Data

The data provided by the various procedures referred to above have been used in a variety of ways, but basically there appear to be two fundamental objectives:

1. to describe the present characteristics of a river, that is, to provide an inventory procedure;
2. to provide a basis for estimating the characteristics of a river under a set of conditions that do not exist at the time of data collection, that is, to provide a predictive tool.

Thus, as an example of the first case, Herrington and Dunham (1967) required data to "permit land managers and fisheries biologists to evaluate the fishery potential of selected streams and diagnose basic deficiencies in fish habitat", and to "be used as a benchmark to determine the magnitude of future changes that may occur", whereas in the second case the IFG incremental method allows "quantification of the amount of potential habitat available for a species and life history phase, in a given reach of stream, at different streamflow regimes with different channel configurations and slopes" (Bovee 1978a).

It is important to distinguish between these two broad objectives because the data collected for one will frequently be inappropriate for the other. The IFG and related "incremental methodologies" which use a computer model to predict conditions in a selected reach at a range of discharges, using data collected at only one discharge, can be applied to only a relatively short reach, unless the river is unusually uniform in character. This is because the incremental methodology, when it uses a computer program such as the US Bureau of Reclamation Water Surface Profile (WSP) program, requires a number of closely spaced cross-sections to adequately define the shape of the water surface and stream bed. The more irregular the channel, the more cross-sections are necessary. Clearly, then, without a massive investment of effort in cross-section surveys, the reach that is used for incremental analysis is more or less unrepresentative of the river as a whole. In fact, the more irregular or variable the river, the shorter and more unrepresentative must the study reach become, as the cross-sections become more closely spaced. On the other hand, cross-sections spaced at wide intervals along a river that are intended simply to describe the full range of river environments are most likely too widely spaced for extrapolation between them, and so cannot be used in the IFG incremental methodology. In some circumstances, for instance in a major river with a flat sandy bed and constant width, cross-sections established for one purpose may be usable for the other, but in most cases this is unlikely, particularly in New Zealand, where rivers tend to be highly irregular in shape and bed profile.

Another distinction between the two approaches is in the type and quantity of data required. The various versions of the incremental method concentrate to a large extent on intensive measurement of depths, velocities and bed sediment character at closely spaced points along the cross-sections; although some other information is collected, for example a description of the bank material and vegetation (Dooley 1976), it is very much subordinate to the hydraulic data. As already noted, this has been a fundamental criticism of the IFG incremental method, but it is not easy to see how other less easily quantified factors can be incorporated into the method. On the other hand, those procedures intended primarily to describe a reach of river may provide a large amount of information on present conditions which cannot be used to predict conditions at other discharges. Such factors as the amount of vegetation overhanging the water surface or the number of dead limbs in the water cannot be included in the incremental approach to prediction, and virtually no research has been carried out to show how they change with changing discharge.

For the purpose of predicting changes in channel character, the "incremental method" is becoming more and more widely used. A variety of procedures have been used; Waters (1976), Swank and Philips (1976), Bishop and Scott (1973), and Collings *et al.* (1972) made measurements of hydraulic conditions at a range of discharges and computed the area usable at each discharge for a particular use. Usable area was then plotted against the measured discharges, to allow prediction of areas at other discharges. This procedure may be called the 'regression method' of incremental analysis, and has been most recently applied in New Zealand by Mosley (1981 d) to the Ohau River.

Bartschi (1976) made measurements at a single "index" discharge at sample cross-sections; the water surface at index discharge was drawn on the plotted cross-sections, as well as additional water-levels from bankfull to zero flow. For each of these the discharge was calculated using the Manning equation, and wetted perimeter measured on the plotted cross-sections. Again, usable area (proportional to wetted perimeter) was plotted as a function of discharge. The most sophisticated version of the incremental method is the IFG method described by Bovee (1978a) and used in the Tekapo and Clutha Rivers by Jowett and Wing (1980) and Jowett (1980). Measurements of cross-section shape, water depth and velocity, water surface slope and bed roughness at one discharge are used by a computer program to predict, at other target discharges, the water surface profile and thence other hydraulic characteristics. Information on fish preferences may then be used to estimate usable areas at each discharge.

The regression and IFG methods of incremental analysis require apparently similar information, but data collected for one are unusable for the other. The regression method requires information at several discharges at a small number of representative cross-sections, whereas the IFG method needs more detailed information at a larger number of closely spaced cross-sections, but at only one discharge. Each method appears most appropriate under certain conditions. Rather obviously, the IFG method requires access to a computer system on which a water surface profile program is available or can be accommodated (in New Zealand, most likely the Ministry of Works and Development (1978) RIVERS-ROADS program package). This implies that the river involved is of national or major importance, and/or that the project involves sufficiently large expenditure that the expense of using a computer-based predictive model is justified. Strictly speaking this type of model may be applied only to rivers which conform to a number of more or less restrictive assumptions, the most important of which is that flow is uniform. The ideal river would be a large, rather straight, single-thread channel with an even bottom, and no large scale bed features like skew riffles to cause deviations in the flow from the straight-downstream course. The most inappropriate case would be a braided river in which flow is at all points converging and diverging in channels of constantly varying width, and branching and joining in a series of separate channels. The more the assumptions are violated, the less confidence can there be in prediction from the single measured discharge, and the less extrapolation is possible (Prewitt 1981).

The regression method appears to be most appropriate for: (1) smaller streams whose characteristics are highly variable from place to place, so that the closely spaced cross-sections required for the IFG method would not be representative of the full range of conditions present; (2) streams and rivers of any size in which flow is highly non-uniform (that is, in strongly meandering or braided streams, or those which have pronounced skew riffles and other large scale bed forms); (3) rivers which are not sufficiently important to justify expenditure on use of a computer-based predictive model, or for which data can rapidly and easily be collected over the range of discharges of interest.

In conclusion, it can be seen that data collection may be for one of three basic purposes:

1. to describe in detail the character of a river at the time the survey is carried out;
2. for use in the regression method of incremental analysis;
3. for use in the IFG method of incremental analysis.

In view of the criticisms levelled at incremental analysis (Smith 1979), it would appear that a full description of the river of interest should in any case be carried out, but because the information needs of the two methods of incremental analysis are different, a decision must be made as to which (if either) is to be used. Criteria to be used in making that decision are basically: (1) are staff and funds available for and does the project warrant use of a computer-based predictive model; (2) is access to a computer available; (3) do conditions conform to the assumptions that underlie use of a program to compute water surface profiles; (4) how much variability in form and how many different aquatic sub-environments are present in the river; (5) is it more feasible to collect data at several discharges at a small number of representative (or randomly chosen) cross-sections, or at one discharge at a larger number of cross-sections; (6) can data be collected at or near to the discharge(s) of greatest concern (e.g., proposed minimum flow after abstraction)? The final decision should be made in consultation with experienced users of the methods (e.g., staff of Ministry of Agriculture and Fisheries, or Ministry of Works and Development).

Discussion

A data collection procedure is proposed that is based on (1) a consideration from first principles of the information needed to describe a body of water and its surroundings and (2) a thorough review and synthesis of other work. These data will provide a detailed description of any river to which it is applied, and a basis for application of the regression method of incremental analysis, if data are collected at several different discharges. If the IFG method of incremental analysis is to be used, more data on hydraulic conditions will be required; these requirements are also dealt with. Even though the IFG method of incremental analysis does not explicitly use many of the data included in the present procedure, it is considered that for fully informed decision-making they must nevertheless be collected.

Selection of Study Reach

Where the impact of a proposed development such as a dam is under consideration, the site for study is automatically selected for the investigator. In most cases, however, water resource development affects a length of river which is too long to be studied in its entirety, e.g., a reservoir may submerge many kilometres of river channel, or abstraction for irrigation will significantly reduce flows from the site of the offtake to at least the next major confluence downstream. In this situation, the characteristics of only a fraction of the river can be documented; that is, the river must be sampled.

The river should first be divided into a series of internally homogeneous sections, using interpretation of aerial photographs to identify stretches of the river along which characteristics such as active channel width (both the average width and variability in width), degree of braiding, sinousity and radius of curvature of bends, and amount and kind of vegetation along the banks, remain constant (Mollard 1973). For example, the Ashley River, North Canterbury, may be divided into five homogeneous sections:

(1) from the mouth to 8 km upstream, in which the river is narrow, slightly sinuous with a single thread channel (often dry in summer) winding across a wide gravel bed, with banks lined with dense willow growth;
(2) from 8 km from the mouth to the confluence with the Okuku River, in which the river has a wide, unstable gravel bed with multiple, braided channels at low flow, and banks which are in places lined with willows but frequently are covered in grass, scrub, or scattered trees;
(3) from the confluence with the Okuku to the mouth of Ashley Gorge, in which the river is similar to section (2), but narrower;
(4) through Ashley Gorge, in which the river is generally single-thread, and with a course controlled largely by bedrock outcrops;
(5) above Ashley Gorge, in which the river has a steep, cobble bed with a tendency to braid, and erodible banks cut into fluvioglacial terraces with a cover of tussock and introduced grasses.

A study reach representative of each homogeneous section may be selected in a variety of ways. If each section is truly homogeneous, one reach should be as representative as another; the most convenient and probably most unbiassed method of selection is to find the easiest point of access to the river and designate it as the middle of the study reach, on the assumption that its precise location is unrelated to the form of the river and occurred "by chance". (This is obviously not the case with a bridge crossing. A bridge *should not*, therefore, be selected as the point of access, both because it may be sited at the narrowest crossing point, and because the bridge itself or any associated training works may affect the character of the reach. It might also be noted here that water level recorder sites should also be treated with suspicion, because of, for example, bedrock control).