QUALITY CONTROL OF HYDROMETRIC DATA

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ABSTRACT

The quality of hydrometric data is vital to correct interpretation of records. This Norwegian text discusses collection methods and the common sources of error in hydrometric data. It then offers methods for checking data, searching for errors and correcting them.

Translation note:

This report is an English translation of *Nordic IHP Report No 4* "Kvalitetskontroll av hydrometriske data". The original, in Norwegian, was published in 1981 by the National Committees for the International Hydrological Programme in Denmark, Finland, Norway and Sweden. The translation is by Svanaug and Alan Nilsen, 43 Carlsen Street, Christchurch 9, New Zealand.

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CONTENTS

SUMMARY

In this publication FAG 6 - The Nordic Hydrological Working Group for Data Processing and Quality Control - presents its final report. The Working Group has included participants from the main data collecting agencies for hydrometric data in Denmark, Finland, Norway and Sweden.

This report deals with the problem of detecting systematic and gross errors in hydrometric data. This is a problem common to most agencies collecting large amounts of data.

The report is divided into five sections. Section 1 gives the background of the Working Group, some fundamental definitions and the result of a study of the relevant literature.

Section 2 reviews methods which are presently used for measuring water levels and discharges in rivers and lakes in the Nordic countries. The processing of data is then described, and lists given of possible sources of errors.

Section 3 lists methods for detecting various types of errors. For the various data streams such as manually collected data, analog data and digital data, recommendations on appropriate methods are given.

Section 4 gives guidelines for identifying the causes for the possible errors indicated by the methods described in section 3. Guidelines are also provided for correcting errors and filling in missing data. The section stresses the importance of keeping a quality record for each station and recommends how corrected data could be marked in the historical records.

Section 5 discusses ways of improving the general quality of hydrometric data. The importance of frequent field inspections is stressed.

Guidelines are then given for quality control during the primary processing of data. The section recommends a number of automatic tests on the water stages, the day to day changes and on the continuity of the discharges in the stream be performed, comparing data at other stations.

This automatic control should sort out obvious as well as possible errors. Obvious errors may be corrected automatically. Data containing possible errors should be analysed by a number of interactive graphical routines.

Appendices 3-11 contain examples of some of the methods described in the report.

1. INTRODUCTION

1.1 Background

Since the latter half of the 19th century, large quantities of basic hydrological data has been collected in the Nordic countries. Apart from rainfall data most of this information consists of data on water levels and flow rates from fixed gauging stations in the national network of each country.

This recording, which is carried out today to a greater degree than ever before is a vital part of the basis for planning the use and management of each country's water resources. It is desirable that the data give as correct a picture as possible of the water volumes available. The data must therefore be as representative and as free from errors as possible.

Gradually, as the data has been analysed, it has been found that this is not always the case. In order to find methods to identify and if possible correct mistakes in the data, a Nordic Hydrological Commission (FAG 6) was set up to deal with quality control and data interpretation questions. The group comprised Jorgen Lundager Jensen from Hydrometric Research, at the Danish Moorland Company, Esko Kuusisto from the Hydrological Bureau in Water Management in Finland, Sverre Krog and Lars Roald from the Hydrological Department in the Norwegian Waterways and Electricity Ministry and Lars Erik Eggertson, and later Kurt Ehlert, from Sweden's Meteorological and Hydrological Institute.

This report outlines the technical results of the operations of FAG 6.

1.2 Basic Definitions

A water level or flow rate observation shows up as a result of one or more individual measurements of, eg, water levels on a height gauge or current speeds at a number of points. During measuring we seek to reach a value that is the closest possible to the true value of the measured amount. In practice there will nearly always be a difference between the measured and the true value. This difference we call the error.

The errors are often classified into three groups:

- Random errors.

- Systematic errors.

- Gross errors.

Random errors are those which arise from the overall uncertainties of measurement. These errors are usually small. They occur by chance, both above and below the true value. Random errors do not greatly affect the mean and their effect can be reduced by increasing the number of measurements or by improving the accuracy of individual measurements.

Systematic errors is the term used to describe errors which cannot be eliminated by increasing the number of readings taken using identical instruments and other conditions. These errors lead systematically to false results. They will affect both the mean and the extreme values. They can be caused by the instruments used, but just as often the flow rate curve is incorrect.

Gross errors describes errors that occur sporadically, resulting from random instrument failure, from human error during measuring or transfer of data to the office, or from misinterpretation of data. If these errors are small, they can hardly be separated from random errors. If they are large the extreme values will be incorrect and in severe case also the mean for the particular time span. Such errors cannot be processed as statistics. Nevertheless, they can often be revealed by statistical methods.

Methods for quality control of data as used in this report describe ways of discovering systematic and gross errors in the data. Such errors are particularly dangerous because they affect the mean as well as the extremes. However, these errors can be found and corrected later.

If as many as possible of the systematic and gross errors are removed, there will still be a residual error caused by the random errors. This category of errors is discussed thoroughly by Herschy (1978). Such errors should be stated in accordance with the standards that ISO has established.

1.3 Publications

Literary research has been carried out to find an account of any methods used to avoid, diminish, establish and correct errors in hydrometrical data.

The general uncertainty in measuring is discussed in many connections, but mostly as a statistical problem in connection with certain instruments and measuring techniques. This has also been of great interest to FAG 6, but does not solve the main task which is to find methods to deal with the errors that are outside the measuring uncertainty interval or that systematically falsify results.

Knowledge of the common measuring uncertainties is of decisive importance if we are to be able to arrange reasonable test criteria to separate out the gross errors.

Certain methods are often used in quality control within different branches of this subject, especially moderation tests. Measuring techniques and the associated physical processes require special controls for water level and flow rate data.

Apart from these considerations there is very little to be found in publications about quality control. Error detection and correction is discussed in very few places, always very briefly, and usually in cursory remarks or specific procedures for one measuring method at a time.

The literature searched contain four different forms of publications:

(1) Books about hydrology (educational, encyclopedias etc).

(2) Books about hydrometry (educational, encyclopedias etc).

(3) Periodicals,

(4) Reports, standards, instructions, small publications etc.

A list of these can be found in appendix 1.

In group 1 quality control is discussed in the second edition of Hydrology in Practice by Ulf Riise; J Otnes and E Roestad (editors). However, there are no other works that discuss this subject.

In group 2 there are three relevant titles. One, of special interest, is R W Herschy, (editor) Hydrometry. This work contains part of a chapter on measuring uncertainties and part of a section about quality control in the chapter on data processing. The various sources of error in the different measuring methods are also discussed.

In group 3 there are no articles of special interest. The periodicals contain very little hydrometric matter and practically nothing about data quality.

In group 4 there is quite a lot of material of interest. There is useful instruction in techniques and advice in the choice of instruments. There are general comments on precise measuring. However, there is a lack of systematic discussion of the individual errors or surveys of data quality.

2. COLLECTION OF HYDROMETRIC DATA, GAUGING METHODS, PRIMARY PROCESSING AND SOURCES OF ERROR

In order to survey which errors can occur in water level and water flow data it is necessary to analyse the gauging techniques and the subsequent processing of the results. This chapter describes concisely the gauging methods used in the Nordic countries today. It then describes schematically how the data is processed on its way to the archives. Finally there is a survey of which sources of error occur for data collected by the various gauging methods.

2.1 Methods of Collecting Hydrometric Data

In this report, hydrometric data refers to flow rate data measured in rivers, outlets of lakes and reservoirs and in transfer tunnels; and water levels measured in rivers, lakes and reservoirs. The gauging methods can be grouped according to measurement principles, data carrying media and methods of data transmission.

2.1.1 Water Level Data

Fundamentally, hydrometric gauging is the measuring of water levels, that is, water levels at fixed gauging stations. Earlier this was mainly done manually, but it is increasingly carried out by automatic recorders.

2.1.1.1 Manual Gauging

Water level data have traditionally been read from a staff gauge, installed vertically in the riverbed and long enough to cover all water levels that may occur at that particular site. In special cases angled staff gauges or a series of staff gauges may be used.

The staff gauge is graduated every 1 or 2 cm. It must be anchored well so it will not be displaced by ice etc. The gauging station site must not be exposed to waves, which would greatly increase the uncertainty of readings. In places where it is difficult to fasten staff gauges, low water bolts are also used. These are metal bars that are anchored to the bed of the river or lake. The water level is read from the surface down to the bolt with a ruler or a measuring tape.

Manual water level observations are usually recorded in observation books and on data forms that are sent to a head office for further processing.

2.1.1.2 Gauging by Automatic Recorders

Water level gauging is increasingly being done by automatic recorders. These comprise a sensor that registers the water level, a chronometer that registers the time and a registration device that stores the results.

Data can be recorded on paper charts drawn by clockwork. This is the most common type of automatic recorders in the Nordic countries today. Alternatively the data can be stored on punched tape or magnetic tape, or taken directly into the memory of an electronic recorder. Such recordings are taken at fixed time intervals and may indicate both the time and the level or the level alone. Data stored in a permanent memory can be transmitted by telecommunications to head office. Alternatively, the module containing the permanent memory can be collected on visits to the station and read at head office.

Most automatic recorders use a float as the sensor. This is usually immersed in a gauging well connected to the river by one or more horizontal pipes.

The float is usually connected to the recording unit by a wire that runs over a wheel with a counterweight at the other end. The installation must be made so all different water levels can be gauged.

To ensure that the recordings correspond with the water level in the river or lake, a scale must be installed at the point of measurement. On visits to the station, and every time the paper or other recording medium is changed, the water level must be read on this scale. It is not enough to read only the gauging scale in the well, because the connection with the river may have been broken.

Other types of sensors in use in Nordic countries include needle gauges which can be lowered or raised to the surface at certain time intervals. Such sensor register the level of the water surface. These are mostly used for water level recording in urban areas.

In Norway pressure-recording charts are used to a certain extent. These are based on the principle that the pressure at a fixed point in a column of liquid is proportional to the height of the column above that point. Usually a bubble arrangement is used to register the pressure.

Alternatively, the water level can be recorded by acoustic signals. Such sensors function in the same way as echo-sounding devices. Gauging stations of this kind are not part of normal station network in the Nordic countries today.

2.1.1.3 Survey of Gauging Techniques Presently Used in the Nordic Countries

Table 2.1 gives a survey of the number of gauging stations for water level gauging in the Nordic countries, divided into the various measuring techniques being used in 1980. There is now both an increasing use of telemetric stations and a greater number of manual stations with recorders.

The difference in the networks of stations can partly be explained on the basis of their historical evolution, but reflects also the difference in the hydrological organisations and the use made of the data.

Table 2.2 shows the distribution of the gauging stations quoted, divided into rivers and lakes.

Table 2.1: Water Level Gauging Stations in the Nordic Countries (1980)

	Denmark	Finland	Iceland*	Norway	Sweden
Total number of stations	238	572	157	1160	300
for flow rate	189	358	105	690	233
for water levels	49	214	21	470	67
Non-Registering Stations					
By direct reading		413	14	612	71
using scale	15			582	68
using low-water bolt addition to scale	0	85		120	20
using low-water bolt alone	0	58		30	3
By indirect reading	0	0		0	0
Registering Stations					
By float,	223	159	123**	548	229
with chart registration	222	159	110**	500	229
with magnetic tape registration	1	0		6	0
By pressure registration	0	0	9	19	0
Telemetric Stations	0	0	3	23	10

* These figures are from Rist (1980)

** Includes 11 artesian recorders

Table 2.2: Water Level Stations in the Nordic Countries According to Type (1980)

	Denmark	Finland	Iceland	Norway	Sweden
Gauging stations in rivers	202	301	105	635	156
manual	3	214		220	24
automatic recorders	199	87		415	132
telemetric	0	0		0	4
Gauging stations in lakes and reservoirs	36	271	21	525	144
manual	12	199		380	47
automatic recorders	24	72		122	97
telemetric	0	0		23	6

2.1.2 Discharge Data

Many different techniques can be found for gauging discharge in rivers. The choice of method depends on the condition of the river where the gauging is to be done, as well as the national practice. This chapter concentrates on techniques used in the Nordic countries. To obtain information about other gauging techniques refer to Herschy (1978).

2.1.2.1 Individual Recordings

Individual recordings describe gauging or the appraisal of the flow rate at a given time or the highest flow rate reached during a flood.

The most common gauging method in the Nordic countries is the so-called velocity-area method. It involves calculating the area of a cross-section of the river and measuring the mean velocity of the river through it. The area is calculated by measuring a number of verticals over the cross-section.

The velocity can be determined using floats and other instruments. Virtually all discharge measurements by this method are taken with the help of current meters which measure the velocity at a number of points on each vertical. The number of revolutions for each gauging is determined by means of a counter and a stopwatch. Data are recorded on a data form or in an observations book.

At power stations and outlet systems, measuring instruments are also used that convert kinetic energy of potential energy, eg, venturi channels.

In turbulent rivers lacking good sites for current meters, a tracer is put in the water to gauge the flow rate. This is called the diluting technique. Tracers such as a common salt, colouring or radio-active isotopes are used. This method has especially been used in Norway. Usually common salt has been used as a tracer.

The dilution technique usually entails laboratory work after readings have been taken. In Norway an alternative procedure has been used which was first published by Sognen and Aastad (1928). Time points, amount of dilution and calibration curves, that are necessary to calculate the flow rate, are recorded on special data forms.

A number of methods exist for indirect determination of maximum discharge during flooding, after the flood has peaked. These are based on charting the peak water levels and thereby the profile of the water surface. The flow rate can then be worked out by calculation according to hydraulic laws.

By such methods Manning's formula is often used to reconstruct peak flow rates in rivers and open channels. Where the river has been narrowed by a bridge, the surface profile will be changed. If this is known, one can estimate the flow rates from the energy and continuity equations. Corresponding techniques can be used to estimate flooding in culverts.

For dams, the flood flow rates can be found with the help of overflow formulae. Choice of an overflow formula depends on the type of dam.

Indirect gauging techniques must be used because there are few gaugings available of extreme floods. This is partly because conditions for measuring at the site become impossible and partly because such floods are often short-lived so that qualified personnel cannot reach the gauging site in time.

Table 2.3 gives a survey of the distribution of various gauging methods used in the Nordic countries.

Table 2.3: Flow-Rate Readings in the Nordic Countries According to Gauging Methods in 1980

	Denmark	Finland	Iceland	Norway	Sweden
Total number of readings	1810*	400		650	200
with allowance for ice**		140		200	40
by current meter	1785	400		620	200
by tracer	0	0		30	0
by float	25	0		0	0
All figures are approximate					

* Includes measurements from all the 202 permanent stations. There were at least as many measurements taken from other localities.

** The need to make an allowance for ice varies a lot from year to year in Denmark. On average an estimated 10% of measurements are taken in connection with the ice allowance.

2.1.2.2 Continuous Methods

Gauging discharge is a time consuming operation requiring special equipment and qualified personnel. By comparison, water level measurement is simple. The relation between water level and discharge is determined by a control section below the gauging station. Depending on the form of the control section, various profiles can be determined for the shape of the discharge curve at high and low water levels. As long as the control section remains unchanged, the discharge curve will remain stable. An important task in quality control is to establish if and determine when the control profile has been changed.

The discharge curve can be expressed either in table form or as an equation of the type:

$$q = a(h - h_o)^b$$

where q is discharge, h the water level, h_o zero point for that particular curve segment and a and b are constants. The relation is determined from concurrent measurements of water level and discharge. Often the curve will be composed of several segments with different values of the curve constants.

At many stations this definite relation will be disturbed by obstructions of ice in winter and vegetation in summer. This requires extra discharge gaugings and special data processing, outlined in section 2.3.

Based on measurement of the energy production, the discharge through a hydro-electric power station can be calculated by the formula:

$$P = pgeQh$$

where P is the power output, p the density of the water, g the acceleration due to gravity, Q the discharge, h the fall and e is efficiency.

This formula gives the immediate discharge. To find the mean discharge per day, the daily energy production and the daily fall are used.

Discharge from reservoirs is calculated from information on gate positions and by the aid of overflow formulae when the water level is known.

In smaller rivers and canals, fixed gauging devices such as weirs and flumes are used. At places of unstable profile, concrete foundation plates can be built on the riverbed to establish better gauging conditions. Such stations are mostly used in connection with special research projects and hardly ever in the normal network of stations in the Nordic countries.

Table 2.4 is a survey of recorder stations in the Nordic countries. Table 2.5 gives a classification of stations grouped by size of catchment area.

Table 2.4: Classification of Discharge Stations in the Nordic Countries

	Denmark	Finland	Iceland	Norway	Sweden
Total number of stations	189	358	105	690	337
Stations with stage/discharge curves	182	205	75	646	233
- with scale and manual reading	0	105	12	206	58
- with registering equipment	160	63	90	410	153
- with registering equipment and gauging weirs	22	57		30	22
Stations without definite stage/discharge curves	7	133	30	44	104
- power stations	2	109		38	96
- reservoirs	5	24		6	8
Stations with direct discharge registration	0	0		0	0

Table 2.5: Classification of Discharge Stations in the Nordic Countries According to Size of Catchment Area

Catchment Area (km^2)	Denmark	Finland	Iceland	Norway	Sweden
> 10	5	33		30	18
10 - 100	111	34		214	32
100 - 1 000	70	106		329	122
1 000 - 10 000	3	132		102	130
10 000 <	0	53		15	35

Table 2.6 shows the number of stations considered to have a stable discharge curve and those influenced by obstructions of ice or vegetation. It also shows how many stations are affected by obstructions downstream.

Table 2.6: Quality Evaluation of Stage-Discharge Curves

	Denmark	Finland	Iceland	Norway	Sweden
Number of stations with stable discharge curves	18	130		300	163
Number of stations with ice obstructions	189	91		368	61
- every winter	149	85		245	36
- occasional winters	40	6		123	25
Number of stations with obstructions caused by vegetation	171	3		6	8
Number of stations with natural alteration of the control profile or the control section	*			12	0
Number of stations affected by downstream obstructions	3	4		4	1
- natural	1	3		2	0
- caused by human activity	2	1		2	1

* Probably occurs to a large number of stations, but vegetation blockages are probably so dominant that the remaining causes cannot be isolated.

2.2 Primary Processing of Data

Hydrometric data for processing and storing in various registers consists mainly of time series, observed at certain points of time with fixed or variable measurement frequency, or by continuous measurement. In addition, correlated values of water level and discharge are observed in order to establish discharge curves.

2.2.1 Time Series Data

At every station the water level or discharge is observed as a function of time.

Data are recorded by different media according to the instruments and purpose of the station.

There are a number of stages that apply to the collection and processing of such data, regardless of which recording medium or gauging technique is used. They are:

(1) The field stage. This includes the gauging itself, the transfer to the recording medium, change of paper or other storage medium, and registering and assembling control data and other information necessary for further processing.

(2) Transfer of data to the office. This can be done through the mail or telecommunications.

(3) Recording and preparing stage. If data are not received they must be requested from the field station. Individual error control and correction of obvious errors and preparation for digitising follow.

(4) Punching or digitising.

(5) Feeding data into the working register with various automatic controls.

(6) Interactive fault-finding and correction, ice conversion and completion.

(7) Feeding into historical archives, final control and approval.

Parts of this process can be done locally in regional offices, although this is not taken into account in the system charts that follow.

2.2.2 Water Level/Discharge

These data also go through a series of stages:

(1) The field stage, which covers the gauging itself with transfer to the punched form. Data are taken to the district office or head office for further processing.

(2) Preparation for punching.

(3) Punching.

(4) Computation.

(5) Evaluation of results. Hydraulic controls. Comparison with existing curve, if any. Approval if needed.

(6) Working out a new curve based on gaugings. Testing of the curve.

Figure 2.1 shows the sequence in the collection of data registered at telecommunication stations and conversion of data with a fine time resolution. Figure 2.2 shows the sequence for error correction and ice conversion. Figure 2.3 shows the sequence of data processing of discharge gaugings. All figures show how quality control can be carried out.

2.3 Processing of Data When the Point of Gauging is Influenced by Obstructions

The use of discharge curves is dependent on the connection between water level and discharge being stable. This in turn is reliant on the gauging stations not being influenced by obstructions downstream (eg, downstream lakes or confluences of tributaries). In such cases the water level should be gauged on two scales and calculated by the two-scale method (which is not discussed here).

A much more important cause for the disturbance of this water level/ discharge connection is when blockages of ice or vegetation are formed in the control section or reach of river. Water level data collected in such times must either be corrected or be converted to discharge using corrected discharge curves.

2.3.1 Ice Blockages and Ice Conversions

In the Nordic countries the winter period varies from 8 months in the north to 1-2 months in the south. During winter there is usually a low run-off. Collectively the volume of run-off makes up usually only 10-30% of the yearly volume. In this period there can be problems in maintaining discharge stations. This influences the accuracy of determining the discharge. One reason is that ice may form in the control section. The ice can be of various types - ice slush floating in the water, a solid cover of ice, solid ice through to the bottom and dams of ice. All types of ice alter the hydraulic properties of the river and usually cause the water-level to rise. In these circumstances the water levels observed will give too high a discharge figure and must be reduced.

Table 2.6 includes the number of stations in the Nordic countries that are influenced by ice.

In Norway correction and ice conversion are usually carried out during the water level observations whereas the discharge is calculated by means of the discharge curve. In the other Nordic countries the corrections on the discharge are calculated out from dammed up water levels.

DIGITAL DATA FROM TELEMETRIC STATIONS

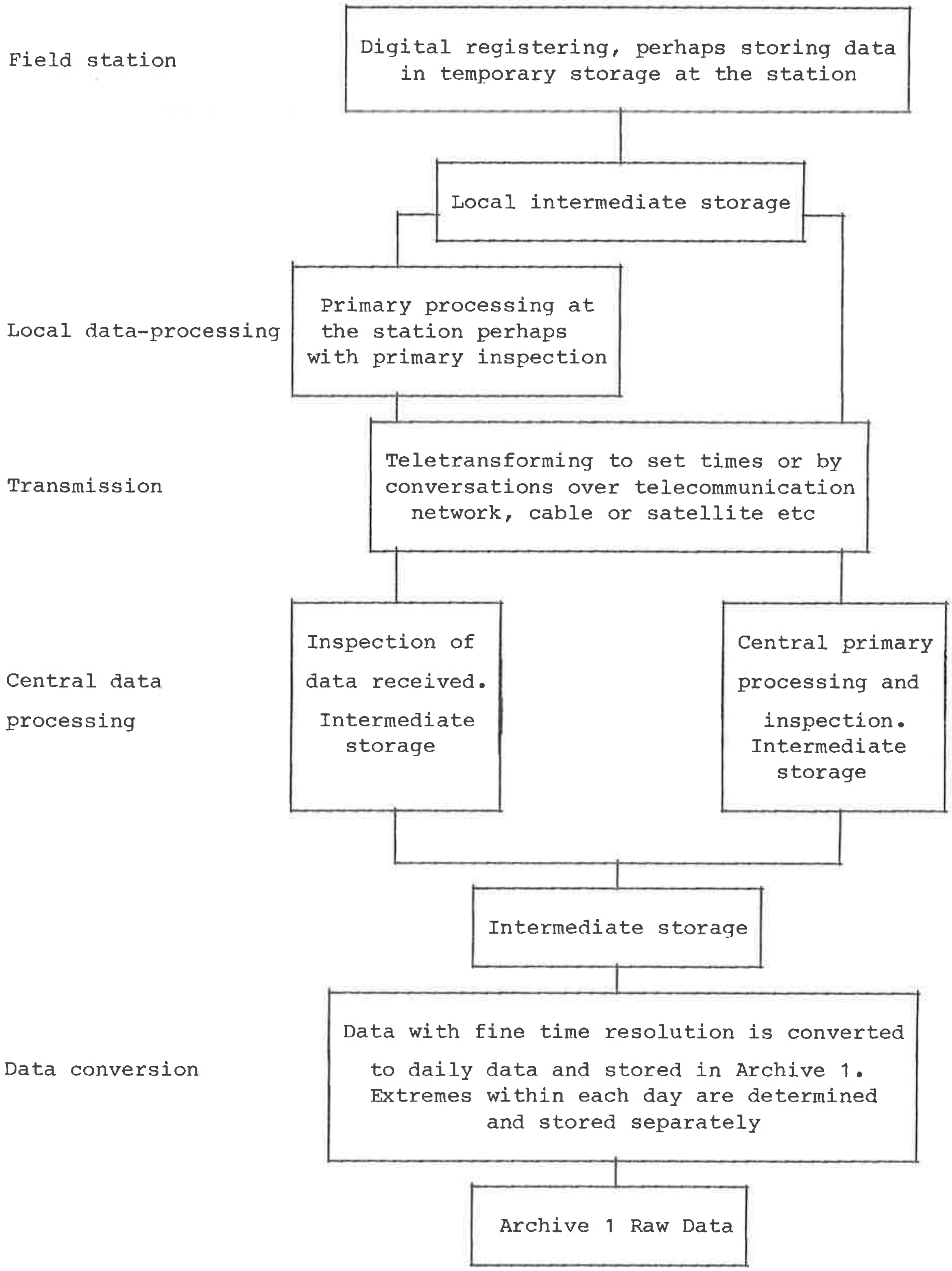


Figure 2.1: Flow Chart for Data from Telemetric Stations, Collection and Conversion

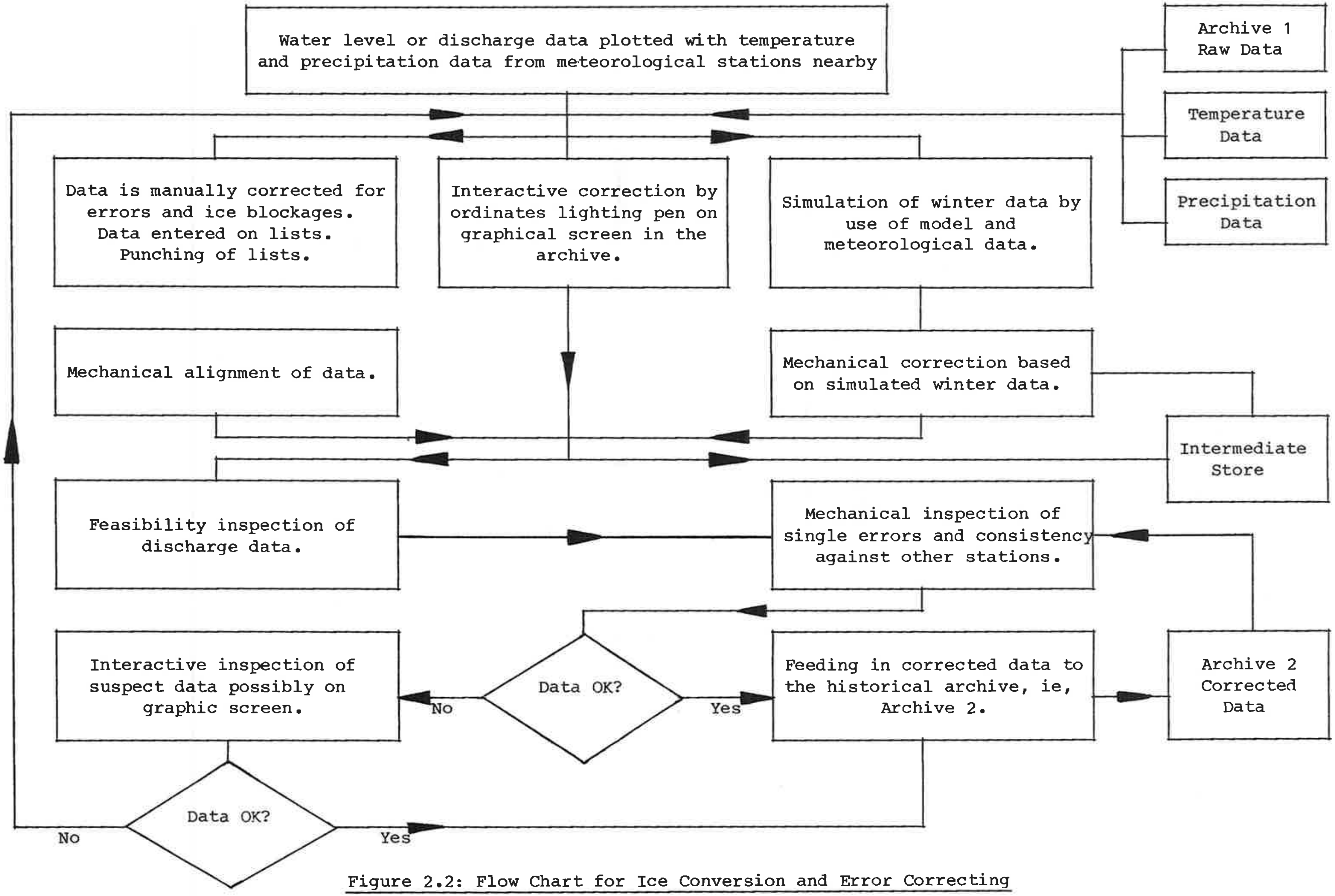


Figure 2.2: Flow Chart for Ice Conversion and Error Correcting

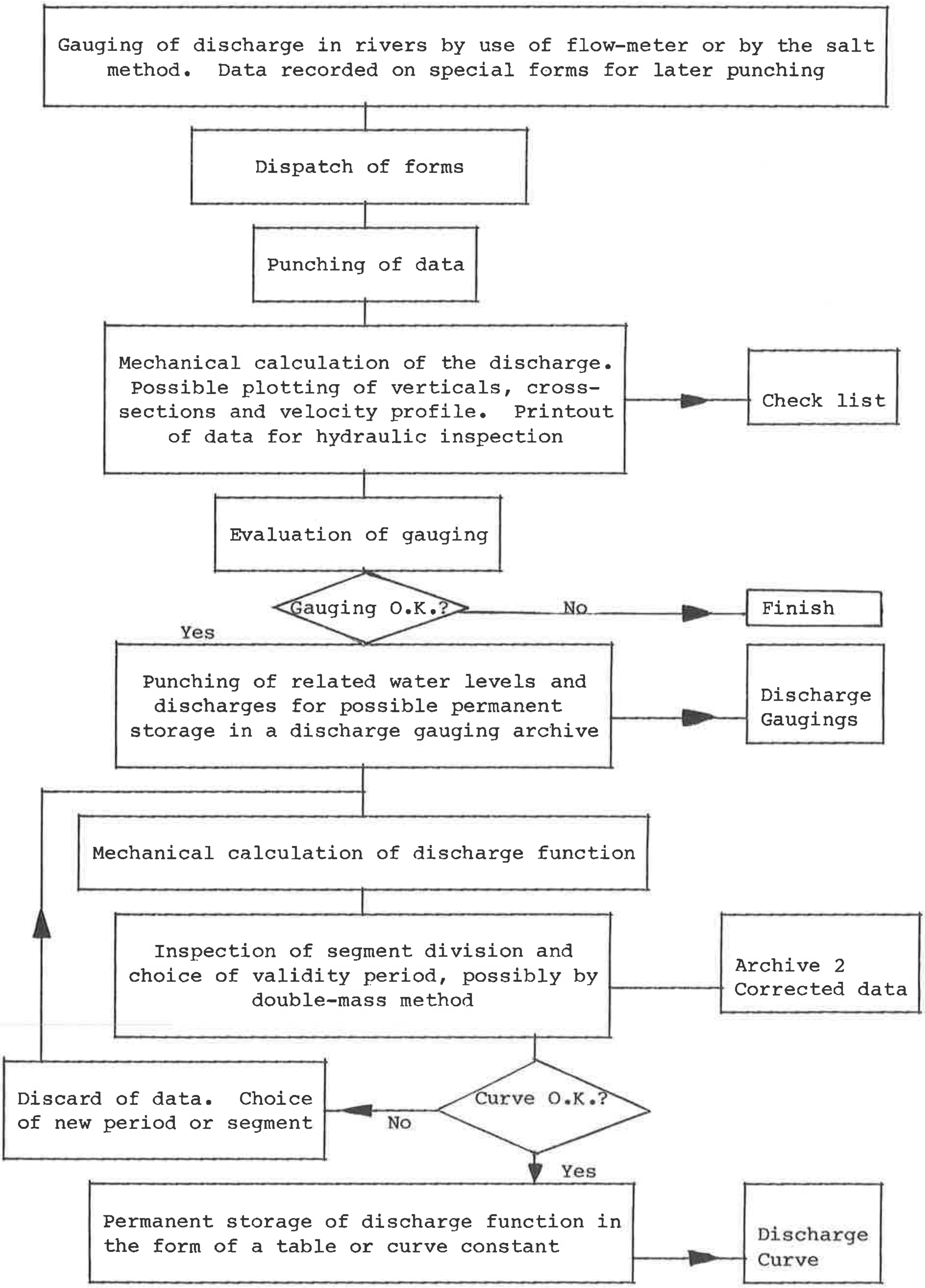


Figure 2.3: Flow Chart for Processing Discharge Data

Such ice conversions are based mainly on a subjective judgment by the hydrologist who performs the conversion. For stations with constant changes of cold and mild weather periods it can be difficult to decide if water level changes are caused by changes in water flow or by ice blockages. Snowfall on ice covered lakes will press out equivalent water masses so the discharge increases even if the temperature is under 0°C. Ice changes upstream can, in the short term, cause storing of water and thereby reduce discharge at the station. When the dam of ice breaks later, there will be minor flooding.

Another phenomenon that occurs in connection with ice cover on a river is that the discharge is quickly reduced because considerable amounts of water are bound up in the form of ice. For example a quiet flowing river that is 50 km long and 100 m wide will bind water in the form of ice that is equivalent to a discharge of 3 cumecs when the mean temperature is -10°C.

2.3.1.1 Procedure for Ice Conversion

The most used technique for ice conversion is the graphical method. Discharge gaugings that have been taken during winter are used as an aid. It is preferable to use as many winter gaugings as possible, but in practice there are usually just one or two gaugings taken at each station during winter. This may be sufficient for stations with stable winter conditions and a decreasing discharge throughout winter, but is not enough in areas with frequent changes between cold and mild periods.

Discharge gaugings during winter are less reliable than those from ice-free conditions. The gauging uncertainty can amount to 50%. At the same time the measured discharge can be far less than in the equivalent ice-free water levels and discharge gaugings that the discharge curve is based on.

The method consists of a hydrograph showing the blocked water levels or discharges. The measured discharges or corresponding blocked water levels are plotted in the graph. Then the blocked data is reduced in such a manner that the new hydrograph goes through the gauged points.

If the discharge falls steadily over the winter it can be interpolated mathematically by determining the recession equation. In practice though, the hydrograph is determined by drawing it through the gauged points manually or interactively on a graphic screen-terminal.

If one or two nearby stations can be found that are not affected by ice blockages, data from them can be used as an aid for ice conversion. Temperature and precipitation records from nearby weather stations can also be used.

Other methods of ice conversion include the "Koupilas" method which is also based on discharge gaugings taken during winter. From the gauged and estimated discharge, calculated from the blocked water level, a conversion factor is found that can vary throughout the winter. This technique suits stations with stable winter conditions best. For stations with unstable winter conditions, the conversion factor will vary irregularly. The technique is most unreliable at the beginning and end of the ice period.

The "Kovalevs" method also uses a conversion factor. This is determined from the geometry of the section and from the water level and ice thickness gaugings.

There have also been attempts to use mathematical runoff models for ice-conversion by calibrating these for frost free periods. Later the model has been used to simulate discharge data in the ice period. Experiments in Denmark show that there are certain problems with this method, because the recession in the ice period seems to disagree with the recession in dry weather periods without frost.

2.3.2 Vegetation Blockages

From Table 2.6 it is apparent that vegetation blockages are especially a problem in Denmark, though the problem is also found to a lesser degree in the other Nordic countries.

Nearly all the Danish gauging stations have reach control, that is the water level at the gauging station is calculated from cross-section and hydraulic roughness in the reach of river downstream.

In reach control the connection between discharge and water level varies depending on profile geometry and hydraulic roughness. Changes in roughness are usually dependent on the seasons, as they are caused by vegetation in the riverbed.

In order to take the vegetation into account, a different method is used in Denmark to calculate the discharge from the water level. As in rivers with section control, discharge curves are established based on correlated gaugings of water level and discharge, taken in ice and vegetation-free periods.

Based on frequent discharge gaugings and knowledge of actual times for cutting vegetation, the discharge is found for times between gaugings. It is calculated from gauged water levels and a discharge curve that is continuously adjusted during the growing period.

2.4 Sources of Errors

The method used to detect errors in water level or discharge data depends on the type of error. The Working Group has analysed the different gauging techniques that are used in the Nordic countries today. The purpose of this analysis has been to find out which types of errors are most likely to be found in data collected by the various methods.

The results of this analysis are shown in the following tables. Here the errors are grouped according to the source of error such as the observer, instrumentation, other installation at the point of gauging, inspection routine, preparation and office routine. The errors are numbered in the tables. Chapter 3 contains tables of the techniques which can be used to detect the various errors.

It must be emphasised that the following tables are not based on any systematic research in archives to establish the actual error frequency. The tables can therefore show errors that never occur. There may also be types of errors overlooked by the Working Group.

Table 2.7: Types of Errors in Reading Off Fixed Scales

No	Caused by	Type of Error
1.1.1	Observer	Systematic error in reading.
1.1.2	"	Metre read instead of decimetre, or opposite.
1.1.3	"	Error in copying, eg, 1.8 instead of 1.08.
1.1.4	"	Misreading because of water level variations at the time of reading (splash or blockage effect).
1.1.5	"	The observer does interpolations himself.
1.1.6	"	Illegible handwriting.
1.1.7	"	Wrong number of days in the month given.
1.1.8	"	Individual errors in observed level.
1.1.9	"	Missing station number and/or date.
1.2.1	Scale	Choice of division and markings that lead to misunderstandings.
1.2.2	"	The scale hangs crookedly or sits incorrectly.
1.2.3	"	The scale cannot be read at all levels.
1.3.1	Installation inspection	The hydrologist chooses wrong zero point.
1.3.2	" "	The hydrologist gives misleading instructions to the observer.
1.4.1	Office processing	Mixed up station numbers or zero point.
1.4.2	" "	Faulty recording by the punch operator.

Table 2.8: Sources of Errors With Chart Water Level Recorders

No	Caused by	Type of Error
2.1.1	Observer	Error in reading the reference watermark (see 1.1.1-1.1.4, 1.1.6).
2.1.2	"	Water level read from the chart instead of the reference scale.
2.1.3	"	Clockwork not wound up.
2.1.4	"	Wrong idling adjustment.
2.1.5	"	Error in time registration and station identification (see 1.1.8, 1.1.9).
2.1.6	"	The pen is not checked.
2.1.7	"	The paper is not fastened on the cylinder.
2.1.8	"	The paper is inserted the wrong way or unevenly.
2.1.9	"	Wrongly scaled chart installed.
2.1.10	"	The paper is not changed on time.
2.2.1	Scale	Error in the reference scale (see 1.2.1-1.2.3).
2.3.1	Diagram	Wrong lines on the diagram.
2.4.1	Instrument	Fault in the turning (reverse) screw.
2.4.2	"	Fault in the coupling (connection).
2.4.3	"	The pen gets stuck in, or tears up the paper.
2.4.4	"	The line slips on the wheel.
2.4.5	"	Float not watertight.
2.4.6	"	Change in shape of the float.
2.4.7	"	Wrong length of the line.
2.4.8	"	The weight or the float get stuck in the well or collide.
2.4.9	"	Fault in the clockwork.
2.4.10	"	Bad balance between float and counterweight.
2.5.1	Well	Poor connection between the well and watercourse. (The connecting pipe filled with silt, broken pipe or ice in the well.) The pipe lies higher than the lowest water level.
2.5.2	"	Poor calming effect.
2.5.3	"	Mixed density in the well (because of saltwater).
2.5.4	"	The well is not vertical.

2.6.1	Installation	inspection	The hydrologist records the wrong water level on the diagram.
2.6.2	"	"	Hydrologist installs the float and counterweight so that registering direction is altered.
2.6.3	"	"	Hydrologist chooses wrong zero point.
2.6.4	"	"	Hydrologist gives wrong instructions to the observer.
2.6.5	"	"	Hydrologist gives wrong exchange proportions.
2.7.1	Office		Mixed up chart scales.
2.7.2	"		Too few water levels taken from the chart.
2.7.3	"		Wrong water level recorded.
2.7.4	"		Misinterpretation of reversed recordings.
2.7.5	"		Chart trace too thick. Difficult to decide which is the mean curve (see 2.5.2).
2.7.6	"		Fault in digitising instruments.
2.7.7	"		Mistaken reconstruction of missing or wrong recordings.
2.7.8	"		Misjudgement of assumed error.

Table 2.9: Types of Errors With Punched-Tape Water Level Recorders

No	Caused by	Type of Error
3.1.1	Observer	(See 2.1.1, 2.1.3-2.1.5.)
3.1.2	"	The observer makes incorrect markings on the tape.
3.1.3	"	Incorrect installation of the tape.
3.1.4	"	Tape wrong way on the spool.
3.1.5	"	The observer has not changed the tape on time.
3.2.1	Scale	Error in the reference scale (see 1.2.1-1.2.3).
3.3.1	Tape	The tape absorbs moisture and swells. This leads to the punching mechanism getting jammed.
3.3.2	"	The tape breaks.
3.4.1	Instrument	(See 2.4.4-2.4.10.)
3.4.2	"	Skips punching or punches too often.
3.4.3	"	Some pins in the punch get jammed.
3.4.4	"	Mechanical breakdown in the punching mechanism.
3.4.5	"	Electronic fault in the signal equipment.
3.4.6	"	Power failure.
3.5.1	Well	(See 2.5.1-2.5.4.)
3.6.1	Installation inspection	(See 2.6.2-2.6.5.)
3.7.1	Office	The tape is torn during interpretation.
3.7.2	"	Wrong identification of the tape.
3.7.3	"	Incorrect punching of start and finish times with relevant water levels.

Table 2.10: Sources of Error for Magnetic Tape Water Level Recorders

No	Caused by	Type of Error
4.1.1	Observer	(See 2.1.1, 2.1.3-2.1.5.)
4.1.2	"	The cassette inserted the wrong way.
4.1.3	"	Cassette not changed in time.
4.2.1	Scale	Errors in the reference scale (see 1.2.1-1.2.2.).
4.3.1	Instrument	(See 2.4.4-2.4.10.)
4.3.2	"	Magnetising error.
4.3.3	"	Dust on the writing head.
4.3.4	"	Power failure.
4.3.5	"	Scratches and wear on the tape.
4.4.1	Well	(See 2.5.1-2.5.4.)
4.5.1	Installation inspection	The hydrologist records the wrong water level when inspecting.
4.5.2	" "	(See 2.6.2-2.6.5.)
4.6.1	Office	Cassettes mixed up.
4.6.2	"	(See 3.7.3.)

Table 2.11: Types of Errors by Digital Recording With Following Teletransmitting of Data

No	Caused by	Type of Error
5.1.1	Mechanical gauging instruments	See 2.4.4-2.5.4 for gauging instruments that use floats. Other gauging principles will lead to other types of errors that should be evaluated individually.
5.2.1	Electronic equipment	Error in conversion from gauging signal to digital value.
5.2.2	" "	Other electronic errors at the field station.
5.2.3	" "	Electronic error at the receiver station.
5.2.4	" "	Programming error at the field or receiver station.
5.2.5	" "	Internal loss of power.
5.3.1	Transmission of data	Break in the transmission line.
5.3.2	" " "	Noise on the line (can lead to errors in the transmitted signal).
5.3.3	" " "	Error in transmission of data from the receiving station to the main computer.

Table 2.12: Types of Error When Gauging in Gauging Weirs and Fixed Gauging Structures

No	Caused by	Type of Error
6.1.1	Recording instrument	See sources of error when recording on charts, punched tape, magnetic tape or telemetered instruments.
6.2.1	Gauging-construction	Gauging weir leaking.
6.2.2	"	Fault in the geometry of the opening.
6.2.3	"	Fault in the construction of the inlet channel.
6.2.4	"	Possible blockage below the weir.
6.2.5	"	Inlet channel and gauging construction are not constant (caused by vegetation and sedimentation effects).
6.2.6	"	Changes in the crown of the dam or the level of the weir invert relative to the scale.
6.3.1	Calibration	Calibration error.
6.4.1	Office	Use of wrong calibration method.

Table 2.13: Types of Errors in Discharge Gauging With Current Meters

No	Caused by	Type of Error
7.1.1	Observer	Error when reading water level.
7.1.2	"	Error when gauging depth or distance from the river bank.
7.1.3	"	Gauging time too short.
7.1.4	"	Gauging time misread.
7.1.5	"	Numbers of signals misread.
7.1.6	"	Number of gauging points insufficient.
7.1.7	"	Misjudgement of water transport past gauging points in contributing creeks.
7.1.8	"	Error in determining the 'threshold' (riverbed etc at gauging station).
7.1.9	"	The current meter is not positioned correctly in relation to the current.
7.1.10	"	The current at the meter is influenced by the boat or observer.
7.2.1	Gauging station or conditions	Rapid change of water level during gauging.
7.2.2	"	Back eddy.
7.2.3	"	Rocks in the gauging profile.
7.2.4	"	Inward current at the bottom in opposite direction to the surface current.
7.2.5	"	Cross current.
7.2.6	"	Build up-silting etc.
7.2.7	"	Ice or vegetation in the river.
7.3.1	Instrument	Calibration fault.
7.3.2	"	Number of signals incorrect.
7.3.3	"	Friction too high (oil viscosity too high, ice in the current meter etc).
7.4.1	Office	Calibration curves mixed up.
7.4.2	"	Punching errors.
7.4.3	"	Error in calculation of the velocity profiles or discharge profile.

Table 2.14: Types of Error When Discharge Gauging Using Salt Solution

No	Caused by	Type of Error
8.1.1	Observer	(See 7.1.1.)
8.1.2	"	Insufficient mixing of the brine.
8.1.3	"	Error in measuring the volume of brine.
8.1.4	"	Time misread during gauging.
8.1.5	"	Misreading of conductivity or resistance.
8.1.6	"	Gauged data misrecorded.
8.1.7	"	Inaccuracy in mixing of secondary solution used during calibration.
8.1.8	"	Inaccurate extraction of volumes of secondary solution during calibration.
8.1.9	"	Insufficient stirring of the solution in the calibration basin.
8.1.10	"	Uncleanliness leading to contamination of the calibration basin.
8.2.1	Gauging section and conditions	(See 7.2.1.)
8.2.2	"	Poor mixing of the brine in the water through the whole profile. (Detected by use of dye.)
8.2.3	"	Variation in the natural conductivity of the water.
8.2.4	"	Temperature difference between river and calibration basin.
8.2.5	"	Precipitation or spray from waterfall into the calibration basin during gauging.
8.2.6	"	Insufficient transport time for the brine in the river leading to an excessive concentration. (Can be corrected by moving the release point upstream.)
8.2.7	"	Insufficient brine so that the salt concentration is difficult to measure.
8.2.8	"	The electrodes lie in a pool with poor exchange of water so representative gaugings are not possible.
8.3.1	Instrument	Unfortunate choice of sensitivity area, such that the highest concentrations fall outside the area or that changes in concentration can hardly be read.
8.3.2	"	Faulty electrodes.
8.3.3	"	Poor connection between electrode and the instrument.
8.3.4	"	Other faults in the instrument.
8.3.5	"	Uneven speed on magnetic tape recorder where used.
8.4.1	Office	Error in punching.

Table 2.15: Types of Error in Adjustment and Use of Discharge Curves

No	Caused by	Type of Error
9.1.1	Observer/hydrologist	Discrepancy in water level reading between the observer and the hydrologist that measures the discharge.
9.2.1	Adjustment of discharge curves	Use of wrong data when adjusting the formula.
9.2.2	" " "	Error in extrapolation to higher or lower ungauged water levels.
9.2.3	" " "	Unsuitable choice of formula during adjustment.
9.2.4	" " "	Unsuitable division of curve segments.
9.3.1	Use of curve to calculate the discharge	Undetected changes in the control section.
9.3.2	Discharge	Vegetation build-up not allowed for.
9.3.3	"	Ice build-up not allowed for.
9.3.4	"	Discharge curves mixed up.

Table 2.16: Types of Error in Data Collected from Storage Lakes and Power Stations

No	Caused by	Type of Error
10.1.1	Observer/gauging equipment	Error in storage lake water level (see 1.1.1 and 1.1.2).
10.1.2	Gauging programme	Observations of storage lake water levels too infrequent.
10.1.3	" "	Missing observations of overflow.
10.1.4	" "	Error in given release gate positions.
10.1.5	" "	Variation in water level between the storage lake scale and the weir crest/release gate.
10.1.6	" "	Error in amount of fall used in calculation of discharge.
10.1.7	" "	Error in measuring energy production.
10.2.1	Calibration errors	Error in storage lake curve.
10.2.2	" "	Error in overflow formula for dam.
10.2.3	" "	Error in calculation of discharge from release gate.
10.2.4	Wear on needles, guide wheels and blades/vanes	Incorrect efficiency value used in calculation of discharge through the power station.

3. SEARCHING FOR ERRORS

3.1 General

Quality control should be carried out at all steps of data collection and processing. It is important that any errors be detected as early as possible. The source of the errors is then usually easier to trace and quicker to remove.

It is therefore important to search for errors:

(a) in the field;

(b) during recording and preparations;

(c) while entering into the recording system;

(d) during ice and vegetation conversion and correlation with historical data.

3.2 Inspection in the Field

The most effective form of control for finding and eliminating causes of error is, without doubt, control incorporated in station inspection.

The various Nordic countries have different routines for station inspection. Inspections are necessary to check that instruments and other gauging equipment function correctly. Furthermore, it is important to detect possible changes in the hydraulic control of water level at the recorder.

All relevant information about the station must be recorded so that it can be included in that station's historical records. At present in Norway an inspection form is filled in when the station is visited (see enclosure 2). Until now these forms have not been processed regularly. Forms of this kind can make a valuable contribution to a continuously updated station history if information is regularly taken out and stored.

3.3 Controls in Recording and Preparation of Data

Many errors can be detected by the recording of incoming data and in preparation for digitising. The following should be especially emphasised:

(a) that data is received;

(b) that the identification of the station is correct;

(c) that there are no obvious writing errors in control data or observation books;

(d) that the recordings seem reasonable;

(e) hydraulic controls of discharge gaugings.

3.4 Controls During Digitising

Some errors can be detected during digitising or punching, especially by experienced operators. By double-punching, punching errors can virtually be eliminated. Double-punching will also reveal if the basis for the punching is so unclear that it can be interpreted in more than one way. Calculation of digitised data and comparison with the basis used are today one aspect of the work in digitising charts. This technique is a severe method of inspection, but possibly unnecessary to check the digitising of diagrams.

3.5 Quality Control Based on the Use of Computers

Quality control of hydrometric data will usually be based on the use of comparative data in one form or another. Data will either be compared to earlier values from the dame series, with corresponding data from nearby stations or with simulated outlet series based on corresponding observations of precipitation and temperature.

A fundamental problem in quality control of data is that the comparable data can also contain errors. This makes it difficult to identify errors definitely. Bigger data-processing institutions yearly receive vast amounts of data. Newer instruments will result in sections of these data coming in with increasing swiftness. If these data are to be processed continuously, the time and effort that can be spent on processing a single data series are limited. As much as possible of the primary data control should therefore be automated. Suspicious data should be identified and noted through a system of automatic routines.

Data that are clearly incorrect should be rejected by the preliminary system or marked as explained in section 4.3. If such errors can be corrected by automatic techniques, that can also be done by the preliminary system.

Usually errors cannot be identified beyond doubt. There is therefore, often the need for a manual evaluation by the person responsible for the station, who knows the conditions at the place of gauging. As a help in such evaluations the person should use a system of interactive control routines. To simplify the work the test results should be written on data lists that contain a minimum of adjacent information. Graphical data charts are very effective in showing errors. This assumes the use of a graphic screen if large quantities of data are to be inspected.

There is a need to check long data-series when these are going to be used in different analyses. In such a control the time pressure is less than with continuous control of new data. It is therefore possible to use more time and resource demanding methods in such controls.

3.6 Methods of Quality Control Using a Computer

Table 3.1 lists methods that can be used to detect errors by means of a computer. The methods are numbered consecutively according to the order in which they are included in the data processing. In the tables which follow, the methods are referred to by their number in table 3.1.

Table 3.1: Survey of Techniques Used for Quality Control of Data

No	Method
1	Double punching by two different operators and mechanical inspection if simultaneous or following data coincide.
2	Comparison of mechanically made monthly totals and totals made previously using the punching basis.
3	Plotting of digitised data from charts for visual comparison with the original data.
4	Compare timing against the earliest and latest dates. If incorrect reject and report.
5	Check whether data are already recorded for the station for this period. If so and if the data deviate from what are already recorded, reject data and report.
6	Check whether the last value of the former reading coincides with the first value in the new data. If there is a large variation, report (and the new data should be rejected).
7	Compare time of recording on the diagram with that in the observer's notes.
8	Compare water level changes in the period of recording with the observer's reading on the reference scale. If the deviation exceeds, eg, 3 cm per chart, report.
9	Record in a manual or mechanical register, time and level variations for each instrument. Trends must be checked regularly. If sudden changes occur, the instrument/station must be inspected.
10	Carry out other controls on the function of the instrument, dependent on the way the instrument works.
11	Compare observed values against fixed or seasonal-dependent limit-values for the variation area. If the observation falls outside them, report.
12	Compare changes occurring between two consecutive values. If the changes are above or below fixed or seasonal-dependent limits, report.
13	Continuous control of 3-5 consecutive values with a search for unlikely combinations. (Best suited for data with a fine time-scale.)
14	Plotting of new observations for every day in the specific month or year on the same diagram as the highest, lowest and the mean value for every day in the month/year for earlier years.
15	Plot the difference between two consecutive days in the same way as in method 14.

16 Calculate monthly and yearly means for the outlet and compare these against data from earlier years.

17 Plot yearly or monthly hydrographs for several surrounding stations. Visually evaluate common variations.

18 Use of regression analysis on a daily basis against surrounding stations to identify situations that deviate greatly from the regression.

19 Use of precipitation/flow models to identify errors.

20 Compare discharges within a catchment area. If the discharge diminishes downstream and there is no transfer of water, a report should be given.

21 Analyse supply to storage dams, or of monthly supply. Long periods with negative supply point towards an error in storage data, storage curve or outlet data.

22 List and check the monthly extremes for every year in the series. (Used to detect gross errors.)

23 Compare yearly or monthly means for each year or month in the series against fixed or seasonal-dependent limits. (Used to detect gross errors.)

24 Analyse enveloping curves and means for each day in the year during the complete data series. (Used to detect gross errors.) As support also use enveloping curves for daily change in observed values.

25 Plot of data series (as yearly and monthly means) in same diagram as data series from other stations. (Detects gross errors, but can also indicate a break in uniformity.)

26 Use of regression analysis for yearly or monthly means. (Used to detect gross errors. Can also be used to indicate a break in uniformity.)

27 Test trends in yearly means. (Can show breaks in uniformity.)

28 Test trends in means for specific months. (Can detect redistribution of water during the year.)

29 Use of time-series analysis for monthly means. (By removing yearly fluctuations the autocorrelation formula can be used to detect breaks in unformity.)

30 Double mass analysis for yearly totals, seasonal totals etc. (Shows a break in uniformity.)

31 Various hydraulic controls for discharge gauging. To be taken in connection with calculations of the gauging results.

32 Frequency analysis of the number of values that fall outside the surveyed part of the scale's actual variation limits. Count up the

number of and contribution to the total outlet of the observed water levels that fall on the extrapolated part of the discharge curve. (Gives a general picture of the uncertainty in the calculated discharge.)

33 Frequency analysis of the difference between two gauging stations worked out from the daily water level on one of them. (Can indicate errors in the discharge curve restricted to certain levels.)

Some of the methods can be used in automatic controls. For such controls some methods need certain additional information if they are to function automatically. Incorrect limits for reasonability tests and particulars about stations for comparison and reference periods are relevant considerations here. Depending on the layout of the data archive and accessible computer resources, it may be necessary to store this kind of information in its own specific archive.

3.6.1 Controls During Feeding In

The majority of data to be fed in are water level data. During initial input they are not usually converted into discharge. The first quality control will therefore mostly be on water level data.

During feeding in, simple automatic control methods should be used that identify if possible, data that are mixed up, and that also test the function of the instrument. Depending on the nature of the preliminary system used, inspection of double punched data can also be done during feeding in. Methods 4-10 give techniques that can and should be built into the preliminary system.

In addition, reasonability tests should be built into the data (see methods 11-13). Such tests must be able to show physically impossible gauging results, but should in addition be able to sort out suspect observations. To avoid too much or no data at all being sorted out, the methods must be combined and used with individual test criteria for each station. This must be decided from knowledge of the normal variation pattern of the station.

3.6.2 Controls in Connection with Ice Conversion and Correction for Vegetation Build-Up

When data are converted because of ice, it is necessary to examine such data thoroughly. Today the graphical method described in section 2.3 is used extensively. By use of data for stations with no build-up, and precipitation and temperature data for surrounding climatic stations, many errors can be discovered and corrected.

After ice conversion, these data should be checked against other stations in the same catchment area or one nearby. Such checks must be used with care if all the stations are ice-converted. Moreover, different watercourses react differently on ice build-ups, depending on the catchment area's characteristics and the conditions in the riverbed near the station.

Nevertheless, the ice conversion must be done in the same manner for the one station for several years in a row. This can be inspected graphically or by certain forms of uniformity control.

For rivers with section control, the data goes through a similar analysis as with ice-conversion before the adjusted discharge curves are determined. This process gives corresponding possibilities for early error detection and correction.

3.6.3 Controls in Connection with Approval of the Yearly Data

Data are usually stored in the archives as daily values. Quality control should therefore be done while these data are being stored. The controls should be done partly for the water levels and partly for discharge data.

Before the data are approved, quality control should include checks of possible single errors over one or several days. Data should also be compared with other data in the same watercourse. Such discharges should be examined to see if they are consistent.

For this kind of quality control methods 11-21 can be used. Methods 11-13 can be used at this step as well as under the primary input. The test criteria that are used should now be seasonal-dependent, thus making them more exact.

The best form of quality control can be obtained by plotting the data. Water-level data should be plotted on the same chart as daily enveloping curves and means throughout the year (method 14). The likelihood of sudden floods or recessions can be evaluated by processing day to day changes in a similar way (see appendix 3).

Discharge data from nearby stations should be plotted on the same chart (method 17). This is used to detect single errors as well as to evaluate the consistency of data in the watercourse (see appendix 4).

Use of regression analysis to determine gross errors or "outliers" (method 18) is effective and can be used in automatic systems (see appendix 3).

Precipitation/Run-off models (method 19) and supply calculations (method 21) can be used for inspection of yearly data, but require more work and should only be used in special cases.

3.6.4 Errors in Long Series

In long series there will partly be:

single gross errors;

systematic error through the whole series;

uniformity breaks of various kinds.

When long series are being used in analysis of diverse kinds, it is important that quality controls be done before the data are used. Gross error that come up as the particular month's or year's absolute highest or lowest value can ruin extreme value analysis if they are not deleted.

3.6.4.1 Gross Errors

To detect single gross errors, the control should be carried out on daily values, including for long series. Only the very worst errors will affect monthly or yearly means to such a degree that such errors can be identified by inspecting these means.

Experiment shows that method 25 can often uncover suspicious data and tell when in the year it occurs. By writing out the monthly extremes for every year in the series, it is usually easy to find the particular year. When evaluating the data for that particular year, methods 14, 15, 17 and 20 can be used.

Use of regression-analysis against surrounding stations has been shown to be an effective way to detect "outliers". These often indicate gross single errors or systematic errors over a limited period. For long series such analysis should be done for pentadedata (see appendix 8).

Data series based on observations a few days apart must be interpolated to give daily values. In such series and in ice-converted series, there can be errors at the beginning of the melting period, and flooding may be omitted from consideration. To check such data where other discharge series are missing, precipitation and runoff models can reveal errors.

3.6.4.2 Searching for Systematic Errors in Long Series

If the same systematic error in data collection has been made during the whole observation period, such errors cannot be detected by the usual homogeneity tests. Use of the wrong discharge curves or systematic errors of reading during the whole observation period are examples of such errors.

These errors can be detected either by control at the station, with inspection of the gauging equipment and procedure, or by various forms of consistency tests.

Possible methods are numbers 17, 20, 21 and 25. By calculating the local flow between the suspect station and another station further up or down the river and comparing it with the discharge at a gauging station in a smaller side river, suspicious data can be checked.

If there is a suspicion that the discharge curve is causing an error, the uncertainty can be cleared up by use of methods 32 and 33 (see appendix 11).

3.6.4.3 Homogeneity Tests

The term homogeneity break is used to describe systematic changes in the data series during the course of time. Such changes can occur suddenly or gradually depending on their cause. Some homogeneity breaks occur at all water levels, while others occur only at high or only at low water levels. Other forms of homogeneity breaks occur only at certain times of the year. The redistribution of water during the year, without affecting the yearly mean is also a form of homogeneity break that often occurs in the data.

Homogeneity breaks can be caused by:

- climatic changes;
- undetected changes in the discharge curve caused by changes in the control profile(s);
- permanent disturbances in gauging instruments or conditions at a given point in time;
- construction of hydropower stations;
- other transfer of water in or out of the precipitation area;
- other human activity in the area, eg, widespread tree felling, swamp drainage, digging of canals, irrigation from wells.

Of these kinds of homogeneity breaks, profile changes and permanent disturbances in the gauging conditions and instruments are errors that must be detected. It can be difficult to differentiate between the various kinds of homogeneity breaks.

If the series itself is used, various trend tests can then be applied, as described in Markovitch (1975). Experiments show that it is difficult to detect homogeneity breaks in this way.

An alternative method is to normalise the series based on the calculated monthly means and the standard deviation for every month in the year. If the yearly fluctuation is still in place, this indicates that the means and standard deviations are not stable during the complete observation period, (method 29). This can be caused by artificial water regulation, but may also come from profile changes (see appendix 8). By dividing the data series in two parts at the assumed homogeneity break, the method can often verify that the actual point of time has been found.

Traditionally, double mass-analysis has been used in searching for homogeneity breaks (method 30). This method is still recommended (see also appendix 10).

By establishing regression formulae between yearly means of two stations and calculating data from the suspect series and then comparing these with the observed data, systematic deviations in parts of the series can indicate homogeneity breaks (method 26).

3.6.5 Control of Discharge Gaugings

When the results of a discharge gauging are available, there are certain controls of the various velocities and calculated discharges that should be carried out.

A test to work out if the critical velocity has been exceeded should be built into the calculation procedure. This control should be done so that every gauging point is calculated from:

$$F = v/\sqrt{g \text{ x } D}$$

where v is the measured velocity, g is the gravity and D is the depth. If $F \geqslant 1$, the critical velocity has been exceeded. In this case a report should be made.

If the velocity at certain points exceeds the critical velocity, this is not necessarily caused by errors. If $F \geqslant 1$, the gauging profile's shape should be appraised to ascertain whether it is caused by error in the velocity gaugings by the profile's position. If the latter, moving the gauging point should be considered.

For every discharge gauging, the area of the gauging profile's cross-section A should be calculated. In addition, the "wetted perimeter" U, hydraulic radius $R = {}^{A}/u$, mean velocity $v_m = {}^{Q}/A$, maximum velocity v_{max}, water surface width 8 and mean depth $D_m = {}^{A}/B$ should be examined.

If $v_{max} > 2v_m$, the verticals should be drawn up and examined more closely.

At gauging points with section control, where the roughness and the profile's shape are unchanged, $v_m/R^{2/3}$ will usually show little variation. In places with section control and possible vegetation build up $v_m/R^{2/3}$ will normally vary systematically with the water level and, in addition, vary with the changes in vegetation. The method used in discharge calculations in Denmark is shown in appendix 12. The control values are grouped at the bottom of the table.

If the gauged discharge varies considerably from the other gaugings from similar water levels and there is no ice or vegetation build-up, the gauging should be examined more closely. As a help in evaluating gaugings, table 2.13 or 2.14 can be used. When there is reason to doubt the gauging, the velocity profiles should be drawn up.

3.6.6 Quality Control of Water Level and Discharge Data Gauged Through Power Stations and in Storage Lakes

Many of the control methods described earlier are based on the water level or discharge varying in a similar way year after year with the precipitation and temperature as guiding factors. In regulated watercourses, the distribution of water throughout the year will usually be changed drastically, and in many instances water will be led into or out of the precipitation area. This makes it difficult to use many of the methods described earlier.

Data collecting in regulated areas is exposed to the same sources of errors as in unregulated areas, but has in addition some special sources of error. Obvious errors should be identified through controls in the preliminary system in the same way as data from unregulated areas.

However, the best controls that can be used are:

(i) calculating the supply of water to a storage lake from the amount of water let out, based on gate openings and possible overflow, lake water levels and storage lake curves. This supply can be compared to nearby unregulated run-off stations or with calculated local supply;

(ii) comparing the discharge through the power station calculated from the production (see chapter 2.1.2.2), with discharge calculated from gate positions or calculated from other gaugings.

4. CORRECTION OF ERRORS

4.1 Identification of Error

Chapter 3 gives a number of methods that can be used to inspect data at the various stages of collection. Data which do not satisfy certain requirements can be separated out with the help of these methods. Some of these data represent genuine extreme situations and should not be discarded. Others are caused by mistakes and should be corrected.

The effect of the various errors on the observed water levels or discharge can be observed by the various tests. From the effect shown, attempts must be made to find the cause of the error. For systematic errors, it is also important to find when the error occurred. When this is clarified, the errors should be corrected.

4.1.1 Identification of the Cause of Error

Virtually all errors described in section 2.4 will lead to mistakes, in the observed water levels or discharges, or in the recorded time for the observations.

The possible effects of errors are:

(a) data loss;

(b) single errors in the levels;

(c) non-systematic errors in the period, ie, records at one station are not in rhythm with data from stations nearby in a limited period;

(d) systematic errors in a limited period, ie, records follow the rhythm from stations nearby but the level is systematically displaced;

(e) systematic errors in the complete series;

(f) time-limited deviation in discharge from nearby stations with stable controlling sections;

(g) homogeneity breaks from a particular point of time.

Table 4.1 shows which inspection methods can be used in the control of data during checking-in and in the control of long data series, arranged according to the effect shown.

Table 4.2 gives a survey of possible sources of errors for the five main data-flow systems arranged according to the detected effect.

Table 4.1: Types of Errors Detected by Various Control Methods

Effect	Usual Cause	Control Method (see Table 3.1)		
		For Control	Input	Control of Long Series
Data disappearance		yes		
Single errors	Observor error. Punching error.		1, 2, 3 ...	
Non-systematic errors in the period	Mix-up. Misinterpretation.		As per booklet	
Systematic errors in the period	Error in the control data, ice or vegetation.			
Deviation in discharge for the calculated period	Ice, vegetation, erosion, sedimentation.			
Homogeneity breaks	Changes in field boundaries. Changes in drainage system. Profile changes.			

Table 4.2: Possible Sources of Error in the Various Data-Flow Systems, Grouped by their Effect on Gauged Water Levels or Discharges

Effect of the Error	Caused By	Type of Error Fixed Scale	Type of Error (see Tables 2.7-2.11)			
			Diagram	Punched Tape	Magnetic Tape	Telemetric Equipment
Data loss	Observer	Not observed				
	Instrument/gauging equipment	1.2.3			As per booklet	
	Forwarding/ transmission	Lost in the mail	Lost in the mail	Lost in the mail	Lost in the mail	5.3.1
	Data mix-up					
Single errors	Observer					
	Instrument/gauging equipment				As per booklet	
	Forwarding/ transmission					
	Control procedure					

Table 4.2: Possible Sources of Error in the Various Data-Flow Systems, Grouped by their Effect on Gauged Water Levels or Discharges (continued)

Effect of the Error	Caused By	Type of Error Fixed Scale	Type of Error (see Tables 2.7-2.11)			
			Diagram	Punched Tape	Magnetic Tape	Telemetric Equipment
Non-systematic error during the period	Observer					
	Instrument/gauging equipment				As per booklet	
Systematic level changes during the period	Office routine					
	Observer				As per booklet	
	Instrument/gauging equipment					
Systematic errors during the complete series	Office routine					
	Gauging routine				As per booklet	
	Instrument/gauging equipment					

4.1.2 Identification of Point in Time

With long term systematic errors the following points should be examined to determine exactly when the error first occurred.

(a) Has there been a change of observer?

(b) When was the station last inspected?

(c) Has there been any human activity in the precipitation area upstream or in the watercourse?

(d) Have there been any especially large floods that could have caused scouring in the watercourse or movement of the scales?

(e) Have there been any extreme ice conditions that might have moved the scale or damaged the connection between the recorder well and the river?

(f) Has the instrument shown sudden changes in time or levels recorded by chart or tape?

(g) Has the frequency of recorded errors for the station suddenly changed?

4.2 Correction and Filling in Gaps in Data

4.2.1 Correction of Errors

When the cause of the error has been established, it can be corrected. It is difficult to issue general procedures for correction of errors. Some errors with obvious causes can easily be corrected, while others can only be corrected from a close knowledge of conditions at the station. In many cases the cause is difficult to find. This is especially so when correcting errors in older data with insufficient background information. Error correction should therefore be undertaken only by experienced hydrologists using their best judgement.

4.2.2 Methods of Filling in Missing Data

At many stations, data observation takes place every few days or data may be partly missing because of insufficient observations, instrument failure and so on. The break in observation can occur by chance, as when data are missing for a few days because of peak floods, or systematically, as when data are missing every weekend. The break period can vary from one missing observation to several months or years. In the historical archives, data are usually stored as a series of daily values. It is therefore necessary to fill in missing data before they can be used in the various analyses.

4.2.2.1 Filling in Missing Water Level Data

Short breaks in water level series are usually filled in by linear extrapolation. This method, however, cannot be used to fill in for peak floods or for long term breaks. It can also lead to considerable errors at the beginning of the snow/ice melting season.

If there are other stations nearby, data can be filled in graphically in the same way as ice-conversion is usually done, as described in section 2.3. Sometimes filling in is done with the help of regression formulae that can be established between the station that needs filling in and one or several stations nearby.

If there are no stations nearby, precipitation and temperature data can be used to approximate extrapolated water levels. For floods, the high water marks can be used to fix the peak water marks.

4.2.2.2 Filling in Missing Discharge Data

Extrapolation of discharge data should, as a rule, be avoided. For discharge determined from observed water levels and for the discharge curve, the extrapolaion should be done on water level data. Surrounding discharge stations that vary rhythmically with the station to be filled in can be used to fill in data in the same way as described in 4.2.2.1 above.

Alternatively, data can be filled in by scaling the discharge at a neighbouring station. The proportion between normal outlets or precipitation areas at the two stations should be used as a scaling factor.

In such a scaling, several stations should be used for comparison. The missing discharge will then be calculated as a weighted sum of the discharges at the comparison stations.

Another method is to calculate the weights that are inversely proportional to the distance between the stations. The method is found in two variations.

Gaps in data can also be filled in based on time-series analysis. One method is based on the determination of a time series models that depicts the memory in the data. By predicting values ahead from the start of the break and backwards from the end of the break, data can be simulated for the broken period. Where the prognoses meet, there will be some differences. The filled-in data should be adjusted so that there will be a smooth transition where these predicted values meet (see Damslet (1978)).

The other method is to establish a transfer model that illustrates the connection between the station that is to be filled in and the comparable station. The model covers the auto-correction in the data with gaps and the cross-correction with the comparing series.

Precipitation runoff models can be used to complete or expand existing data series. The method assumes that available representative precipitation and temperature data can be found.

For breaks of short duration, it is sufficient to use simple extrapolation or scaling by use of surrounding stations. For longer breaks, however, it is necessary to use one of the more complicated methods mentioned above.

4.3 Marking of Errors

As data are getting easier to obtain on disks or magnetic tape and the hydrometric data are being used for more diverse purposes, the need arises for dispatching information about data quality when the data themselves are sent.

Some quality control will be done automatically by the preliminary system. This will detect suspicious data from the reasonability tests and can mark data according to the test results.

Table 4.3 gives suggestions for marking of data. Such marks can be connected to the data in certain packet routines that are used in the filing system. The shaping of the packet will depend on the computer and file-structure.

Table 4.3: Suggestions for Marking Data Quality

Mark	Significance
0	Not controlled.
1	Controlled. Found correct.
2	Controlled. Found suspicious.
3	Controlled. Found incorrect.
4	Controlled. Original value found suspicious, new value determined by automatic methods.
5	Controlled. Original value missing or incorrect, new value determined by automatic methods.
6	Controlled. Original value suspicious, new value determined manually.
7	Controlled. Original value missing or incorrect, new value determined manually.

4.4 Error Statistics

An aid in identifying errors and in the systematic surveillance of stations is to set up error statistics for every station. A close watch on the frequency of errors, allows systematic errors to be discovered before they could be detected by a homogeneity test.

Information collected by routine inspection of the station should be included in the error statistics. In Norway, a special inspection form is filled in on visits to the station (see appendix 2). Information from this should be recorded together with the error statistics.

For data from automatic recording equipment, it is useful to store differences in the level and time between the gauging scale in the river and the instrument. In addition, the occurrence of the various errors should also be registered.

5. CONCLUSIONS AND RECOMMENDATIONS

There is a clear need to reduce the number of errors that occur in the large amounts of water level and discharge data being collected in the Nordic countries. This can be done:

(a) by using improved gauging methods and equipment;

(b) by taking preventive action;

(c) by expanding quality control;

(d) by the systematic recording of detected errors and defects to be used later to correct established weaknesses.

Improved gauging methods and equipment can also lead to a reduction of the sporadic errors that occur because of gauging uncertainties. Technically advanced equipment can, on the other hand, easily lead to data loss, and it it therefore a question of deciding priorities.

The preventive actions are:

- more thorough education and motivation of the observers;
- more frequent inspection in the field;
- more frequent control gaugings;
- good maintenance of instruments including recalibration;
- standardising of the methods for error correction;
- better training of the personnel that perform the primary data processing.

The extended quality control should be done by the instructions described in chapter 3. The controls should be done on as many steps as possible in the primary processing. When data are being fed in, they should be passed through a number of simple automatic tests that separate the suspicious data and give reports about them. Some of the automatic testing methods depend on certain test criteria or information about reference series being stored in a special register.

Suspicious data should be inspected by a system of interactive control routines that can be shown to advantage on a graphical screen terminal.

Before the final approval of a year's data and transference to the archives, the data should be put through a number of control routines that compares it with earlier values of the series and, if possible, with data from reference stations. If errors are suspected, a more thorough inspection method should be used.

Historical data that will be used in model simulations and various analyses should be analysed with a set of control routines that can indicate single errors and homogeneity breaks.

The results from the quality control routine should be presented as simply as possible. The suspicious data should be listed separately or the results should be presented graphically.

Established errors should be registered systematically and watched over so that changes in the error frequency are detected as soon as possible and the cause found. Emphasis should be on correction of detected inadequacies in methods of classification and instruments.

REFERENCES

Damsleth, E., 1978: Interpolating missing values in a time series. Norwegian Calculation Centre, Publication No 605.

Hansen, E., 1973: Analysis of hydrological time series. Polytechnical Publishers, Copenhagen.

Herschy, R. W. (ed), 1978: Hydrometry: principles and practices, Chichester. Wiley, 1978.

Markovitch, R. D., 1975: Mathemetical-Statistical methods of testing consistency and homogeneity of meteorological and hydrological elements of the human environment. Federal Hydrometeorological Institute, Belgrade.

Otnes, J. and Roestad, E. (eds): Hydrology in Practice, 2nd ed. Engineering Publishers.

Rist, S., 1980: Hydrological Network and Operational Status of Water Gauges. Water in the Nordic Countries.

Sognen, R., Aastad, J., 1928: New methods for determining discharge in natural and man-made water courses. Technical Magazine. Oslo.

APPENDIX 1: PUBLICATIONS USED IN THE LITERATURE SEARCH

Group 1: Books on hydrology. (Educational books and encyclopedia).

Otnes, J. and Roestad, E. (eds), 1978, Hydrology in Practice. Engineering Publishers, contains sections about quality control of data.

Group 2: Books on hydrometry

(1) Andre, H. et al., 1976: *Hydrometry Practice in the River Eyroller*, Paris.

(2) Herschy, R. W. (ed), 1978: *Hydrometry: Principles and Practices*, Wiley.

Herschy has much information about gauging uncertainties and sources of error in connection with the description of the various gauging methods and instruments. The book contains a chapter about gauging uncertainties for discharges and a three-page section about quality control in connection with data collection and processing.

(3) Schaffernak, F., 1975: *Hydrography*. Julius Springer, Vienna, 1975.

Group 3: Magazines and Other Publications

(1) *Water in the Nordic Countries*.

(2) *Nordic hydrology*.

(3) *Journal of Hydrology*.

(4) *Water Resources Research*.

(5) *Journal of Hydraulic Engineering* (ASCE)

(6) *German Watercourse Information Report*.

Of these publications the last contains the most material about hydrometry, but not much on data quality.

Group 4: Statements, Norms, Instructions etc

(1) *U.S. Geological Survey*

Stream Gauging Procedure, (Water-Supply Paper 888), Washington D.C., 1945

Manual of Hydrology, Washington D.C., 1959-1972.

Surface Water Technique.

Techniques of Water Resources Investigations, US Geological Survey, Washington D.C., 1967.

(2) Instructions for discharge gauging. Federal Institute of Hydrology, Koblenz, 1971 (in German).

(3) Report from the Office for Water Management. No 18. Berne 1926: Research and discharge gaugings. 1985 (1958?) (in German).

(4) German Association for Water Management. Report No 3. Nature Gauging in Water Power. Possibilities and Limits of Newer Gauging Procedures, 1977 (in German).

(5) Water Research Centre and Water Data Unit (Reading, England) has published: Symposium on River Gauging by Ultrasonic and Electromagnetic Methods, WRC, Marlow, 1974.

(6) Water Resources Board, Reading, has published a series of Technical Notes, of which:

Rating of Current Meters. Water Resources Board (Roading) Technical Notes No. 1, 1965.

Logarithmic Plotting of Stage-Discharge Observations. Water Resources Board (Roading) Technical Note No. 3, 1965

Wind Set-up in Relation to River Gauging. Water Resources Board (Roading) Technical Note No. 6, 1965.

The Magnitude of Probable Error in Water Level Determination at a Gauging Station. Water Resources Board (Roading) Technical Note No. 7, 1966.

Evaluation of Errors. Water Resources Board (Roading) Technical Note No. 11, 1967.

(7) International Symposium on Hydrometry, Koblenz, 1970. UNESCO/WMO/IAHS. No 99, 1970. This contains several articles about gauging accuracy, but not about error detection.

(8) Hydrologic Information Systems. Paris, Geneva: UNESCO-WMO 1972. (Studies and Reports in Hydrology No. 14.)

(9) Standardisation in Hydrology and Related Fields. Report on WMO/IHD Project. Report No 18. Geneva: WQMO, 19 (WMO-No. 351).

(10) ISO has published several international standards for discharge gaugings (see point 9).

(11) There are also British Standards for discharge gaugings (not examined).

(12) The English Water Data Unit, Reading, has published. Technical Memoranda:

Brown, C A and Stephenson, P M: Data Processing and Computing Capabilities. Water Data Unit Technical Memorandum No. 1, 1975.

Marsh, T J and Stephenson, P M: Surface Water Data Processing - A Guide to Practice. Water Data Unit Technical Memorandum No. 5, 1976.

_______________: Punched Tape River Level Recorders. Water Data Unit Technical Memorandum No. 6, 1976.

Herschy, R W: An Evaluation of the Braystoke Current Meter. Water Data Unit Technical Memorandum No.7, 1976.

Herschy, R W: The Effect of Pulsations on the Accuracy of River Flow Measurement, Water Data Unit Technical Memorandum No. 10, 1978.

_______________: Interrogable Devices. Water Data Unit Technical Memorandum No. 16, 1977.

(13) WMO: Guide to Hydrological Practices. WMO Publication No 168. WMO Geneva, 1974.

This is an instruction book that includes gaugings and processing of surface water as well as other hydrological elements. Quality control of precipitation data is directly discussed.

WMO: Volume I Data Acquisition and Processing. Fourth Edition Geneva 1981.

(14) WMO: Manual on Stream Gauging: I-II, Operational Hydrology Report No 13. WMO No 519. Geneva 1980.

(15) Environment Canada, Inland Waters Directorate, Water Resources Branch, Ottawa has published:

(1) Manual of Hydrometric Data Computation and Publication Procedures, June 1975.

(2) Automated Streamflow Computation, January 1974.

(16) Starosolsky, O and Juszkalay, L: Intercomparison of Principal Hydrometric Instruments. Report on First Phase 1972-76 (WMO Commission for Hydrology, report from working group, published 1978).

APPENDIX 2: NORWEGIAN HYDROMETRIC STATION INSPECTION FORM

Norwegian Water and Electricity Department, Hydrological Section

INSPECTION OF HYDROMETRIC STATION

(The purpose of the inspection is to make sure the station is capable of giving correct and readable recordings).

Station No .... Code .... Name ....

Watercourse .... Tributary ....

Inspection Date .... By .... Last inspection date ....

---

1 Water level scale: River ☐ Lake ☐ Storage Lake ☐

Water level before inspection .... time ....

Scale from ..... m to ..... m was ..... cm too high/low. Corrected ......

Scale from ..... m to ..... m was ..... cm too high/low. Corrected ......

Scale from ..... m to ..... m was ..... cm too high/low. Corrected ......

Scale from ..... m to ..... m was ..... cm too high/low. Corrected ......

Scale from ..... m to ..... m was ..... cm too high/low. Corrected ......

Cause of the error: ....

The water level is to be corrected from .... to .... inclusive.

Used as control is KM .... m from the scale.

KM has the height of .... m on the scale.

Is the water level, after control and possible correction of scale, recorded on the list and in the book? ....

If not, why not ....

....

2 Recorder

Range in stilling well from .... m to ..... m; stood .... cm too high/low.

Corrected ....

Which time showed on the recorder? .... Corrected time ....

Cause of the error: ....

Has the error been corrected? ....

Which water level did the recorder show .... m. Water level in stilling well is .... m

Cause of the error: ....

Has the error been corrected? ....

Is there ice in the riser pipe? Yes/No.

Is the connection between river/riser pipe in order? Yes/No.

If not, what is wrong and what has been done to correct it? ....

....

....

Is correct date, time and waterlevel recorded on the recorder? ....

....

3 Other instruments

Do other instruments, if any at the station, function satisfactorily? ....

....

4 Flood pipe

The zero point on the flood pipe should, in relation to the scale, be .... m.

The floodpipe has been inspected and found to stand ..... cm too high/low.

Corrected ....

Has the floodpipe been prepared for recording the next flood? ....

5 Discharge gauging

Gauging done? Yes/No. If not, why not ....

Gauging done .... m further above/below the station. Method ....

....

Evaluation of gauging conditions ....

6 Ice conditions at the deciding profile

Ice covered ☐ Partly ice covered ☐ Ice free ☐

7 Have the observations been done satisfactorily? ....

....

8 Information that must be recorded

(eg, profile changes, new observer, change of recorder)

....

....

9 Other information

....

....

....

APPENDIX 3: METHODS 11, 12, 13 AND 18. AUTOMATIC REASONABILITY TESTS

Object

To detect obvious errors automatically.

Description of the Methods

The daily observed data is compared with test limits that apply for the whole year or for each month of the year (method 11).

The difference between two consecutive days is compared with the test limits that apply for the full year or for each month of the year (method 12).

Sliding trend tests inspect groups of consecutive data to see if the variation is plausible. Here tests of suspect patterns can be built in (method 13).

Regression analysis against another station detects significant 'outliers'. The regression formula can be determined from earlier years' data (method 18).

Interpretation of the Results

Physically impossible gauging results are clearly wrong and must be discarded. Of the remaining data that has been sorted out by the reasonability tests, some will have been caused by errors while some will be actual extremes. It will therefore be necessary to divide up the reasonability tests so they separate clearly unreasonable data that must be discarded and data that must be evaluated manually before approval.

It is difficult to find test criteria that only filter out wrong values. In an automatic system, a combination of several methods should therefore be used to limit the sorting out of suspicious data as much as possible. Slightly suspicious data could be only marked and not separately listed.

Comments on the Methods

It is necessary to prepare limiting values for every data series in an easily accessible archive for this quality-control to function quickly and effectively. Limiting values should be determined individually for each station as regional test criteria will probably be so wide that few errors will be detected.

Method 13 is used, for instance, in Great Britain and is further described in Herschy (1978) section 11-7. Such methods are most suitable where data are recorded with fine time resolution as in digitised recording stations. For data stored as daily means, it will be difficult to separate out errors, especially when the daily variation is great.

Example

Reports on errors identified by automatic test values should be given as short check lists. Tables A3a and A3b gives an example of transcripts from an inspection programme that checks each year's data against previously established limiting values for highest and lowest acceptable water level, rising and falling. The programme examines whether data lacks single days and if the observed water levels lead to the discharge being shown as nil. It particularly examines if there are any metre errors in the data.

Table A3a: Summary of Quality Control for WG 1123 - OI, 1961-1970

YEAR	NUMBER OF MISSING DATA	NUMBER OF POSSIBLE ERRORS	NUMBER OF PROBABLE ERRORS	COMMENTS
1961	92	2	2	Must be checked
1962	95	None	None	Satisfactory
	87	None	None	Satisfactory
	96	None	None	Satisfactory
	93	2	2	Must be checked
	90	None	None	Satisfactory
	88	12	2	Must be checked
	91	None	None	Satisfactory
	95	2	2	Must be checked
1970	92	None	None	Satisfactory

This is a summary of quality control from one station. Years that have been approved can perhaps be omitted from this table to make it more explicit.

Table A3b: Result of Quality Control for WG 1123 - OI, 1961

DATE	WATER LEVEL (metres)	CHANGE (metres)	DISCHARGE (cumecs)	INDICATION	EVALUATION
12/1	642.00	-1.02	.30	Low water level	
12/1	642.00	-1.02	.30	Large fall	Possible error
12/1	642.00	-1.02	.30	Approximately 1 metre	Possible error of 1 metre
16/1	642.99	.99	16.40	Large rise	Probable error
16/1	642.99	.99	16.40	Approximately 1 metre	Error of 1 metre
30/1	642.00	-1.01	.30	Low water level	
30/1	642.00	-1.01	.30	Large fall	Possible error
30/1	642.00	-1.01	.30	Approximately 1 metre	Possible error of 1 metre
2/2	642.99	.99	16.40	Large rise	Probable error
2/2	642.99	.99	16.40	Approximately 1 metre	Error of 1 metre
27/5	644.56	253.60	.15	High water level	Large flood
28/5	644.58	260.01	.02	High water level	Large flood
29/5	644.61	269.89	.03	High water level	Large flood
30/5	644.63	276.58	.02	High water level	Large flood
31/5	644.65	283.52	.02	High water level	Large flood
1/6	644.67	290.38	.02	High water level	Large flood
2/6	644.68	293.91	.00	High water level	Large flood
3/6	644.62	273.20	-0.06	High water level	Large flood
4/6	644.57	256.79	-0.09	High water level	Large flood

This table gives the result of the various controls for every day, where one or more errors has occurred in two of the control years with data. This transcript is used in evaluation of the data and in necessary error correction.

APPENDIX 4: METHOD 17: PLOTTING OF DATA FROM ONE OR MORE STATIONS ON THE SAME GRAPH

Object

To detect single errors in data and to detect discharge inconsistencies in a watercourse with several gauging stations.

Description of the Method

In searching for single errors, the daily values in the actual year for the station that is being checked are plotted. On the same screen/graph the changes from day to day should be plotted on a separate axis. In this kind of chart the water level data should be used.

In evaluating the consistency of the data, daily discharge data for several stations within the same catchement area should be plotted on the same graph. If stations upstream have larger discharge values over a longer period than a lower station and there is no appreciable amount of water being transferred or stored between the two stations, it indicates that the data is inconsistent. In regulated areas, the feed-in to the two points should be plotted instead of the outlet.

Comments on the Method

Plottings of this type are very good in detecting errors. Even though many of the gross errors can easily be detected by various automatic reasonability tests, there are many errors that will remain undetected by such controls, but readily show up on a graphical presentation. Before data is finally approved it should be plotted on a graph. Similarly, long dataseries should be examined by such graphical methods when they are used in a check. For this inspection it is especially suitable to plot data on a graphical screen, especially if the program product allows for a segment of suspicious data to be drawn up and rescaled.

Examples

Figures A4a and A4b show examples of detection of single errors in the data. The series that has been used is strongly suppressed because of storage lakes upstream. The error therefore shows up very clearly in this example. In rivers with sudden water level fluctuations, the errors will show up to a lesser degree, but they will nearly always be detected.

Figure A4c shows an example of plotting related water levels for three stations in the Glomma River in Norway. This is intended to check if the discharge is increasing consistently downstream. This is the case here, but the graph discloses a metre error in the middle water levels in August and that there is an error in the data in October for the station in the middle.

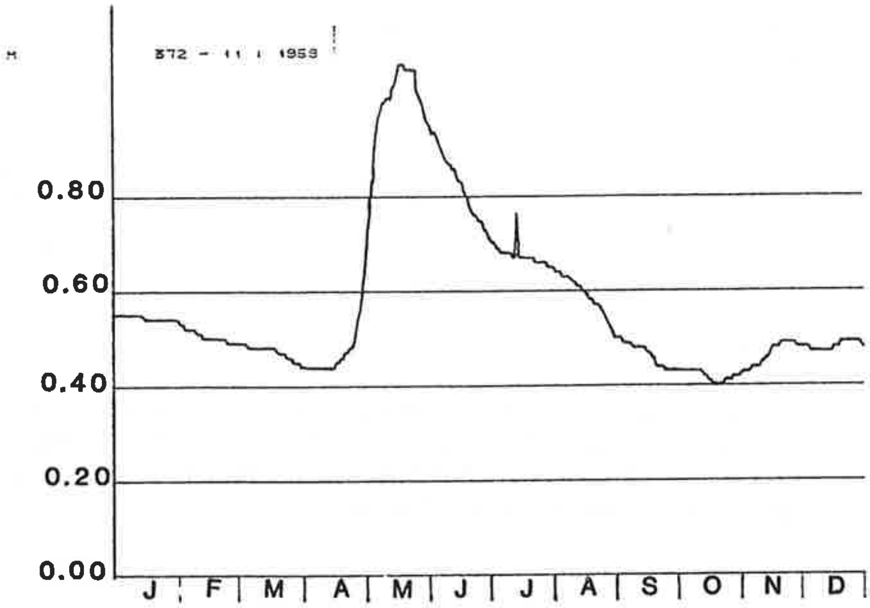


Figure A4a: Plot of daily water levels for vm 372, the Femund end of the Trysil River in Norway. The Diagram discloses an error of 10 cm in July.

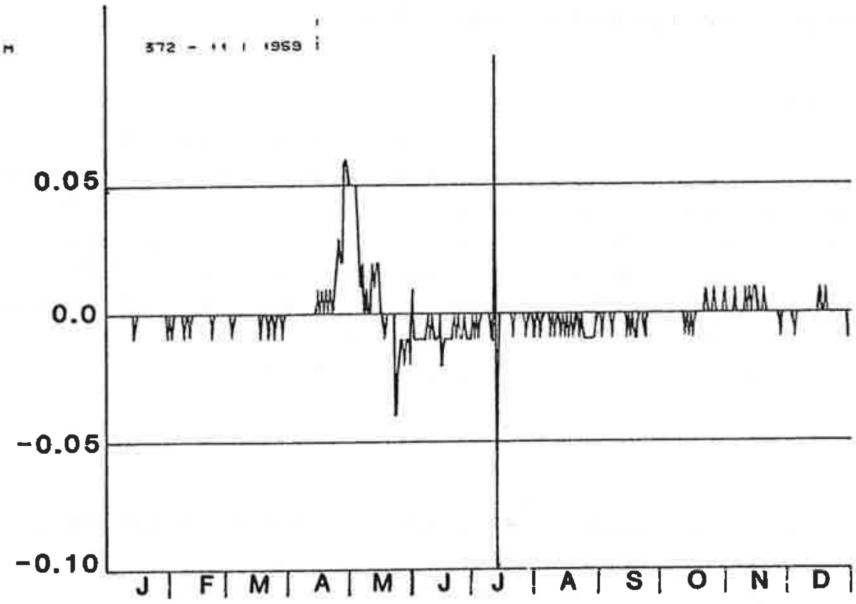


Figure A4b: Plot of changes in water level from day to day for the same station and year as in figure A4a. The error shows clearer in this graph.

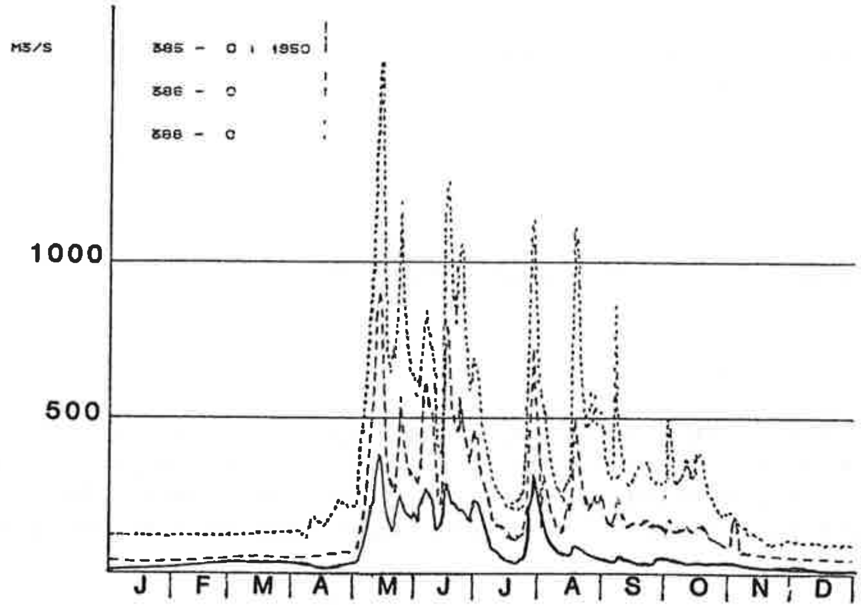


Figure A4c: Consistency evaluation of the discharge gauged at three stations in the Glomma River. This is the case this year, but the graph discloses a metre error early in August, and a suspicious flood early in November for vm 386.

APPENDIX 5: METHODS 14 AND 15: GRAPHIC REASONABILITY CONTROL OF THE YEAR'S DATA

Object

To detect single errors or level-displacement over shorter periods during the year.

Description of the Method

The year's data are plotted on a hydrograph together with the maximum, mean and minimum value for every day of the year in the comparison period. Similarly, day to day changes are plotted on the same chart. They are the greatest rise and fall in level for every day in the year of the reference period.

Interpretation of the Results

The year's data are evaluated visually on a graphic screen. If the data falls outside the enveloping curves, the curve's shape should be examined. Gross errors will, in many cases, show up very clearly in difference-plotting. By comparing the two graphs, many suspicious cases may be found.

Comments

This method is recommended to be used together with method 17 in the graphical final approval of the year's data. Errors in the data are most easily seen by plotting the water levels. The enveloping curves will show up errors in the reference period. Analysis of the enveloping curves can be used to identify errors in long series and is discussed in Appendix 6.

Examples

Figures A5a and A5b show examples of errors detected in the yearly data at the end of the month of May. The error involves a fall from one day to the next that is much greater than the largest observed fall in the comparison period. Correspondingly, this leads to nearly as great a rise of water level.

Comparison Period 1930-1959
Water Level Data

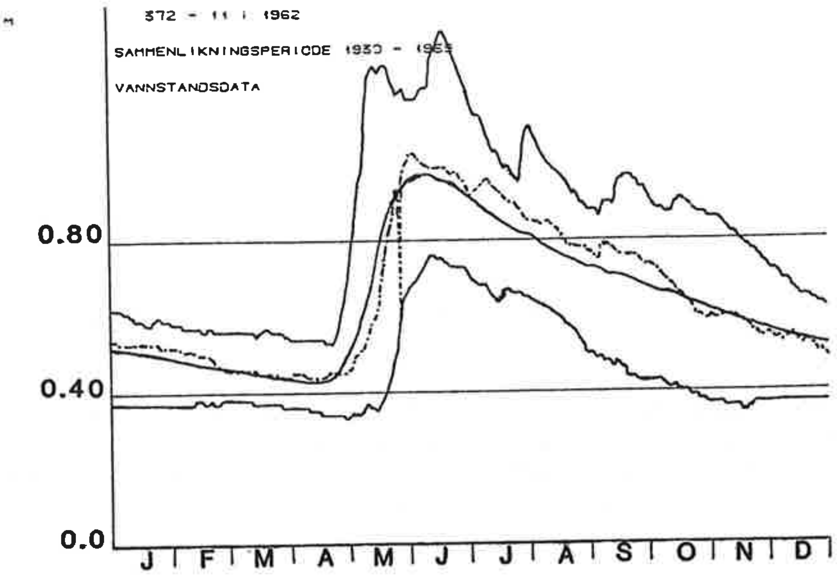


Figure A5a: Plot of the year's water level data on the same graph as the highest, mean and lowest daily value in the period 1930-59. In the year's data, there is an error of 35 cm at the end of May.

Comparison Period 1930-1959
Water Level Data

1. Methodical Differences (Ordinance Differences?)

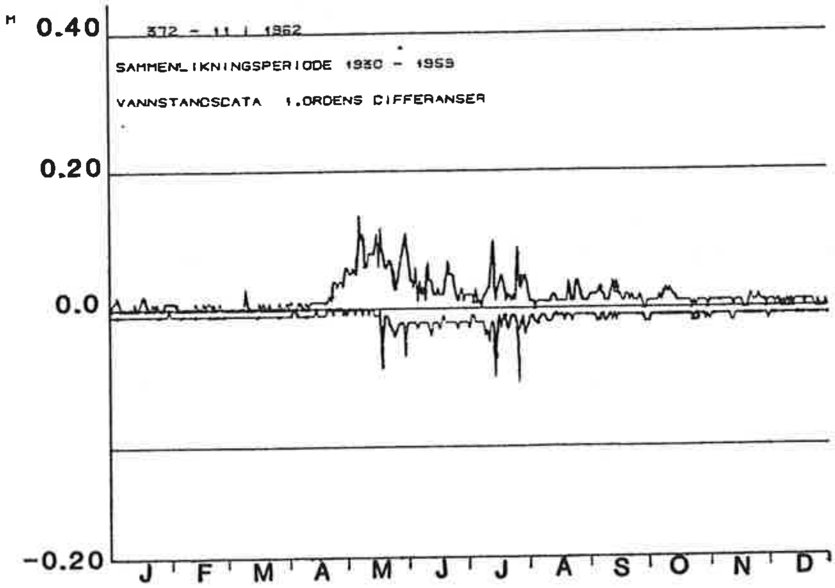


Figure A5b: Plot of day to day water level changes for the year on the same graph as the highest rise and fall for each day in the period 1930-59. The year's data is marked only if it falls on or outside the enveloping curves.

APPENDIX 6: METHOD 24: ANALYSIS OF ENVELOPING CURVES

Object

To examine long series of data to detect gross single errors.

Description of the Method

The maximum, mean and minimum value for every day of the year are calculated for the data series as described in method 14. Similarly, the enveloping curves are calculated for daily changes of value for every day of the year as in method 15.

The enveloping curves and the mean curve are plotted on one graph for the original data and on one for the daily changes as shown in figures A6a and A6b. This should be done on a graphic screen of an interactive program. The plots should then be evaluated by the hydrologist who has done the quality control.

Interpretation of the Results

Many gross errors can easily be detected by looking at the two graphs separately and then together. From the graphs, possible errors can be identified, together with the days on which they occur, but not necessarily which year.

Errors that influence the extreme values in parts of the year can be seen from the first graph, when there is an extreme value on one or a few days (see figure A6a). Such errors are most easily detected on low water levels, but can also be discovered during flood water levels if the natural variation from day to day is not extremely large.

Gross errors can also occur on mean water levels. Such errors can be identified by examining the enveloping curves for changes from day to day. If the lower enveloping curve shows a marked minimum followed by a corresponding maximum for the top enveloping curve, there is reason to suppose there is a gross error in the data. The timing of extremely large jumps should be defined and examined more closely by other methods.

Comments of the Method

This method is ideal for producing a quick survey over possible gross errors in the data. It can be used on both water level and discharge data.

Experiments show that errors can be most easily found when water level data is analysed.

The method allows for date fising of the possible errors during the year. If, however, the actual year needs to be determined, other methods should also be used (see appendix 7).

If very long series are to be inspected, it is preferable to divide up the series into shorter periods and check each of these separately. This will reduce the possibility of gross errors concealing smaller errors.

An interactive program for this kind of quality control has been prepared by Norway's Watercourse and Electricity Department. It is regularly used in inspection of long data-series.

Example

Figures A6a and A6b show enveloping curves for 30 years of a data series for Femunden in Norway. Figure A6a shows there is a very clear error in the low water level in April. This is confirmed by figure A6b where the biggest negative change occurs before the largest positive change. Several of the other peaks of the enveloping curve for day to day changes indicate errors. Overall inspection discovered one error of 35 cm, one of 20 cm and three of 10 cm in the water level. In smaller, moderated series, small errors like these can scarcely be discovered. Figures A6c and A6d show corresponding enveloping curves for 30 years of data for the Horningdals lake. Here there is a 1 m error for one week in August. In the figures, this shows up especially clearly on the difference-plotting.

Comparison Period 1932-62
Discharge Data

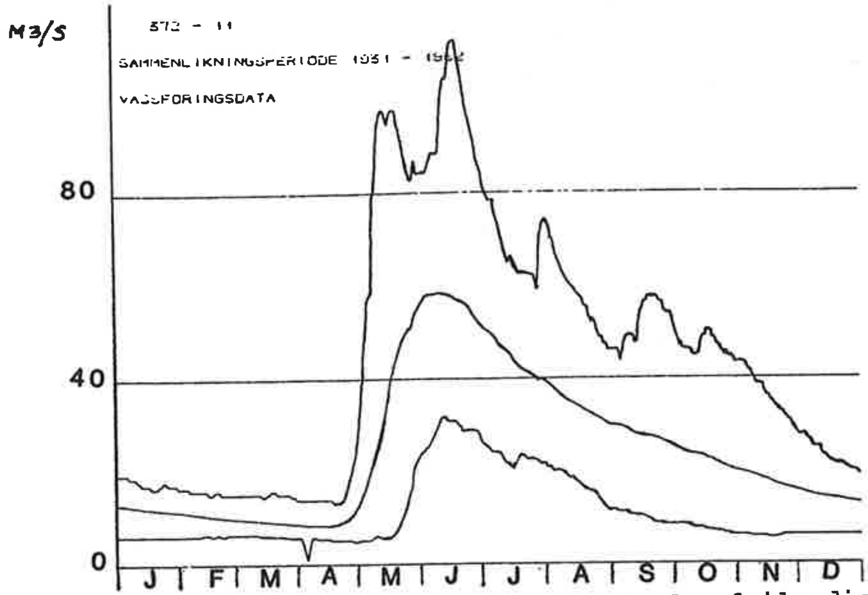


Figure A6a: Analysis of the enveloping curves for daily discharges in the Femund end of the Trysil River in Norway, with a comparison period of 1932-62. From the graph one can detect an error in April.

Comparison Period 1931-1962
Discharge Data: Methodical Differences

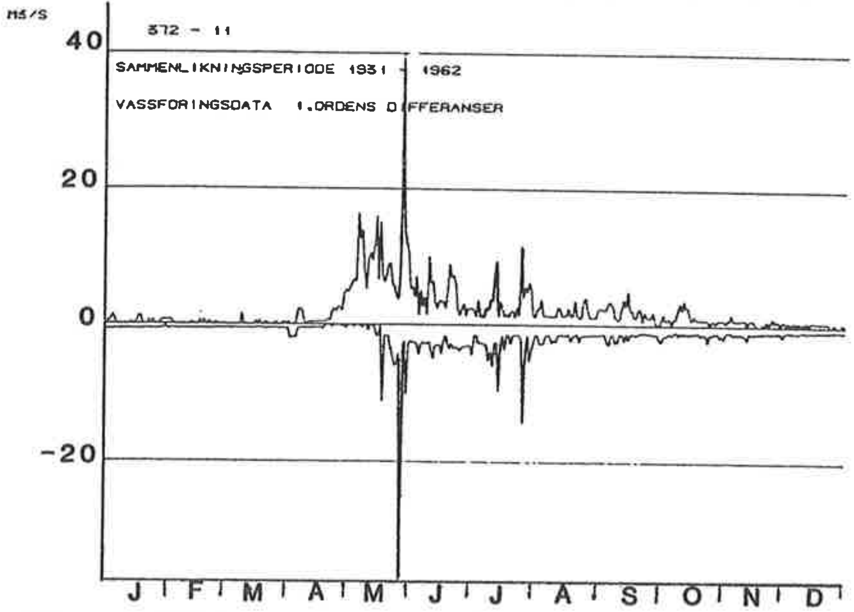


Figure A6b: Analysis of the enveloping curve for day to day changes in the discharge in the Femund end of the Trysil River in Norway, with a comparison period 1931-62. The graph reveals five errors.

Comparison Period 1901-1930
Water Level Data

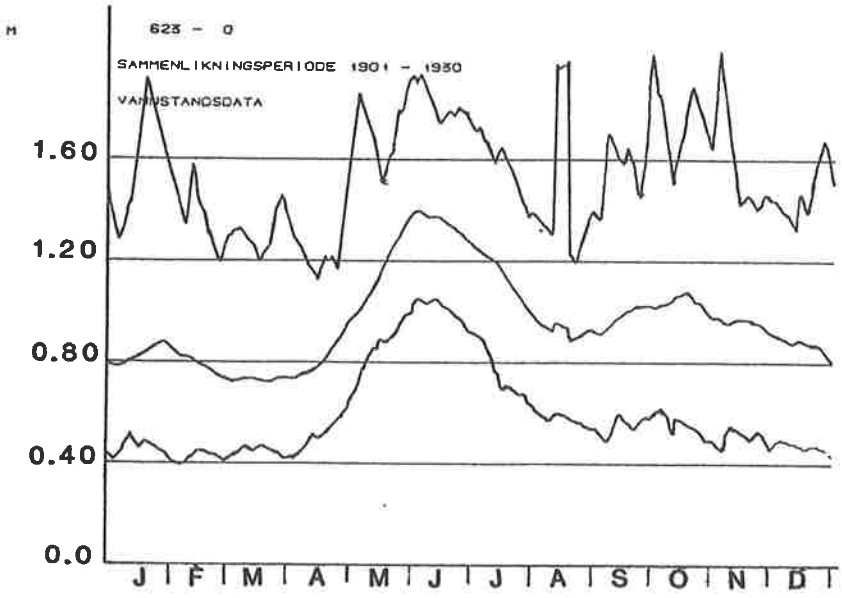


Figure A6c: Enveloping curves for daily water levels in the Hornindals Lake in Norway, with a comparison period 1901-30. The graph reveals that in one of the years there was a displacement of level by 1 m.

Comparison Period 1901-1930
Water Level Data: Methodical Differences

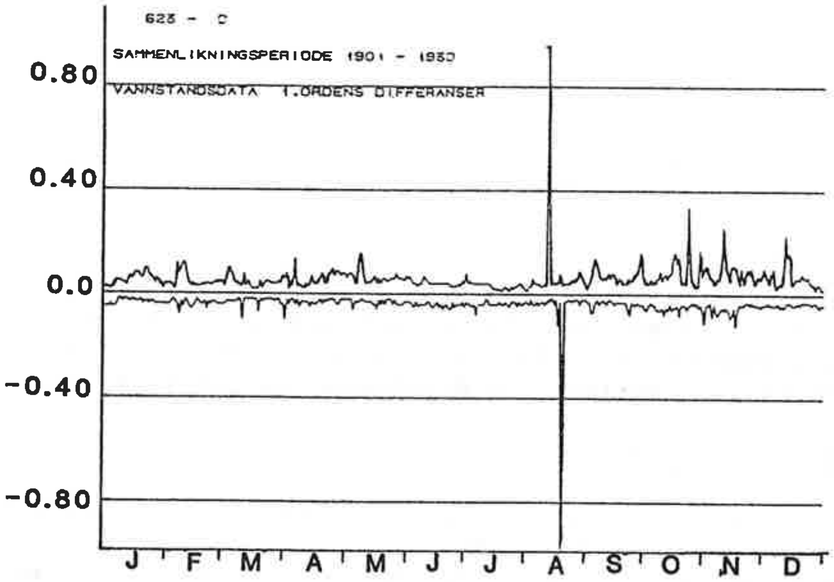


Figure A6d: Enveloping curves for daily water level changes in the Hornindals Lake in Norway, with a comparison period 1901-30. The error shows up much clearer in this diagram.

APPENDIX 7: METHOD 22: TABULATION OF THE HIGHEST AND LOWEST VALUES AND CHANGES FROM DAY TO DAY FOR EACH MONTH AND YEAR IN THE SERIES

Object

To fix the date of gross errors found by use of method 20 for long data series.

Description of the Method

For each month of the data series, the highest and lowest daily values are found. These are presented in table form. Correspondingly, the largest daily rises and falls in waterlevel or discharge are tabulated.

Interpretation of the Results

By the use of method 24, the timing of gross errors can be fixed within the year. The year of occurrence, however, cannot be determined. The actual year of error is found by comparing these times with the tables.

Comments

Inspection of extreme values is much more exacting than traditional methods (which Herschy also describes) namely reasonability tests of monthly means. The tables can be used directly in search of gross errors.

Examples

Table A7a, b, c and d shows examples of tables of extreme values as described above.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1930	20.85	15.82	12.78	15.82	71.58	71.58	44.95	36.26	18.57	17.86	19.31	16.48	71.58
1931	14.55	12.78	11.69	9.24	88.61	84.15	47.67	38.61	32.92	26.88	22.46	18.57	88.61
1932	15.17	14.55	11.69	9.70	72.92	84.15	55.19	30.81	25.05	22.46	20.85	17.86	84.15
1933	12.22	10.66	9.24	9.70	36.26	38.61	36.26	51.96	43.63	26.88	17.86	11.69	51.96
1934	10.17	9.70	9.24	12.78	97.92	70.25	44.95	42.33	49.07	42.33	27.83	20.85	97.92
1935	18.57	16.48	13.94	13.35	50.50	66.36	67.64	49.07	27.83	25.05	24.16	21.64	67.64
1936	19.31	15.17	12.78	10.66	77.02	74.27	43.63	43.63	37.42	22.46	16.48	15.82	77.02
1937	13.35	11.16	10.17	25.05	65.09	70.25	55.46	37.42	19.31	17.86	14.55	14.55	70.25
1938	12.22	11.16	9.24	12.78	71.58	82.70	60.16	53.19	37.42	50.50	43.63	27.83	82.70
1939	19.31	15.17	12.78	10.66	50.50	58.97	68.94	54.32	30.81	15.17	9.24	8.36	68.94
1940	7.55	6.79	6.43	5.75	46.30	44.95	35.12	39.83	42.33	29.79	22.46	20.07	46.30
1941	12.78	10.17	8.36	7.55	27.83	39.83	35.12	36.26	37.42	31.85	22.46	14.55	39.83
1942	13.35	11.16	9.24	12.22	47.67	54.32	53.19	38.61	25.05	25.05	25.95	22.46	54.32
1943	19.31	15.82	12.78	12.78	62.60	72.92	43.63	27.83	25.05	23.30	26.88	20.85	72.92
1944	14.55	12.78	11.69	10.66	50.50	112.92	78.42	39.83	35.12	34.01	29.79	18.57	112.92
1945	16.48	15.82	15.82	17.16	97.92	91.65	71.58	29.79	20.85	15.17	12.22	10.66	97.92
1946	9.70	8.36	7.95	17.86	47.67	53.19	46.30	29.79	35.12	32.92	20.85	15.17	53.19
1947	13.94	11.69	8.36	8.79	60.16	47.67	39.83	28.80	14.55	9.70	6.09	6.09	60.16
1948	6.09	6.43	6.43	12.78	47.67	47.67	34.01	29.79	32.92	29.79	23.30	17.16	47.67
1949	14.55	11.69	10.17	21.64	84.15	88.61	54.32	44.95	35.12	21.64	14.55	11.16	88.61
1950	11.16	11.16	10.17	10.66	72.92	85.62	79.83	74.27	46.30	27.83	22.46	15.82	85.62
1951	13.35	12.22	10.66	8.79	57.78	60.16	60.16	35.12	39.83	25.95	14.55	11.69	60.16
1952	11.69	10.17	8.36	25.95	49.07	94.76	82.70	39.83	25.95	17.86	13.35	11.16	94.76
1953	10.17	9.24	7.95	18.57	67.64	74.27	62.60	49.07	32.92	23.30	18.57	15.17	74.27
1954	12.78	11.16	9.24	7.55	44.95	43.63	55.46	58.97	41.07	24.16	17.16	12.78	58.97
1955	12.22	10.66	9.70	7.55	23.30	55.46	55.46	28.80	17.86	15.82	11.69	10.66	55.46
1956	9.70	9.70	9.24	7.55	41.07	66.36	55.46	30.81	42.33	39.83	25.95	14.55	66.36
1957	12.22	9.24	7.95	7.55	58.97	57.78	56.61	56.61	57.78	50.50	31.85	20.85	58.97
1958	14.55	10.17	7.95	7.55	53.19	71.58	44.95	29.79	26.88	22.46	20.85	18.57	71.58
1959	14.55	13.35	11.16	25.95	71.58	54.32	32.92	20.85	11.69	8.36	11.16	11.16	71.58
1960	10.66	10.66	9.24	8.36	65.90	74.27	65.09	54.32	42.33	26.88	20.85	16.48	74.27
1961	13.35	11.69	9.24	15.17	55.46	55.46	41.07	51.96	32.92	25.05	25.05	20.85	55.46
1962	13.94	12.78	9.70	9.70	62.60	65.09	56.61	42.33	35.12	28.80	17.86	14.55	65.09
1963	12.78	10.17	8.79	8.36	71.58	70.25	55.46	46.30	31.85	24.16	20.85	15.82	71.58
1964	11.69	9.70	8.36	15.17	32.92	35.12	39.83	36.26	42.33	42.33	35.12	21.64	42.33
1965	15.82	14.55	11.69	10.66	62.60	81.26	66.36	36.26	37.42	36.26	25.95	16.48	81.26
1966	13.94	10.66	11.16	10.66	97.92	88.61	43.63	46.30	32.92	21.64	20.85	14.55	97.92
1967	13.94	12.22	9.70	9.24	121.79	131.06	63.84	39.83	34.01	29.79	31.85	24.16	131.06
1968	17.86	14.55	12.78	21.64	61.38	74.27	55.46	24.16	11.69	7.55	7.16	6.79	74.27
1969	7.16	7.16	6.43	7.55	46.30	51.96	30.81	20.85	14.55	14.55	14.55	11.69	51.96
1970	10.17	8.36	8.36	8.36	58.97	66.36	37.42	35.12	21.64	30.81	25.05	17.86	66.36
MID	13.36	11.53	9.96	12.43	61.74	68.60	52.59	40.02	31.83	25.96	20.82	15.94	30.40
MAX	20.85	16.48	15.82	25.95	121.79	131.06	82.70	74.27	57.78	50.50	43.63	27.83	131.06
MIN	6.09	6.43	6.43	5.75	23.30	35.12	30.81	20.85	11.69	7.55	6.09	6.09	5.75

Table A7a: Highest daily discharges for Station 372 in the years 1930-1970.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1930	15.82	12.78	10.66	9.24	17.16	41.07	36.26	18.57	12.22	12.22	15.82	14.55	9.24
1931	13.35	12.22	9.24	7.95	9.70	44.95	31.85	34.01	22.46	20.85	17.86	12.78	7.95
1932	12.22	11.69	9.70	9.24	9.70	54.32	30.81	25.05	20.07	17.86	18.57	12.22	9.24
1933	10.66	9.24	8.36	8.36	9.70	31.85	20.85	36.26	27.83	17.86	12.22	10.17	8.36
1934	10.17	9.24	8.79	7.55	13.94	43.63	35.12	36.26	37.42	28.80	20.85	17.16	7.55
1935	16.48	13.94	11.16	9.70	13.94	50.50	50.50	27.83	20.85	21.64	20.85	19.31	9.70
1936	15.82	12.78	10.17	9.24	11.16	43.63	29.79	35.12	22.46	14.55	14.55	13.35	9.24
1937	11.16	10.17	9.24	8.36	27.83	55.46	38.61	20.07	16.48	14.55	13.35	11.69	8.36
1938	11.16	9.24	8.36	7.95	13.35	56.61	49.07	25.95	27.83	28.80	28.80	19.31	7.95
1939	15.82	12.78	10.66	9.70	10.17	50.50	51.96	31.85	15.82	9.24	6.79	6.79	6.79
1940	6.79	6.09	5.75	4.83	5.13	30.81	25.95	21.64	29.79	21.64	15.17	12.78	4.83
1941	10.17	8.36	7.16	6.43	5.43	29.79	21.64	21.64	32.92	22.46	13.94	13.35	5.43
1942	11.16	9.24	7.16	7.16	12.22	47.67	39.83	25.95	21.64	22.46	22.46	19.31	7.16
1943	13.35	12.78	10.66	9.24	15.17	44.95	28.80	22.46	20.07	17.86	21.64	13.94	9.24
1944	12.78	11.69	10.17	9.24	10.17	53.19	39.83	25.05	29.79	29.79	17.86	15.82	9.24
1945	15.17	14.55	13.94	13.35	17.86	72.92	30.81	20.07	15.17	12.22	11.16	9.70	9.70
1946	8.36	7.95	7.95	7.95	20.07	44.95	29.79	21.64	21.64	20.85	13.94	13.94	7.95
1947	11.69	8.36	7.55	7.55	9.24	34.01	28.80	14.55	9.70	6.09	5.43	6.09	5.43
1948	6.09	6.09	6.43	6.43	13.35	34.01	29.79	20.85	20.85	23.30	17.16	14.55	6.09
1949	11.69	10.17	9.24	9.24	23.30	54.32	35.12	35.12	23.30	14.55	11.16	10.66	9.24
1950	11.16	10.17	8.79	9.70	10.66	72.92	49.07	46.30	28.80	22.46	15.82	13.35	8.79
1951	12.22	10.66	8.79	8.36	8.36	55.46	36.26	30.81	25.95	14.55	11.69	11.69	8.36
1952	10.17	8.36	7.55	7.55	27.83	49.07	41.07	25.95	17.86	13.35	11.16	10.17	7.55
1953	9.24	7.95	7.16	7.16	21.64	57.78	50.50	32.92	23.30	18.57	15.17	12.78	7.16
1954	11.16	9.24	7.55	6.79	6.79	28.80	30.81	42.33	24.16	17.16	12.78	11.69	6.79
1955	10.66	9.70	7.55	6.43	6.43	24.16	29.79	17.86	15.82	11.69	10.66	9.70	6.43
1956	9.70	9.24	7.55	6.43	6.43	42.33	30.81	22.46	21.64	25.95	14.55	12.22	6.43
1957	9.24	7.95	7.55	7.16	7.16	46.30	42.33	39.83	39.83	31.85	21.64	14.55	7.16
1958	10.17	7.95	7.55	7.16	7.16	44.95	29.79	27.83	17.16	17.16	18.57	14.55	7.16
1959	13.94	11.16	8.79	8.79	30.81	26.88	21.64	11.69	8.36	7.16	8.36	10.17	7.16
1960	10.66	9.24	8.36	.97	7.16	60.16	55.46	42.33	26.88	20.85	16.48	13.94	.97
1961	11.69	9.24	8.36	7.55	15.82	41.07	36.26	34.01	23.30	20.85	20.85	13.94	7.55
1962	12.78	9.70	8.79	8.79	9.70	54.32	42.33	32.92	28.80	17.16	13.94	11.16	8.79
1963	10.17	7.95	7.16	7.16	9.24	38.61	46.30	28.80	23.30	20.85	15.82	11.16	7.16
1964	9.70	8.36	7.16	6.43	16.48	26.88	31.85	25.95	37.42	34.01	20.85	15.82	6.43
1965	14.55	11.69	10.17	8.79	10.66	63.84	34.01	23.30	23.30	23.30	15.82	13.94	8.79
1966	9.70	8.79	9.70	8.79	8.79	44.95	29.79	28.80	22.46	17.86	13.94	12.78	8.79
1967	12.22	9.70	9.24	7.16	8.36	66.36	32.92	27.83	21.64	20.07	22.46	18.57	7.16
1968	14.55	12.78	10.17	9.70	26.88	49.07	24.16	11.69	7.16	6.43	6.43	5.75	5.75
1969	6.43	6.43	6.09	5.43	7.55	25.88	20.85	14.55	10.66	12.22	11.69	10.17	5.43
1970	8.36	7.55	7.55	7.16	7.55	38.61	26.88	21.64	18.57	20.85	17.86	13.35	7.16
MID	11.42	9.83	8.63	7.86	12.93	45.82	34.83	27.07	22.31	18.83	15.51	12.90	18.99
MAX	16.48	14.55	13.94	13.35	30.81	72.92	55.46	46.30	39.83	34.01	28.80	19.31	72.92
MIN	6.09	6.09	5.75	.97	5.13	24.16	20.85	11.69	7.16	6.09	5.43	5.75	.97

Table A7b: Lowest daily discharges for Station 372 in the years 1930-1970

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1930	0.00	0.00	0.00	1.27	4.65	1.27	7.52	0.00	.68	1.23	.74	.66	7.52
1931	0.00	0.00	0.00	.44	8.38	0.00	6.08	1.14	0.00	1.70	1.58	.72	8.38
1932	1.23	0.00	0.00	.46	9.16	5.62	0.00	.95	.82	1.62	.78	.63	9.16
1933	0.00	0.00	0.00	.46	2.06	1.19	1.92	2.67	0.00	1.58	0.00	.49	2.67
1934	0.00	0.00	0.00	1.00	16.50	2.78	1.24	2.51	2.78	1.27	0.00	.74	16.50
1935	1.38	0.00	0.00	.57	2.85	2.49	1.28	0.00	.80	.88	.86	.80	2.85
1936	0.00	0.00	1.62	.49	6.65	0.00	2.16	1.16	0.00	.64	.66	0.00	6.65
1937	0.00	.49	0.00	2.68	5.34	2.61	1.27	0.00	.72	0.00	.61	.54	5.34
1938	0.00	0.00	0.00	.56	7.37	4.28	5.25	1.07	2.16	3.72	0.00	0.00	7.37
1939	0.00	0.00	0.00	.49	3.66	5.25	3.76	2.20	.97	.52	.41	0.00	5.25
1940	.39	.35	0.00	0.00	3.27	3.27	2.16	4.12	2.51	1.00	1.30	.76	4.12
1941	0.00	0.00	0.00	.39	6.47	2.25	0.00	2.16	1.16	0.00	0.00	.61	6.47
1942	0.00	0.00	0.00	.93	3.72	1.46	0.00	0.00	0.00	.88	.90	.82	3.72
1943	.61	.64	0.00	1.09	3.72	5.27	0.00	.88	.88	.84	.93	0.00	5.27
1944	.61	0.00	.49	.49	5.57	10.19	7.23	3.75	2.06	1.09	0.00	.72	10.19
1945	.66	.64	.64	.68	16.02	2.93	0.00	.82	0.00	0.00	0.00	.47	16.02
1946	0.00	0.00	0.00	1.38	4.04	1.46	0.00	.90	2.06	0.00	.63	0.00	4.04
1947	0.00	0.00	0.00	.43	15.22	0.00	2.35	0.00	.49	0.00	.33	0.00	15.22
1948	0.00	.35	0.00	1.09	6.47	0.00	0.00	0.00	1.07	.90	0.00	0.00	6.47
1949	0.00	0.00	0.00	2.46	6.08	1.50	1.24	1.32	0.00	0.00	0.00	.51	6.08
1950	0.00	0.00	.46	.49	6.91	1.47	6.41	1.23	0.00	0.00	0.00	0.00	6.91
1951	0.00	0.00	0.00	0.00	8.17	1.20	11.83	0.00	3.57	0.00	0.00	0.00	11.83
1952	0.00	0.00	0.00	2.65	2.98	9.18	0.00	0.00	0.00	0.00	0.00	0.00	9.18
1953	0.00	0.00	0.00	3.40	4.12	1.35	1.23	0.00	0.00	0.00	0.00	0.00	4.12
1954	0.00	0.00	0.00	0.00	5.67	1.02	3.57	1.18	0.00	0.00	0.00	.54	5.67
1955	0.00	0.00	0.00	0.00	2.21	2.78	0.00	0.00	0.00	0.00	0.00	0.00	2.78
1956	0.00	0.00	0.00	0.00	5.11	3.68	0.00	0.00	3.93	0.00	0.00	0.00	5.11
1957	0.00	0.00	0.00	0.00	7.21	0.00	2.72	0.00	5.25	0.00	1.00	0.00	7.21
1958	0.00	0.00	0.00	0.00	12.54	3.93	0.00	0.00	0.00	.82	0.00	.66	12.54
1959	0.00	0.00	0.00	5.11	6.74	1.13	9.61	0.00	0.00	.40	.51	.51	9.61
1960	0.00	0.00	0.00	2.35	4.29	2.58	2.44	2.61	0.00	0.00	0.00	0.00	4.29
1961	0.00	0.00	0.00	1.52	6.47	2.36	1.24	3.88	.93	1.74	1.74	0.00	6.47
1962	0.00	0.00	0.00	.46	40.14	2.49	1.23	1.27	3.20	.70	.70	.61	40.14
1963	.56	.43	.40	.41	8.02	2.83	1.46	1.16	2.01	1.66	.78	.61	8.02
1964	.52	.46	0.00	1.72	3.12	3.20	2.35	6.47	3.57	2.25	.88	.80	6.47
1965	.64	.56	0.00	.49	3.75	2.78	2.46	1.14	1.92	2.16	.90	.66	3.75
1966	0.00	.49	.51	.49	11.00	6.27	1.19	2.46	1.07	.78	.70	.61	11.00
1967	0.00	0.00	0.00	.43	12.84	5.51	1.27	2.35	0.00	1.00	2.06	.86	12.84
1968	0.00	0.00	.49	2.61	5.23	2.69	4.12	0.00	.52	.37	.36	.35	5.23
1969	.37	.37	.35	.39	3.15	2.78	2.01	.63	1.13	.61	.61	.52	3.15
1970	.47	0.00	.41	0.00	4.51	4.87	2.16	.95	1.54	1.70	0.00	0.00	4.87
MID	.18	.12	.13	.97	7.35	2.88	2.46	1.24	1.16	.78	.49	.37	1.51
MAX	1.38	.64	1.62	5.11	40.14	10.19	11.83	6.47	5.25	3.72	2.06	.86	40.14
MIN	0.00	0.00	0.00	0.00	2.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A7c: Largest daily discharge increase for Station 372 in the years 1930-1970.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1930	-.78	-.64	-.56	-.49	0.00	-2.89	-1.32	-1.14	-.72	-.70	-.74	-.66	-2.89
1931	-.61	-.57	-.54	-.44	-2.96	-2.69	-4.04	-1.19	-1.09	-.93	-.82	-.72	-4.04
1932	-.63	-.63	-.52	-.46	0.00	-2.87	-1.46	-1.02	-.88	-.82	-.78	-.72	-2.87
1933	-.54	-.49	-.44	-.43	0.00	-1.19	-1.88	-1.46	-1.32	-.95	-.70	-.54	-1.88
1934	0.00	-.47	-.44	-.43	-4.15	-2.58	-1.32	-1.27	-1.40	-1.29	-.97	-.78	-4.15
1935	-.72	-.66	-.59	-.51	0.00	-1.27	-1.46	-1.43	-.95	-.88	-.86	-.80	-1.46
1936	-.74	-.64	-.56	-.47	-1.38	-1.46	-2.16	-1.29	-1.16	-.82	-.66	-.64	-2.16
1937	-.57	-.51	-.47	-.44	0.00	-1.31	-3.72	-1.19	-.76	-.72	-.61	-.61	-3.72
1938	-.54	-.51	-.44	-.41	-.76	-4.28	-5.25	-1.46	-1.16	-1.43	-1.29	-.97	-5.25
1939	-.74	-.64	-.56	-.49	-1.43	-2.36	-2.47	-2.69	-1.04	-1.00	-.44	-.41	-2.69
1940	-.39	-.36	-.35	-.32	-1.35	-2.20	-2.01	-1.16	-2.40	-1.74	-1.46	-.76	-2.40
1941	-.56	-.47	-.41	-.39	-.35	-1.22	-1.11	-.88	-1.16	-1.07	-.82	-.61	-1.22
1942	-.57	-.51	-.44	0.00	0.00	-1.23	-1.46	-1.22	-.90	0.00	-.90	-.82	-1.46
1943	-.74	-.64	-.56	-.49	-2.44	-1.46	-1.32	-.97	-.88	-.80	-.93	-.80	-2.44
1944	-.61	-.56	-.52	-.47	-.49	-3.44	-5.99	-2.06	-1.11	-1.09	-1.46	-.72	-5.99
1945	-.66	-.64	-.64	-.59	-5.91	-2.99	-2.83	-1.97	-.80	-.63	-.54	-.51	-5.91
1946	-.46	-.41	0.00	0.00	0.00	-1.46	-2.51	-1.00	-1.11	-1.07	-.78	-.63	-2.51
1947	-.59	-.52	-.41	0.00	-1.46	-2.61	-1.22	-.97	-.61	-.46	-.33	0.00	-2.61
1948	0.00	-.35	0.00	0.00	0.00	-1.37	-1.09	-1.00	-1.07	-1.00	-.84	-.68	-1.37
1949	-.61	-.52	-.47	0.00	0.00	-4.24	-2.89	-1.32	-1.11	-1.66	-.61	-.51	-4.24
1950	0.00	-.51	-.47	0.00	0.00	-1.47	-2.78	-2.66	-2.67	-.97	-.82	-.64	-2.78
1951	-.57	-.54	-.49	-.43	0.00	-1.17	-2.35	-1.14	-1.22	-.90	-.61	0.00	-2.35
1952	-.52	-.47	-.41	0.00	0.00	-3.11	-5.16	-1.24	-.90	-.70	-.57	-.51	-5.16
1953	-.47	-.44	-.40	0.00	0.00	-1.35	-2.69	-2.51	-1.07	-.84	-.72	-.63	-2.69
1954	-.56	-.51	-.44	-.39	0.00	-2.56	0.00	-1.46	-1.27	-.86	-.68	-.56	-2.56
1955	-.54	-.49	-.46	-.39	0.00	0.00	-1.46	-1.00	-.70	-.64	-.52	-.49	-1.46
1956	0.00	-.46	-.44	-.39	0.00	-2.47	-1.46	-1.02	-1.27	-1.88	-.90	-.61	-2.47
1957	-.54	-.44	-.40	-.39	-1.18	-1.46	-1.35	-1.46	-2.36	-2.35	-1.97	-.80	-2.36
1958	-.61	-.47	-.40	-.39	0.00	-4.87	-1.32	-1.00	-.95	-.82	-.78	-.72	-4.78
1959	-.61	-.59	-.51	0.00	-5.16	-2.40	-9.61	-.80	-.52	-.41	-.51	-.51	-9.61
1960	0.00	-.49	-.44	-1.93	0.00	-2.61	-3.63	-1.46	-1.27	-.93	-.78	-.66	-3.63
1961	-.57	-.52	-.44	-.41	-1.23	-1.46	-1.24	-1.46	-1.09	-.88	-.88	-.78	-1.46
1962	-.59	-.56	-.46	-.44	0.00	-1.25	-2.72	-1.27	-1.11	-.97	-.70	-.61	-2.72
1963	-.56	-.47	-.43	-.39	-1.33	-3.81	-2.89	-2.67	-1.92	-1.66	-1.54	-.64	-3.81
1964	-.52	-.46	-.41	-.37	-1.07	-2.11	-2.35	-1.97	-2.46	-3.57	-2.20	-.80	-3.57
1965	-.64	-.61	-.54	-.47	0.00	-2.84	-4.81	-2.20	-.86	-2.20	-1.79	-.66	-4.81
1966	-.59	-.47	-.51	-.49	-3.14	-6.27	-2.56	-1.35	-1.09	-1.54	-1.38	-.61	-6.27
1967	-.59	-.54	-.46	-.44	0.00	-5.37	-2.89	-2.35	-1.09	-.84	-1.79	-.86	-5.37
1968	-.70	-.61	-.56	-.49	-1.21	-3.50	-3.50	-1.58	-.52	-.39	-.37	-.36	-3.50
1969	-.37	-.37	-.35	-.33	0.00	-2.83	-1.70	-.80	-1.16	-.61	-1.16	-.52	-2.83
1970	-.47	-.41	0.00	-.41	0.00	-4.12	-3.27	-2.16	-1.58	-1.92	-.90	-.70	-4.12
MID	-.51	-.52	-.44	-.38	-.90	-2.49	-2.62	-1.47	-1.19	-1.10	-.93	-.62	-1.10
MAX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIN	-.78	-.66	-.64	-1.93	-5.91	-6.27	-9.61	-2.69	-2.67	-3.57	-2.20	-.97	-9.61

Table A7d: Largest daily decrease in discharge for Station 372 in the years 1930-1970.

APPENDIX 8: METHOD 26: USE OF REGRESSION-ANALYSIS TO DETECT ERRORS IN LONG SERIES

Object

1 To detect gross errors (outlines) in long data series.

2 To detect homogeneity breaks in long data series.

Description of the Method

The connection between water level and discharge for the whole data series can be determined by use of regression analysis. If data deviate outside the confidence limits, that will be noted. This control should be done with data calculated as pentad or weekly means. Longer mean periods can moderate single errors so much that they fall within the confidence limits.

For the series being checked, regression analysis on yearly or monthly means is applied, and observed or calculated values for the series are plotted. Gross homogeneity breaks will show that the calculated values in a part of the period lie over and the rest under the observed values.

Comments on the Method

The method can be used in automatic controls in the same way as Method 18 for control of daily values of the year. In many cases, it has been shown to be effective without sorting out too much data for inspection. A condition for the method to work well is that the stations are correlated well. The other reasonability tests described in appendix 2 can also be used.

As a homogeneity control, the method is poorer than the traditional double-mass analysis, but it can contribute to confirm effects established by double-mass analysis.

Example

Tables A8a and A8b shows an example of a transcript of outliers detected by use of the method.

RL.MP.	YEAR	X	Y	YPRED	DIFF	GR.VERDI
3	1961	645.140	642.360	642.982	-.622	.165
33	1963	645.730	643.470	643.744	-.274	.165
34	1963	645.750	643.340	643.770	-.430	.165
35	1963	645.740	643.310	643.757	-.447	.165
36	1963	645.750	643.430	643.770	-.340	.165
34	1965	646.010	643.860	644.106	-.246	.165

Table A8a: Control transcript for searching for gross errors based on regression against a neighbouring station.

```
         645.0     645.1     645.3     645.4     645.6     645.7     645.9     646.0     646.2     646.4     646.5
            .----------.----------.----------.----------.----------.----------.----------.----------.----------.----------.
H  644.6  I                                                                                    ...       ++   1  I
1  644.6  I                                                                                  ..       +++        I
1  644.5  I                                                                                ..       ++ 1     ... I
2  644.5  I                                                                              ..       ++       ..    I
3  644.4  I                                                                           ...       ++       ..      I
   644.4  I                                                                         ..       +++ 1  1  ..        I
   644.3  I                                                                       ..       ++       ...          I
   644.3  I                                                                     ..1      ++       ..             I
   644.3  I                                                           1      ...      +++       ..               I
   644.2  I                                                    1           ..       ++ 1     ...                 I
   644.2  I                                                              ..       ++ 1     ..                    I
   644.1  I                                                            ..     1 ++       ..                      I
   644.1  I                                                 1       ...      +++  1    ..                        I
   644.0  I                                                       ..      1++ 1  1  ...                          I
   644.0  I                                                     ..       ++ 11    ..                             I
   643.9  I         21                                 1     ...13 2211++31111  ..                               I
   643.9  I          1                                     ..  123  +++12     ..                                 I
   643.8  I                                             2..3111 11++11 2 11...                                   I
   643.8  I                                      1     ..1 11 21++22 1    ..                                     I
   643.8  I                                         ... 1 3122++3111 1  ..                                       I
   643.7  I                                       ..2 1 212+++       ...                                         I
   643.7  I       1                             ..3 11525++3 3     ..                                            I
   643.6  I                                   ..4114311++21 1    ..                                              I
   643.6  I                                ... 111X1+++        ..                                                I
   643.5  I                              ..  1 672++2       ...                                                  I
   643.5  I                          1 ..  1288X++511     ..                                                     I
   643.4  I                        1 ..2 2 X77++312     ..  1                                                    I
   643.4  I                     1 ...1134Xt+++ 32 1   ..      1                                                  I
   643.4  I                     .. 2162X5++2       ...                                                           I
   643.3  I                   ..217X8XX++        ..           2                                                  I
   643.3  I                ... 133XX1++        ..                                                                I
   643.2  I             1.. 2196X5+++1       ..                                                                  I
   643.2  I            .. 1189X3++ 11     ...                                                                    I
   643.1  I          ..2 2XXX3++  21    ..                                                                       I
   643.1  I       ...2  96X5++  1     ..                                                                         I
   643.0  I     ..   4X5X+++1 1 1  ...                                                                           I
   643.0  I   ..   11XX++1 1     ..                                                                              I
   642.9  I ..   1 XX++11      ..                                                                                I
   642.9  I.    19+++31      ..                                                                                  I
   642.9  I   4X++X5231   ...                                                                                    I
   642.8  I   ++5X12    ..                                                                                       I
   642.8  I ++XX241   ..                                                                                         I
   642.7  I+11      ..                                                                                           I
   642.7  I2     ...                                                                                             I
   642.6  I    ..                                                                                                I
   642.6  I  ..                                                                                                  I
   642.5  I .                                                                                                    I
   642.5  I            1                                                                                         I
   642.5  I                                                                                                      I
   642.4  I                                                                                                      I
   642.4  I           1                                                                                          I
            .----------.----------.----------.----------.----------.----------.----------.----------.----------.----------.
         645.0     645.1     645.3     645.4     645.6     645.7     645.9     646.0     646.2     646.4     646.5
                                                                                                        H1122 ->
```

Table A8b: Plot of correlation diagram. Suspicious data are found to the left of the diagram.

APPENDIX 9: METHOD 29: USE OF TIME SERIES ANALYSIS TO DETECT ERRORS

Object

To detect homogeneity breaks in long data series.

Description of the Method

A data series Q_t, made up from monthly means over a long period, is given. The data series will, under Nordic conditions, contain a more or less distinct variation. This can be expressed by the mean value P^i and the standard deviation S^i for every month of the year.

If the series is homogeneous, the yearly variation could be eliminated from the data series by use of the following equation:

$$y_t = (Q_t - P_i)/S_i$$

where y_t is a derived normalised data series and i is the number of the month of the year that corresponds to the point of time t in the data series (see Eggert Hansen (1973)).

The normalised series y_t, is then inspected to see if the yearly variations have actually been removed. This can be done by calculation and plotting the autocorrelation function or by spectrum analysis of the y_t-series.

Interpretation of the Results

If the autocorrelations quickly fade away, as shown in figure A9a, the method does not indicate a homogeneity break. If the yearly variation is clearly present, it can be caused by regulating effects during the break. Such regulated effects can be caused by large transfers of water that drastically reduce the catchment area.

Water regulating can also result in the yearly discharge being maintained, but the water being redistributed during the year. Figure A9b shows an example of this.

Profile changes can also be detected by this method. Figure A9c gives an example of this. By dividing the series into two parts, before and after the break, and reporting the analysis for each part, the two shorter periods will each be homogeneous.

Climatic effects can, in some cases, be detected by use of this method. They show up in the form of long term variations on the correlograms. If the effect is caused by climate, it can be esablished by analysing stations nearby. The pattern shown in figure A9d is traced in 6 stations within the area and is assumed to be caused by climatic effects.

Comments on the Method

The method is of a type called pattern analysis. The pattern searched for here is yearly variations given by seasonal changes in temperature and precipitation.

The autocorrelaions are strongly correlated with each other. This complicates the evaluation of the significance of the detected effects. The method seems, however, to be able to detect various types of homogeneity breaks.

Smaller build-ups or scouring in the control profile will mainly affect the discharge curve for low water levels. Such profile changes are difficult to detect by double-mass analysis which is especially sensitive to changes in the curve on middle and high water levels. The autocorrelation method is sensitive for profile changes over the full range of variations of the station. The method is therefore a valuable supplement to the traditional double-mass analysis.

An interactive program has been prepared for the method by the Norwegian Water and Electricity Department.

Autocorrelation Function for the Standardised Series
Oren: Gusja River

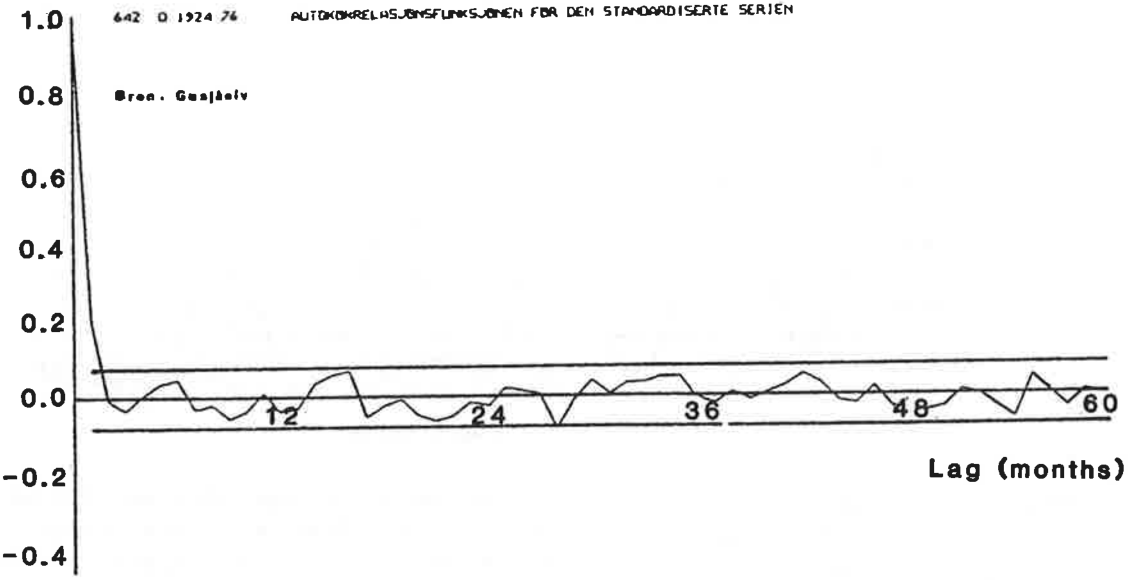


Figure A9a: The graph shows the autocorrelations for delays of 1 to 60 months for a data series where the yearly variations have been removed. Because the autocorrelation function does not include and cycle, the series is judged to be homogeneous.

Autocorrelation Function for the Standardised Series
Insal Lake: Mals River

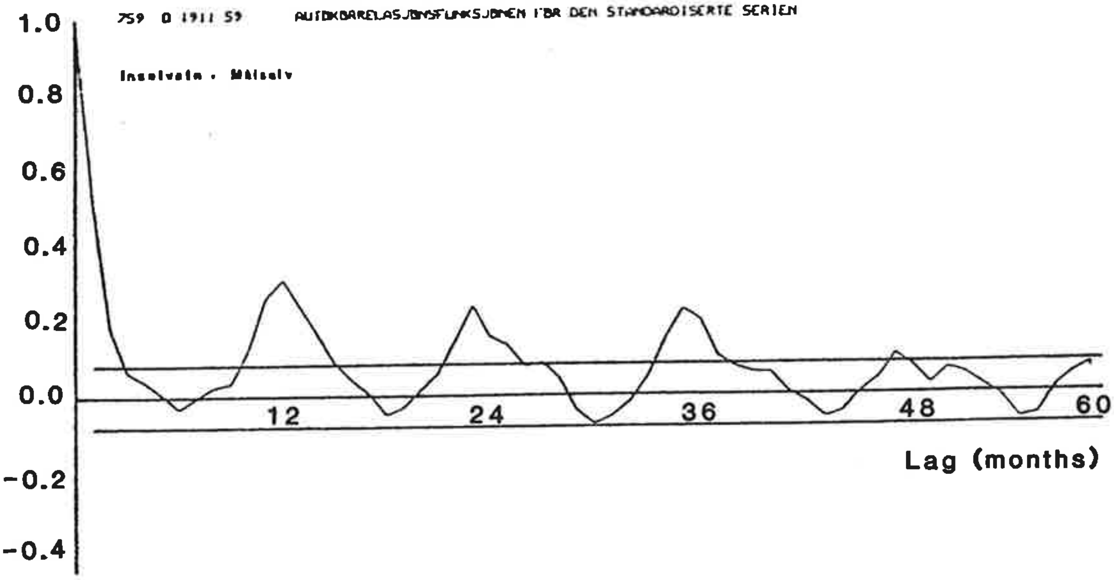


Figure A9b: The data series in this example was regulated in 1930. The regulation involved redistribution of water during the year. If data for the period before regulation is analysed, the autocorrelations will not contain any marked yearly variation.

Autocorrelation Function for the Standardised Series
Gaslands Lake: Ringstad River

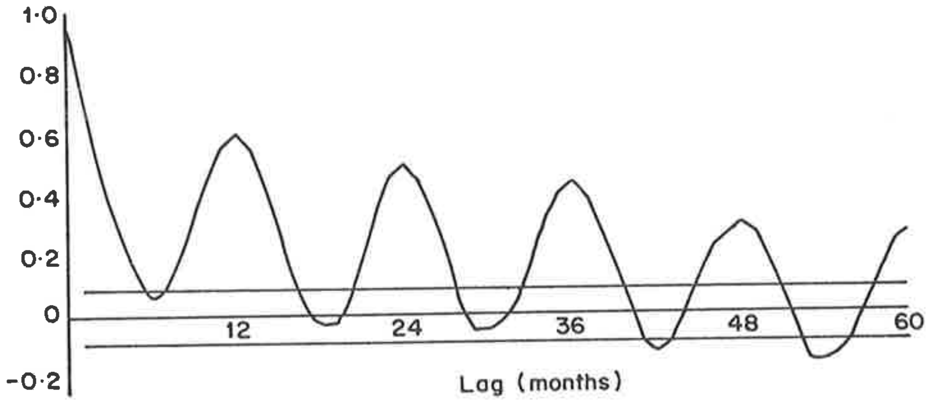
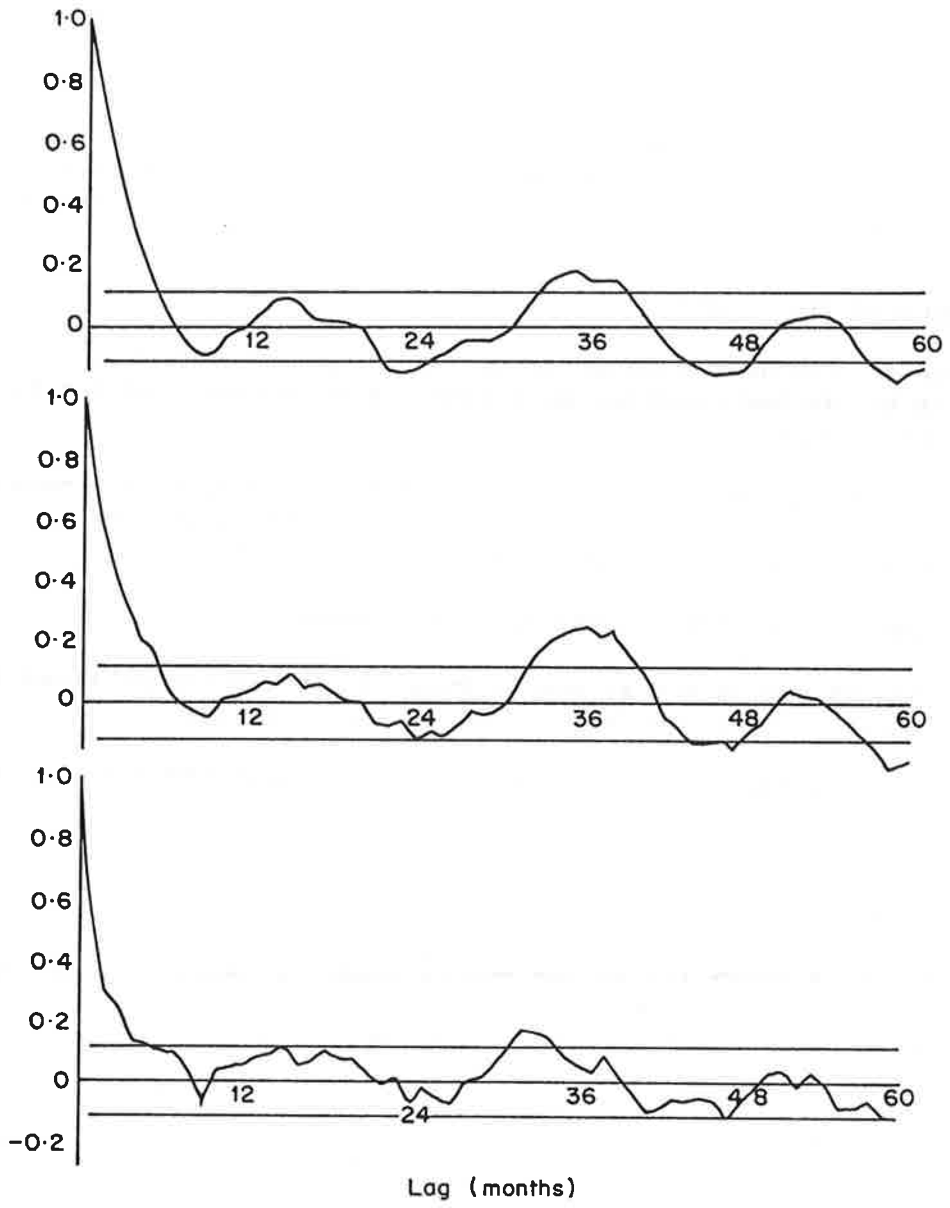


Figure A9c: For this series the autocorrelation was also maintained in spite of attempts to remove it. The cause was a homogeneity break that especially influenced the lower water levels. The break was due to earthworks in the riverbed.



Autocorrelation Function for the Standardised Series

Figure A9d: The three graphs here indicate a cycle of 1½ years in the data after the yearly variation has been removed. The middle and upper series are in the main course of the River Trysil, while the lower is for a tributary. Corresponding cycles have been found at at least three other stations in the same area. This is an example of a regional effect that must be accepted.

(NB: The River Trysil starts at Lake Femunden in Norway and after crossing the border into Sweden is called the River Klara.

APPENDIX 10: METHOD 30: DOUBLE MASS ANALYSIS

Object

To detect homogeneity breaks in long data series. Such breaks can be caused by undetected changes in the control section at the point of gauging, which can make the discharge curve and the calculated discharges systematically wrong.

Description of the Method

The double-mass method involves accumulated yearly totals for the station that is to be checked, plotted as a function of accumulated yearly values for another station.

It can be difficult to decide if a break point represents a homogeneity break or not. In a modified method, the data will be transformed in such a way that a homogeneity break can more easily be found.

The calculations are done in the following order:

1 The mean values $\overline{X}_A$ and $\overline{X}_B$ are calculated for the two stations for the yearly totals over the full common period (N years).

2 The relative values for both stations are calculated for each year.

$$Y_{Ai} = X_{Ai}/\overline{X}_A$$

$$Y_{Bi} = X_{Bi}/\overline{X}B$$

for i = I, N where X_{Ai} is the yearly total for series A, and X_{B1} is the yearly total for series B in the year no. i in the common period. The mean value for these relative values is I.

3 The accumulated deviation from the mean values of the relative values are calculated for each station.

$$V_{Ai} = \sum_{j=1}^{i} (Y_{Aj}-I) \qquad V_{Bi} = \sum_{j=1}^{i} (Y_{Bj}-I)$$

for i = 1, N.

4 The difference between the two values is calculated

$$Z_i = V_{Ai} - V_{Bi}$$

for each year.

5 The difference is plotted as a function of time as shown in figure A10c.

Interpretation of the Results

1 Conventional Double-Mass Analysis

If the stations are in the same climatic region, and there is no marked storage over several years for the one station and both stations are homogeneous, the points will mainly fall in a straight line as shown in figure 10a. If one of the staions is not homogeneous, there will be a break point on the line, as shown in figure A10b. By using several comparing stations it can be determined whether the break is in the series being checked or in the comparison series.

If there appears to be a break during one single year, but the extension of the straight line defined by the period before this year is paralled with the straight line defined by the later years, that is usually caused by one single year deviating because of unusual precipitation conditions. This usually shows up in connection with extremely wet years.

2 Modified Double-Mass Analysis

If the two time series are homogeneous the Z_i values will fluctuate about the time axis. If there is a homogeneity break in one of the series, the Zi values will reach a minimum or a minimum at the point in time when the break occurred.

Comments on the Method

Double-mass analysis is the most useful method for homogeneity control of long series. The method does, however, react to homogeneity breaks of other causes, as for instance power-regulating and other forms of transfer of water when these influence the yearly means. It can be difficult to interpret the results of double-mass analysis, especially for areas with large local variations in outlet conditions. Other methods should therefore be used in addition to double-mass analysis.

Certain profile changes will only influence the discharge on lower water levels. Such homogenity breaks cannot be established by the usual double-mass analysis. A possibility is then to analyse data from certain parts of the year. This can only be done for stations with little water storage in the catchment area.

Examples

Figure A10a and figure A10b show the results of double-mass analysis using the conventional method.

Figure A10c shows the results of modified double-mass analysis for discharge from a representative area in Velen at the outlet of Lake Velen. Svansvik in Lidan that runs out into Vänern Lake is used as a comparison station.

The upper graph illustrates accumulated relative deviation from the mean value for each station, while the lower graph shows the difference Z_i.

The graph shows that the observations were moved from a fixed scale in the lake to a recorder below the outlet. The reason for the break is therefore thought to be uncertainty in gauging of high discharges before the station was moved.

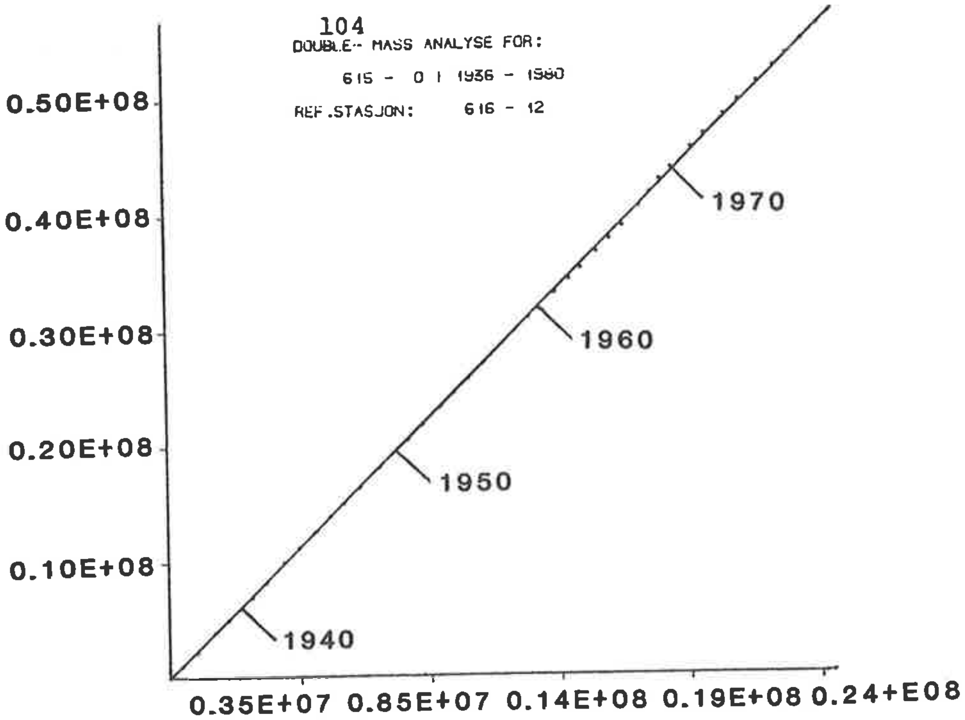


Figure A10a: Traditional double-mass analysis between two stations in Gaula in Norway. The data does not deviate from the straight line. The series is therefore judged to be homogeneous.

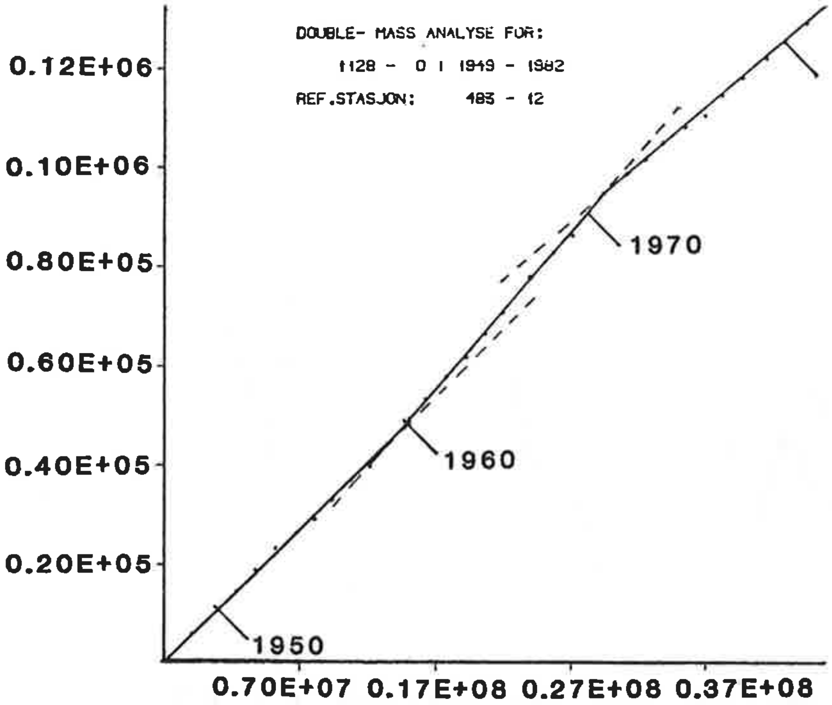


Figure A10b: Traditional double-mass analysis between two stations in Mana in the Skien River in Norway. At station 1128 a gauging dam was built in 1971, at the same time as a new discharge coefficient was being used. The break in the double-mass curve is judged as a homogenity break. This is confirmed by analysis against other stations in the area.

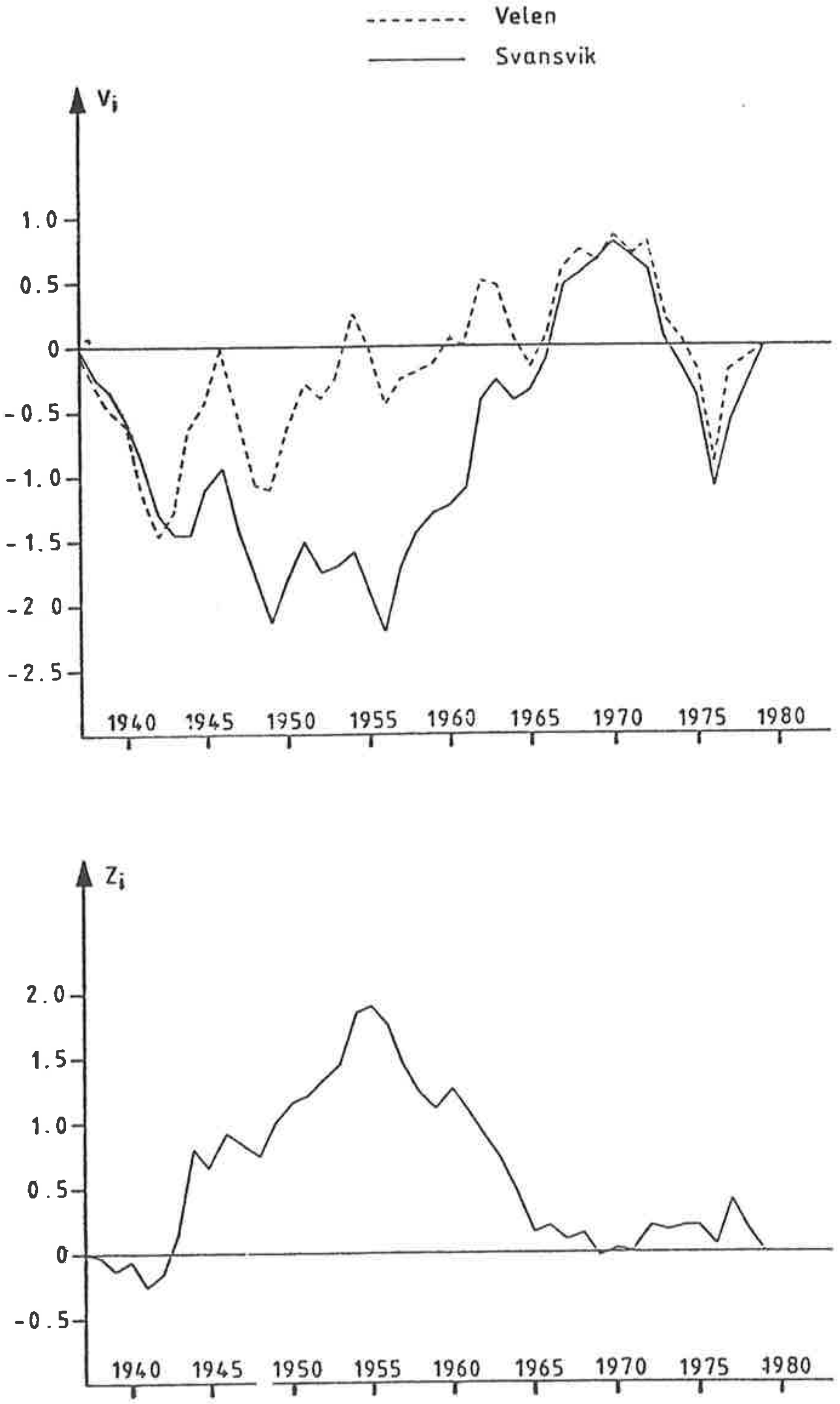


Figure A10c: Example of modified double-mass analysis

APPENDIX 11: METHOD 32: EVALUATION OF THE IMPORTANCE OF EXTRAPOLATION OF THE DISTANCE CURVE

Object

To estimate the uncertainty in the yearly discharge because of the discharge curve.

Description of the Method

For every year in the data series it is calculated how large a part of the yearly discharge that is determined by the extrapolated part of the discharge curve. The results are presented in table form as shown in table 11a.

Comments on the Method

The method cannot be used to detect errors but is useful in evaluating the reliability of data. If the current station is used in control against other stations, less stress should be laid on the stations where the extrapolations are important.

DATABASE FOR QUALITY CONTROL OF DISCHARGE

Water Measurement No 851: Code 0: Field Area 0

Highest measured discharge QM = 118.10 m^3/s
Lowest QL = .99 m^3/s
is submitted point measured :

QMAX: The year's highest discharge. In days 1: Number of days with discharge over QM

QMIN: The year's lowest discharge. In

RMAX: Proportion between total discharge. In days 2: Number of days with discharge

Calculated on basis of under QL
Upper extrapolated part of
The discharge curve and total year's discharge

RMIN: Propertion between total discharge

Calculated on basis of
Lower extrapolated part of
The discharge curve and total year's discharge

YEAR	CMAX	RMAX	CMAX/CM	DAGERT	OHEN	RHIN	DAGERS
1905	-	-	-	-	-	-	
1906	193.06	5.50	1.63	4.	2.74	0.00	0.
1907	87.47	0.00	.74	0.	2.03	0.00	0.
1908	128.68	5.92	1.09	4.	1.54	.26	13.
1909	144.52	2.88	1.22	2.	.45	.37	38.
1910	144.52	12.82	1.22	9.	1.47	.32	17.
1911	170.96	2.95	1.45	2.	1.69	.03	2.
1912	178.10	3.68	1.51	2.	1.08	.33	18.
1913	140.43	7.31	1.19	6.	.58	.11	11.
1914	353.15	13.42	2.99	10.	1.14	.10	9.
1915	166.32	2.45	1.41	1.	.69	2.03	96.
1916	314.45	6.29	2.66	3.	.83	.35	31.
1917	395.32	27.78	3.35	19.	.01	.30	39.
1918	225.77	5.45	1.91	4.	3.60	0.00	0.
1919	166.32	8.99	1.41	5.	.01	.70	65.
1920	217.23	24.87	1.84	24.	1.27	.08	7.
1921	190.50	4.72	1.61	5.	2.42	0.00	0.
1922	203.54	8.76	1.72	7.	1.47	.17	12.
1923	310.76	19.17	2.63	18.	1.62	.18	14.
1924	190.50	17.01	1.61	14.	2.12	0.00	0.
1925	246.68	10.89	2.09	9.	3.34	0.00	0.
1926	353.15	10.45	2.99	7.	2.52	0.00	0.
1927	178.10	13.96	1.51	12.	.74	.13	13.
1928	166.32	10.41	1.41	9.	.78	.04	5.
1929	178.10	14.94	1.51	15.	1.03	.48	44.
1930	144.52	5.76	1.22	5.	2.85	0.00	0.
1931	231.60	15.25	1.96	12.	1.86	.03	2.
1932	246.68	7.23	2.09	5.	1.69	.07	4.
1933	178.10	7.59	1.51	4.	1.69	.16	7.
1934	166.32	9.01	1.41	8.	2.74	0.00	0.
1935	353.15	17.41	2.99	11.	2.12	0.00	0.
1936	200.88	9.72	1.70	5.	1.27	.51	23.
1937	180.53	21.02	1.53	16.	1.08	.51	33.
1938	279.02	20.20	2.36	23.	1.27	.06	8.
1939	190.50	18.64	1.61	16.	1.27	.16	12.
1940	490.87	15.29	4.16	6.	1.14	.67	47.
1941	124.93	1.93	1.06	1.	1.33	2.15	88.
1942	203.54	23.06	1.72	20.	1.14	.49	41.
1943	314.45	13.74	2.66	12.	3.74	0.00	0.
1944	124.93	.98	1.06	1.	3.09	0.00	0.
1945	217.23	14.33	1.84	12.	4.18	0.00	0.
1946	150.82	4.88	1.28	4.	1.86	.02	1.
1947	124.93	3.60	1.06	3.	1.14	.76	53.
1948	378.02	36.99	3.20	32.	1.94	.01	1.
1949	124.93	1.01	1.06	1.	8.62	0.00	0.
1950	178.10	6.77	1.51	6.	2.42	0.00	0.
1951	185.47	4.84	1.57	3.	1.14	.46	29.
1952	166.32	8.35	1.41	8.	3.34	0.00	0.
1953	353.15	16.90	2.99	15.	3.34	0.00	0.
1954	166.32	7.68	1.41	6.	2.22	0.00	0.
1955	166.32	4.64	1.41	4.	2.22	0.00	0.
1956	134.46	8.04	1.14	7.	2.03	0.00	0.
1957	217.23	5.98	1.84	5.	3.09	0.00	0.

YEAR	CMAX	RMAX	CMAX/CM	DAGERT	OHEN	RHIN	DAGERS
1958	178.10	5.86	1.51	4.	1.77	.15	8.
1959	134.46	2.97	1.14	2.	2.52	0.00	0.
1960	91.80	0.00	.78	0.	1.86	.17	6.
1961	279.02	5.72	2.36	4.	4.82	0.00	0.
1962	178.10	12.60	1.51	11.	2.12	0.00	0.
1963	190.50	8.43	1.61	5.	1.40	.64	32.
1964	144.52	3.46	1.22	3.	1.54	.26	18.
1965	166.32	11.65	1.41	8.	1.94	.02	1.
1966	203.54	7.77	1.72	5.	1.94	.04	2.
1967	262.48	28.40	2.22	34.	5.91	0.00	0.
1968	155.13	12.33	1.31	11.	2.32	0.00	0.
1969	203.54	9.77	1.72	6.	2.03	0.00	0.
1970	161.78	5.54	1.37	4.	1.54	.65	39.
1971	178.10	15.47	1.51	16.	4.66	0.00	0.
1972	124.93	2.74	1.06	2.	1.14	.24	14.
1973	203.54	9.30	1.72	8.	4.99	0.00	0.
1974	203.54	7.91	1.72	6.	4.03	0.00	0.
1975	190.50	10.74	1.61	10.	2.22	0.00	0.
1976	121.27	1.09	1.03	1.	2.85	0.00	0.
1977	150.82	4.43	1.28	3.	2.22	0.00	0.
1978	166.32	7.84	1.41	6.	2.97	0.00	0.
1979	178.10	13.96	1.51	12.	2.03	0.00	0.
1980	203.54	9.36	1.72	6.	1.40	.73	40.

MEAN OF ALL DISCHARGES	31.66
STANDARD DEVIATION	32.97
UNEVENESS	2.27
KURTOSIS	13.16
COEFFICIENT OF VARIATION	1.04
UNEVENESS/VARIATION COEFFICIENT	2.18

Table 11a: Database for Quality Control of Discharge

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