A Review of Current Knowledge

THE MEASUREMENT OF FREE SURFACE FLOWS

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Review of Current Knowledge

This review is one of a series of Reviews Of Current Knowledge (ROCKs) produced by FWR. They focus on topics related to water supply, wastewater disposal and water environments, which may be the subject of debate and inquiry. The objective of each review is to produce concise, independent scientific and technical information on the subject to facilitate a wider understanding of the issues involved and to promote informed opinion about them.

Review of Current Knowledge

THE MEASUREMENT OF FREE SURFACE FLOWS

Compound gauging structure on the River Tees at Barnard Castle

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1 Introduction

In the widest sense 'hydrometry' embraces the measurement of all the elements in the hydrological cycle including surface water flows, groundwater movement and associated phenomenon such as sediment movement and morphology. This ROCK concentrates on a major element within hydrometry, namely the measurement of free surface flows. It does not cover flows in closed conduits and pipes although some of the methods described can be used for these applications.

Much of the research into the methods of measuring free surface flows was carried out in the 1960s and 1970s and was stimulated in the United Kingdom by the Water Resources Act of 1963. However, there have been some significant advances in more recent times, particularly in the fields of remote sensing, data processing and data storage.

Research has led to the development of a series of International and British Standards. The policy has been to work through the International Standards Organisation (ISO) which is based in Geneva and publishes hydrometric Standards which may be used anywhere in the world. These Standards, where applicable to United Kingdom conditions, are then published as dual numbered British Standards by the British Standards Institution (BSI). The aim is to achieve worldwide consistency in the methods used to collect data on free surface flows. There has been a series of committees dealing with hydrometry since the 1960s, typically with 15 to 20 participating member countries, and many Standards have been produced. The current listing of International Standards is given in the Appendix which is divided into five main categories:

1. Velocity area methods
2. Flow measurement structures
3. Instrumentation
4. Sediment transport
5. Groundwater

The measurement and subsequent recording of free surface flows has many important uses which are discussed in Chapter 2. These include:

1. Water resources studies
2. Flood risk analyses
3. Flow data for engineering design
4. Sediment related studies
5. Laboratory studies

Chapter 3 covers a range of subjects associated with the measurement of free surface flows. These include:

Measurement of velocity and water level
1. Mechanical and acoustic current meters
2. Water levels

Measurement of flow
1. Velocity area methods
2. Flow measurement structures
3. Dilution gauging
4. Ultrasonic methods
5. Electromagnetic methods
6. Volumetric and weighing techniques

The storage and availability of surface runoff information, from a national and an international perspective, are described in Chapter 4. The use of telemetry to acquire, and collect centrally, large quantities of data in real time is described in Chapter 5 together with the subject of uncertainties in measurement.

Chapter 6 covers a recent development which embraces modern digital technology and enables large quantities of reliable data to be obtained relatively quickly.

2 Uses of free surface flow information

Civilisation depends on water, water for domestic consumption, water to grow crops, water for industrial processes, etc. However, civilisation is also vulnerable to the problems which stem from too much or too little water in the form of floods and droughts. Water management is an ever increasing challenge as the world population increases and man-induced global warming begins to make an impact.

Hydrometric data collection is on-going and provides essential information for inputs to analyses and numerical models which assess present and future conditions. The data provide the essential foundation upon which improved river and water management strategies can be developed.

River flows are the combined result of the many climatological and geographical factors which interact within a drainage basin. Flow data are the most directly appropriate component in the hydrological cycle for a wide range of applications. These include the assessment and management of water resources (including the provision of water for food production), the design of water-related structures (reservoirs, bridges, flood banks, urban drainage schemes, sewage treatment works, etc.) and flood warning and alleviation schemes. In addition, flow data are essential for assessing and developing hydro-power potential and enhancing both the ecological health of water courses and wetlands and their amenity and recreational value.

As with many environmental datasets, data on free surface flows assume a particular importance at a time of actual or anticipated change. With global warming expected to impact very unevenly on precipitation and river flows, in both spatial and temporal terms, continuous observational records are the key to identifying, quantifying and interpreting hydrological trends. These records will help in the development of strategies to deal with floods and droughts in the future.

Specific uses of surface water information are described in the following sections of this chapter.

2.1 Water resources studies

A more extensive coverage of worldwide water resources is to be found in a previously published ROCK (**White W R.** (2010) *World water: resources, usage and the role of man-made reservoirs*). More recent data are presented below.

Fresh water resources represent but a small part of the total amount of water in the world. The International Commission on Large Dams (**International Commission**

on Large Dams (ICOLD). (2007). *Dams and the World's Water*) suggests that 97.5% of the world's water is the saltwater found in the oceans and only 2.5% is fresh water. Furthermore, not all of the fresh water is readily available to mankind. Most of it, nearly 70%, is tied up in the form of glaciers and snow cover in the Arctic and Antarctic regions. The residual fresh water resources are almost entirely to be found in groundwater. Lakes and river storage amount to only 0.3% of the total fresh water resources.

Fresh water is taken as that which is not saline or brackish. It is derived from precipitation and occurs in glaciers, natural lakes, man-made reservoirs, rivers and groundwater. The Food and Agriculture Organisation of the United Nations (FAO) provides information on fresh water resources (**Food and Agriculture Organization of the United Nations (FAO). Water Resources, Development and Management Service.** (2013). *AQUASTAT Information System on Water in Agriculture*). The freshwater resources are determined for each country by considering river flows, groundwater recharge and an estimated "overlap" between the two. In addition, the fresh water resources are considered in terms of those generated within the country and those which enter or leave that country as a result of rivers which cross international boundaries.

The Food and Agriculture Organisation of the United Nations uses various definitions to describe surface water resources, groundwater resources and the interaction between the two. When assessing the water resources of individual countries, FAO considers flows into and out of those countries from and to adjacent areas. Some of these flows are regulated by international agreements. Probably the most useful measure for individual countries is of the Actual Renewable Water Resources, (ARWR). These actual totals include the quantity of flows reserved to upstream and downstream countries through formal and informal agreements or treaties. The actual flows are often much lower than the natural flow due to water scarcity in arid and semi-arid regions.

In recent times the Food and Agriculture Organisation of the United Nations has presented water resources data graphically and the latest plots are given below. The plots should be judged in the light of the world population of approximately seven billion in 2011 and rising at about 1.5% per annum.

Figure 1 shows the Annual Renewable Water Resources per person per year across the globe. The figures range from less than 500 m^3/year for inhabitants in Northern Africa and much of the Middle East to more than 5000 m^3/year for inhabitants of much of North and South America, West Africa, Northern Europe, Central Asia and Oceana.

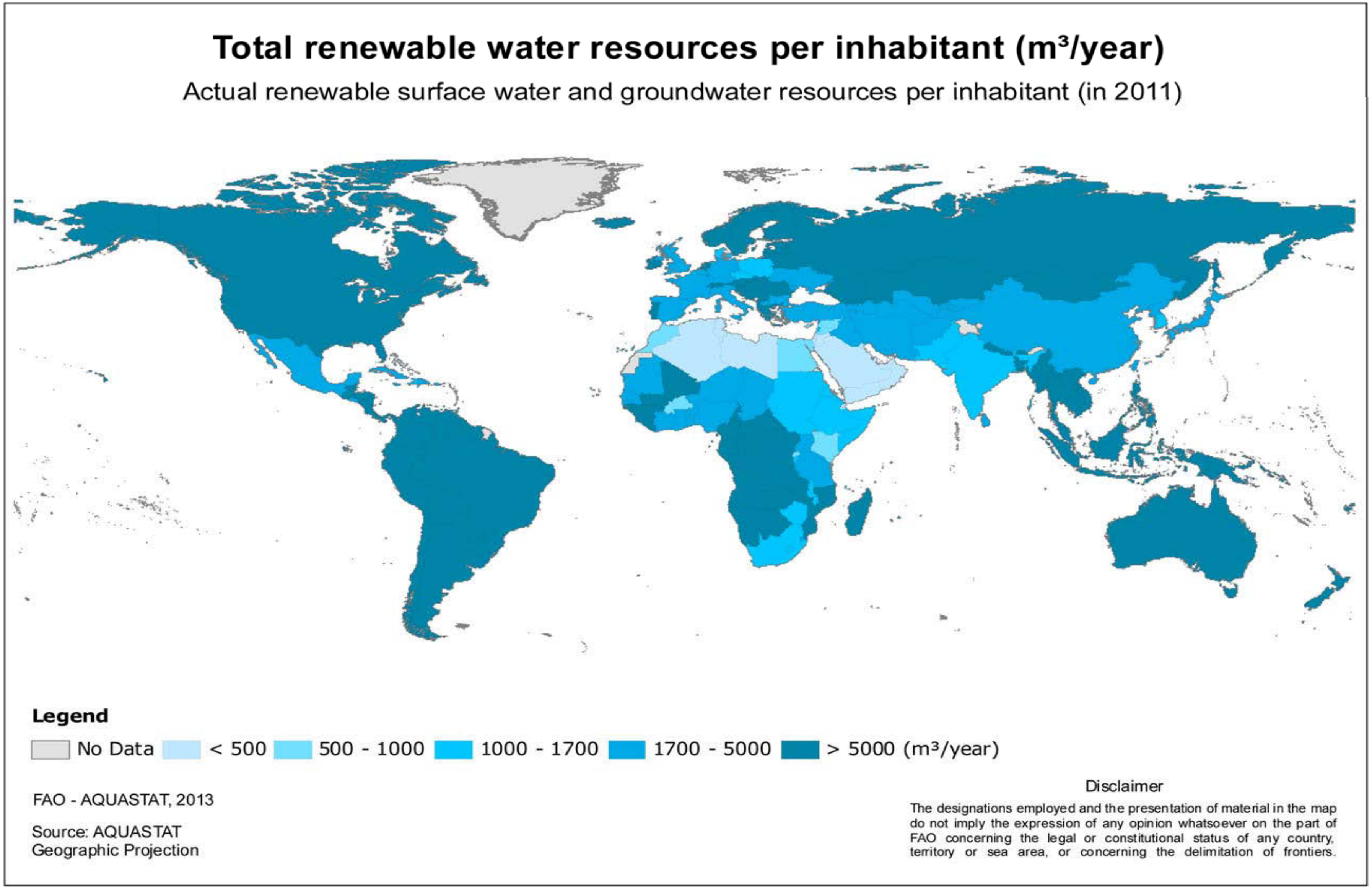


Figure 1 Renewable water resources per person
Source: FAO AQUASTAT database

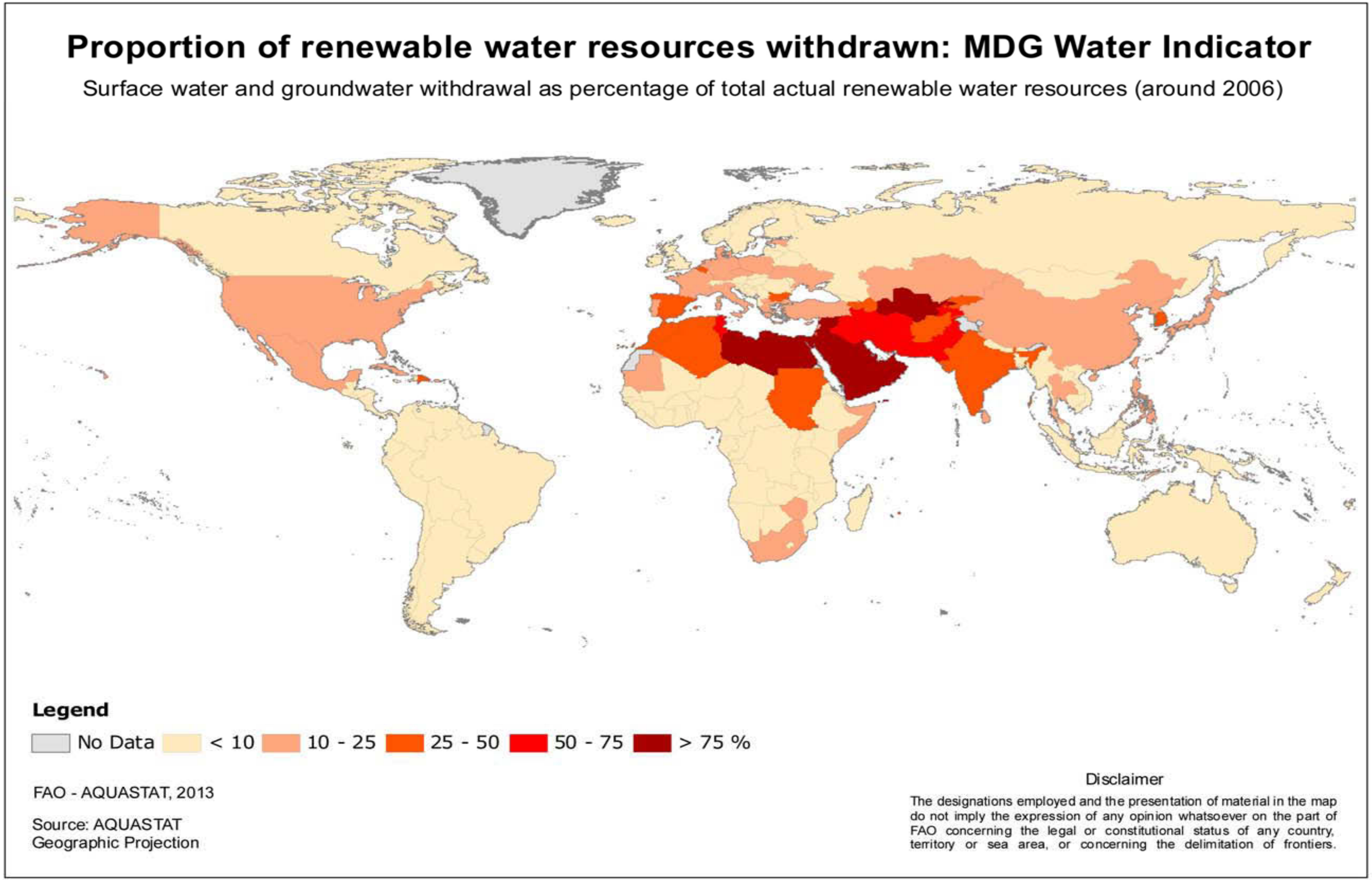


Figure 2 Renewable water resources currently exploited
Source: FAO AQUASTAT database

Figure 2 shows how much of the Annual Renewable Water Resources are currently consumed in agricultural, industrial, domestic and other uses. There are potentially serious shortages in Northern Africa and equatorial countries as far east as India and Bangladesh.

It is particularly important in areas of water scarcity that the water resources are soundly based upon reasonably accurate measurements of surface water flows. However, it is not always possible to gain these direct measurements, particularly in remote areas or where streams are ephemeral. In these circumstances measurements of rainfall followed by computer analyses using rainfall / run-off relationships provide an additional powerful tool.

2.2 Flood risk analyses

Again this topic is covered more comprehensively in a recent ROCK (**White W R and Samuels P G.** (2011) *Floods: alleviation, protection, response and risk management*).

The question is often asked "What is the probability of a flood of a certain magnitude occurring at a particular location in any one year?" To answer this question with any degree of certainty demands that a considerable amount of local data is collected over an extended period of time and that these data are subjected to rigorous statistical analyses and modelling.

There are at least five characteristics which are useful in comparing one flood with another. These are:

1. Peak water level observed during the flood event
2. Date and time at which the peak level occurred
3. Peak discharge during the flood event
4. Duration of the flood and the shape of the flood hydrograph
5. Flooded area

Probably the two most important of these are the *peak discharge* and the *flooded area*.

In the case of modest floods, for example for those where the river remains within its bank, it is relatively straightforward to determine the *peak flow*. There may be an established flow gauging station nearby at which the peak flow can be read from the known stage-discharge relationship at the site. If this is not the case, relatively simple hydraulic calculations can provide the discharge from a knowledge of the cross-sectional area of the channel, the slope of the channel and the estimated roughness of the wetted perimeter.

Where over-bank flow occurs during flood events the calculations are still manageable but there is an extra element of uncertainty due to the interactions between the flow in the river and the flow over the adjacent flood plain. The calculations are only valid for relatively straight channels with flood plains of near-uniform width.

During major flood events, straightforward calculation techniques become untenable and other more sophisticated approaches are called for. In recent years 2-D and 3-D numerical models have been developed and these are able to simulate more complex situations. The models are valuable tools with which to retrospectively simulate and quantify observed flood events and, in particular, to establish the peak discharges which have occurred.

The extent of the *flooded area* is important because it defines the area subject to damage and disruption. Data on flooded areas has historically been gathered either from visual observations taken at ground level or from aerial photography. A recent development has been the use of satellite imagery combined with powerful computerised database systems to store and display data in a readily digestible form. This technique has great potential and is currently the subject of major research investigations to determine what data might be presented and in what form.

The measurement of surface water flows is thus one of the important building blocks which enable the prediction of flood magnitudes and frequencies to be established. Subsequent analysis of the data can also deduce flooded areas and hence potential damages, both physical and economic.

Plate 1 Flooding of the River Thames in Oxford
Source: http://www.oxfordhistory.org.uk

2.3 Flow data for engineering design

There are many applications of flow data which relate to construction projects and, in particular, civil engineering works associated with transport, water supply, flood protection and hydropower. This section gives a few examples.

Flood defence works

In designing flood defence works it is necessary to have firm estimates for the hydraulic parameters against which the works will be effective, stable and durable. Design flows, water levels and velocities need to be established at the outset.

The design flow depends upon the nature of the area which is to be protected and the damages which might occur during flood events. For example, agricultural land is often protected against floods which have a probability of 0.03 of occurring in any year whereas urban areas are protected against less likely floods, often with a probability of 0.01 of occurring in any year.

River works

In many parts of the world, rainfall and runoff are variable and it is expedient to store water in reservoirs so that reliable water supplies are available for agricultural, industrial, domestic and other uses. The questions then arise, where to site the reservoir and what reservoir capacity to provide. To answer these questions long periods of recorded flows, or synthesized flows from rainfall records, are required. If the reservoir is oversized it will rarely fill and some of the capital outlay will have been wasted. If the reservoir is undersized, spills from the reservoir will be greater and more frequent, water will be wasted and, potentially, the capacity of any overflow spillways will be under designed thereby endangering the infrastructure. Hydropower is discussed in a previous ROCK (**White W R.** (2013) *The role of water in the production of energy*).

Plate 2 Kariba Dam on the Zambesi River, Zimbabwe / Zambia
Source: Author

Other types of structures found on rivers are numerous and, in most cases, a knowledge of anticipated flows is necessary for their design. For example, the design of off-takes for water abstraction requires a knowledge of the long term variations in river flow and also the range of water levels at the site. Over bridges require a similar knowledge of the hydraulic parameters.

Plate 3 Road bridge across Rea Brook at Hookagate, Shropshire
Source: Author

2.4 Sediment related studies

Water movement causes the erosion of sediments and these sediments are transported down river systems, through estuaries and along coastlines. The mechanisms vary but research over the last century has provided the means of determining quantitatively the erosion, deposition and transport rates of a wide range of sediment types based on a knowledge of a) water flow conditions and b) the nature of the sediments being transported.

Sediments can be classed into two types:

1. Very fine sediments which tend to travel in suspension, held there by the turbulence of the flow
2. Coarse sediments which travel in close proximity with the bed and are moved by the shear forces imposed by the moving water

The quantity of fine sediments in motion is governed by the supply into the water course from the surrounding land areas, whereas the quantity of coarse sediments in motion depends upon the water flow parameters.

There are now reliable models available which predict sediment movement from a knowledge of the water movement and the nature of the sediments. They are used for such studies as:

1. Degradation and erosion in rivers, estuaries and coastal waters
2. Sedimentation in reservoirs and the flushing of sediments from reservoirs
3. Morphological change in straight, meandering and braided river channels
4. The stability and movement of navigation channels in estuaries
5. Beach erosion, deposition and littoral drift along coastlines

Plate 4 Braided Waimakariri River, Canterbury Plains, New Zealand
Source: Author

2.5 Laboratory studies

The traditional method of investigating proposed engineering works, prior to the advent of high powered computing facilities, was to build and test a physical model of the proposed works and to impose the anticipated hydrometric input parameters. Flow patterns and water levels could then be established.

More recently, computational models have provided a much cheaper and no less accurate simulation tool for many applications. However, they also require input data such as observed flows, water levels, wave heights, etc.

Physical models still have advantages in some areas where our knowledge of the detailed physics of the situation is lacking. In these situations, it is better to rely on the principles of similitude used in physical modelling than to risk putting much simplified equations into computer analyses.

3 Methods available for measuring free surface flows

3.1 Measurement of velocity and water level

3.1.1 Mechanical current meters

Historically the most common instrument used for measuring velocity has been the mechanical current meter. These meters consist of a propeller mounted on a horizontal axis or a series of cups which rotate around a vertical axis. An electronic signal is transmitted by the meter on each revolution allowing the revolutions to be counted and timed. The rate at which the meters revolve is directly related to the velocity of the water and hence the timed revolutions provide a measure of the water velocity.

Two typical current meters are shown in Plates 5 and 6.

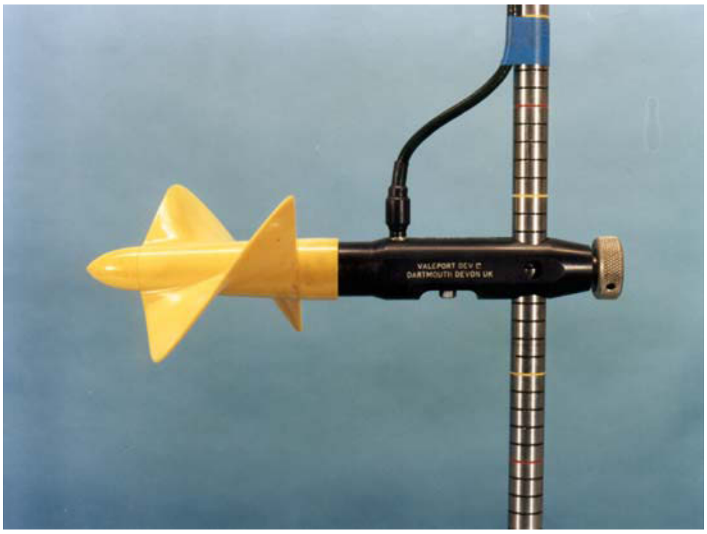


Plate 5 Braystoke current meter
Source: Author

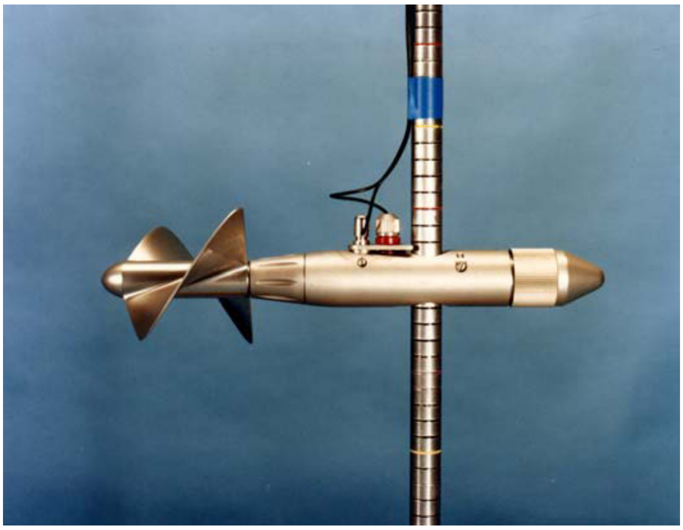


Plate 6 Ott current meter
Source: Author

The calibration of these meters cannot be determined theoretically and hence they are tested in the laboratory in a current meter rating tank similar to the one shown in Plate 7. Calibration is carried out on a regular basis because wear and tear of the meters can make small differences in their performance characteristics.

Plate 7 Current meter rating tank
Source: Author

Using mechanical current meters, velocity profiles in the vertical can be established by taking a series of readings as the meter is lowered gradually from the surface down to the bed. This is usually achieved by suspending the meter from a horizontal wire spanning the watercourse and using a winch and pulley system, from the river bank, to raise and lower the meter.

Alternatively, arrays of meters can be mounted on poles and the outputs from individual meters are logged separately. This method speeds up the process and is particularly useful where flows are varying significantly with time. An example of this approach is shown in Plate 8.

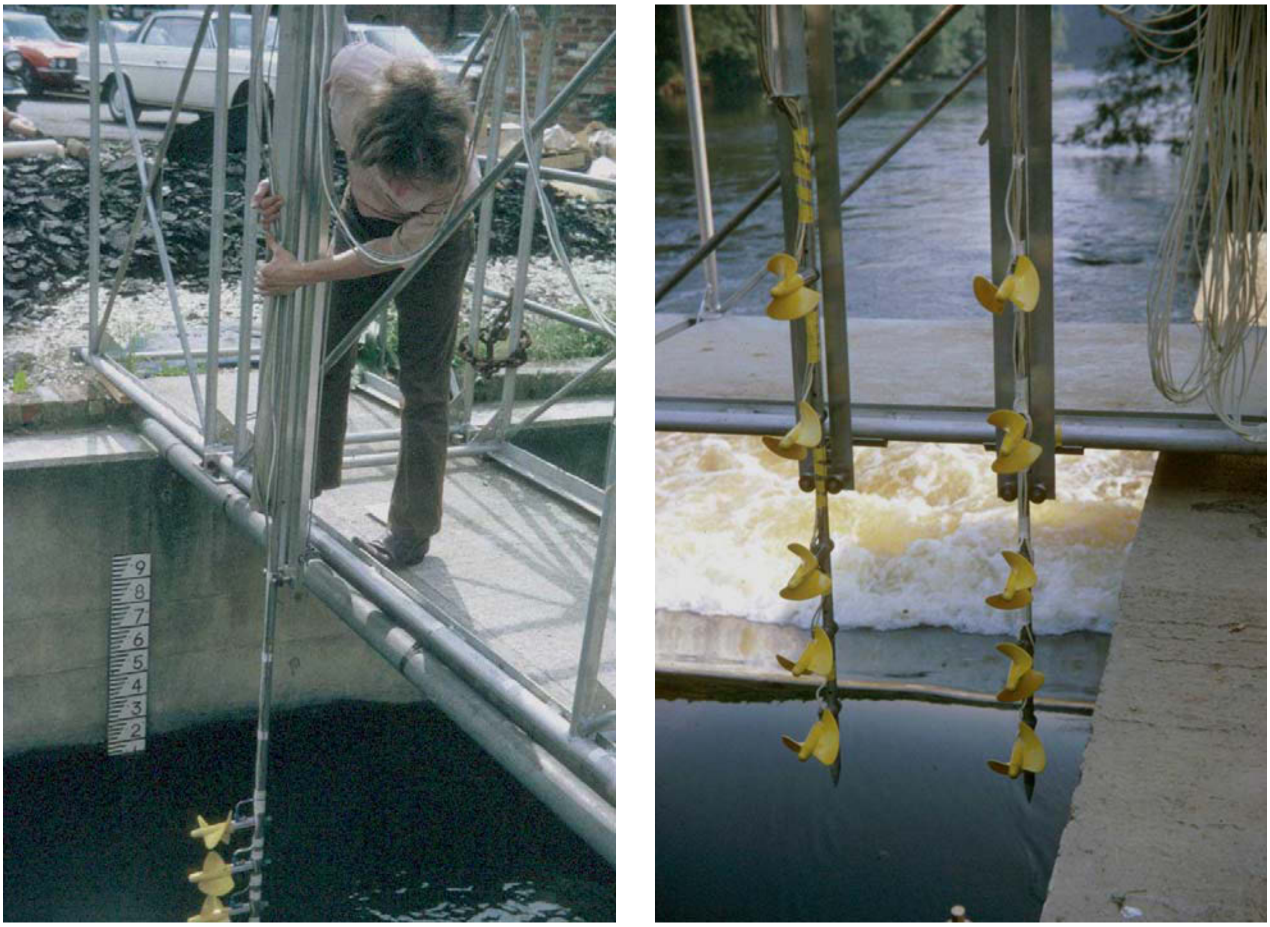


Plate 8 Multiple array of current meters to establish vertical velocity profiles
Source: Author

3.1.2 Acoustic doppler meters

In recent years, advances in technology have enabled velocities and velocity profiles to be measured using acoustic transmission through moving water. The Acoustic Doppler Current Profiler (ADCP) can acquire large quantities of spatial data very quickly and represents a major step forward in the flow measurement field. An example is shown in Plate 9.

The ADCP uses the *doppler effect* to determine water velocity by sending a sound pulse into the water and measuring the change in frequency of that sound pulse reflected back to the ADCP by sediment or other particulates being transported in the water. The change in frequency, or *doppler shift*, that is measured by the ADCP is translated into water velocity. The sound is transmitted through the water from a transducer which receives return signals throughout the distance range of the instrument. The ADCP also uses acoustics to determine water depth by measuring the travel time of a pulse of sound. In some cases the ADCP is capable of giving information on the concentration of fine sediments travelling in suspension.

ADCPs can be mounted on mechanisms which rotate and also pivot from the vertical to the horizontal thereby opening up the possibility of scanning whole cross-sections from one location. This is particularly useful in the survey of long, deep reservoirs of the type frequently found upstream of dams. Alternatively the ADCPs can be mounted on boats and the track of the boat provides the spatial coverage, see Section 6.1.

The use of ADCPs facilitates the collection of large quantities of data in a relatively short time. Hence they produce a detailed view of spatial flow conditions quickly and reduce errors associated with any unsteadiness in the flow during the measurement period.

Plate 9 **Head of an Acoustic Doppler Current Profiler with four transducers**
Source: http://www.isodaq.co.uk

3.1.3 Water levels

Water levels can be measured using a variety of methods.

One common approach is to use a stilling well in the river bank or attached to a vertical wall or a bridge pier. Water enters and leaves the stilling well through underwater pipes allowing the water surface in the stilling well to be at the same elevation as the water surface outside. The water level is then measured inside the stilling well using a float or a pressure, optic, or acoustic sensor. The measured water level, when related to the datum for the site, is referred to as "stage" and the values are stored in an electronic data recorder at regular intervals, usually every 15 minutes.

3.2 Measurement of discharge

Discharge is the volume of water moving down a stream or river per unit of time, commonly expressed in cubic metres per second. In general, the discharge through a particular cross-section, be this in a river or an estuary or defined tidal passage, is computed by multiplying the area of water in the cross-section by the average velocity of the water in that cross-section:

$$\textit{Discharge}\ (m^3/s) = \textit{Cross-sectional Area}\ (m^2) \times \textit{Mean Velocity}\ (m/s)$$

It is impractical to measure velocity on a continuous basis wherever a continuous record of discharge is to be determined. However, the continuous measurement of water level is practical and this provides the basis for most discharge measurement stations in rivers. At any particular site, the relationship between water level and discharge is established, either by field measurements in natural channels or the use of devices such as calibrated flow measurement structures. Thereafter water level is recorded and subsequently converted to discharge, usually using computer based procedures.

3.2.1 Velocity area methods

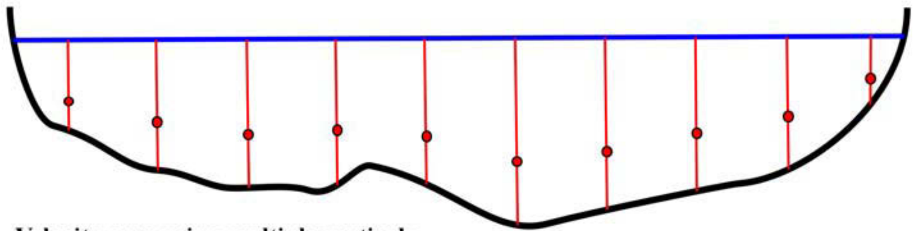
ISO 748:2007 is the main Standard which deals with the velocity area method. However, there are numerous other Standards which deal with certain aspects of the method. These are listed under the work of the sub-committee ISO/TC 113/SC1 in the Appendix.

The velocity area method is usually used in natural river channels and tends to be the method of choice for very large rivers because of the high capital costs of alternatives.

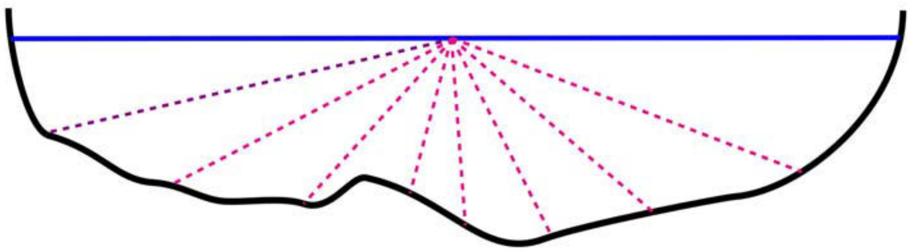
If current meters are used, the water cross-section is divided into numerous vertical sub-sections. In each sub-section, the area is obtained by measuring the width and depth of the sub-section, and the water velocity is determined using current meters. The mean velocity of the water in each sub-section is obtained in a number of ways depending on the accuracy requirement. In the simplest case a single measurement of velocity is made in each sub-section. This measurement is taken at 0.6 times the depth below the water surface and assumes a logarithmic distribution of velocity from the bed upwards. If greater accuracy is required, more than one measurement is made along the vertical centre line of each sub-section. Normally the maximum feasible number of measurements is five due to time constraints.

The discharge in each sub-section is computed by multiplying the area of the sub-section by the measured velocity. The total discharge is then computed by adding the discharges of each sub-section. Water level is recorded during each measurement period.

If ADCPs are used there is greater flexibility. Vertical sections can be used as with current meters but additionally the ADCPs can be rotated and swung from the vertical to the horizontal and this opens up the possibility of scanning whole cross-sections from one location, see Figure 3.



a) Velocity area using multiple verticals



b) Velocity area using multiple rays (ADCP only)

Figure 3 Velocity area methods for the measurement of flow

In rivers, subsequent analysis of all the simultaneous discharge and water level measurements yields a stage-discharge calibration for the site and enables subsequent processing to be based on continuous water level measurements alone.

The development of an accurate stage-discharge relationship requires numerous measurements of discharge over a wide range of flows. In addition, the relationship must be continually checked because stream channels can and do change, often caused by erosion or deposition of sediments, seasonal growth of vegetation, backwater effects from downstream tributaries, etc.

Most river gauging stations transmit data by telephone lines, radio or satellite to a central processing area where the water level data is converted to discharge using the developed stage-discharge relationship. Further processing yields long-term statistical data for the particular site, see Chapters 4 and 5.

3.2.2 Flow measurement structures

On rivers of modest size, flow measurement structures form a convenient and relatively accurate means of measuring flows. With one or two exceptions they are not used on large rivers due to the large capital expenditure required compared with velocity area installations.

Flow measurement structures are not seriously affected by changes in the nature of the upstream and downstream channels but they are sensitive to the precise dimensions of the structure and the condition of the structure itself. In most cases the structure is installed high enough to ensure that the discharge is related uniquely to the upstream head ie. the upstream water level relative to the crest or invert of the structure. However, some structures have the additional advantage that they may be operated in the drowned flow range where discharge is a function of both the upstream and the downstream water levels.

The United Kingdom invested heavily in flow measurement structures following the Water Resources Act of 1963 which required flows in main rivers to be measured, mainly for water resources purposes. Of around 1500 flow measurement stations in the United Kingdom, approximately half involve the use of a flow measurement structure. These structures are almost exclusively of a type which has been carefully calibrated in a laboratory and supported by a few specialised check-calibrations in the field (**White W R.** (1975) *Field calibration of flow measuring structures*). Flow measurement structures which have been thoroughly researched in this way have been standardised by the International Standards Organisation

(ISO) and the British Standards Institution (BSI) (**White W R.** (2001) *Standard Specifications for Flow Measurement Structures*). See also the Appendix.

Structures which do not comply with International Standards are few and far between and are not considered in this ROCK.

The most common types of flow measurement structure which comply with International Standards are given in the following sections together with a brief description of their characteristics and usage.

Thin plate weirs

ISO 1438:2008 describes the design and performance specifications for thin plate weirs, see the Appendix.

Plate 10 V-notch thin plate weir
Source: HR Wallingford

Thin plate weirs are used extensively in laboratories. Some have a horizontal crest which may or may not occupy the full width of the approach channel, whilst some have a V-notch crest. These different types have different characteristics in terms of the range of flows which can be consistently measured, the V-notch having the greatest range.

The crest itself has to be machined strictly in accordance with the ISO Standard and must not be damaged or eroded in subsequent use. For this reason thin plate weirs are best used for clean water applications typically found in laboratories. Their application in sediment laden streams is not to be recommended because of the damage to the weir crest which the passage of sediment will cause.

Two dimensional triangular profile weirs

ISO 4360:2008 describes the design and performance specifications for two dimensional triangular profile weirs, see the Appendix.

The two dimensional triangular profile weir is often referred to as the "Crump" weir after E S Crump who first advocated the use of this type of weir based on his work on Indian irrigation canals (**Crump E S.** (1952) *A new method of gauging stream flow with little afflux by means of a submerged weir of triangular profile*). The discharge in these canals had to be measured with as little afflux (head loss) as possible due to the very shallow longitudinal slopes. He chose an upstream slope of 1 (vertical) to 2 (horizontal) because this approximated to the angle of repose of any sediment which would approach the weir from upstream and the 1 (vertical) to 5 (horizontal) downstream slope to minimise turbulent energy losses on the downstream face.

The two dimensional triangular profile weir exhibits a constant coefficient of discharge and this was an advantage for processing the data in the days before high powered computers. Nowadays it is less of an advantage. One aspect of this type of weir which remains a bonus today is that the weir can be used in the drowned flow range using a pressure tapping, set just downstream of the crest, together with the upstream head measurement. This system yields approximately three times the accuracy of the computed discharge when compared with devices which use upstream and downstream head measurements to evaluate drowned flows.

Plate 11 shows the weir operating in the modular flow range. Dye has been injected into the separation pocket which forms just downstream of the crest and indicates a consistent curvilinear upper surface. The size of this pocket increases in proportion to the upstream head of water and this is the reason for the constant coefficient of discharge.

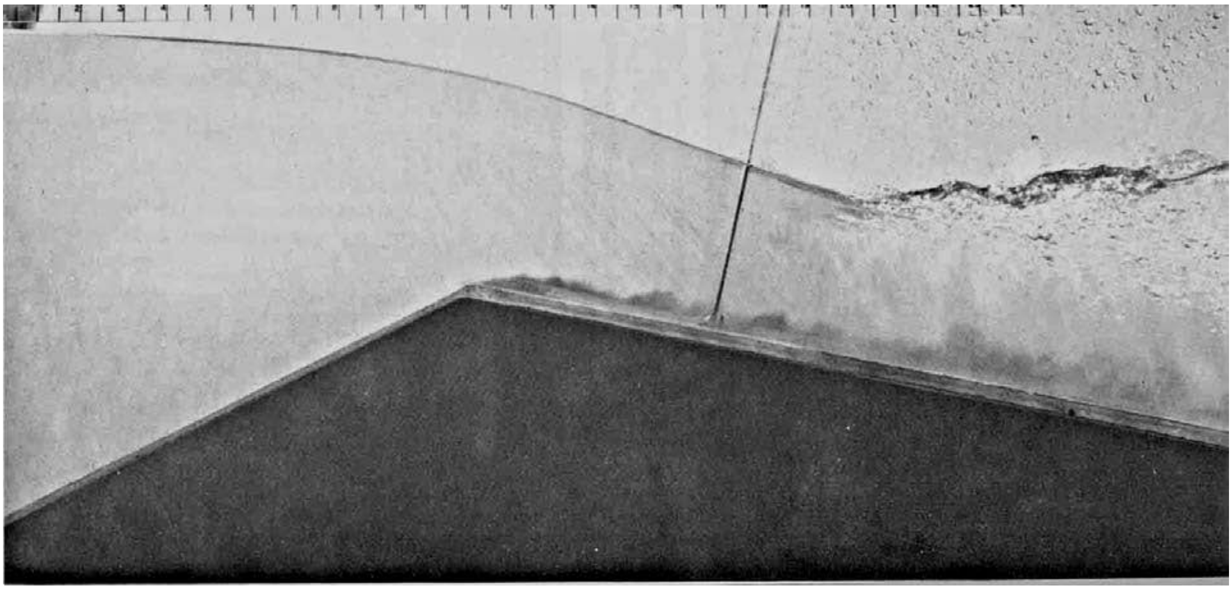


Plate 11 Two dimensional triangular profile weir - modular flow conditions
Source: HR Wallingford

Plate 12 shows the weir operating in the drowned flow range where near surface flows are much more diffuse on the downstream face of the weir.

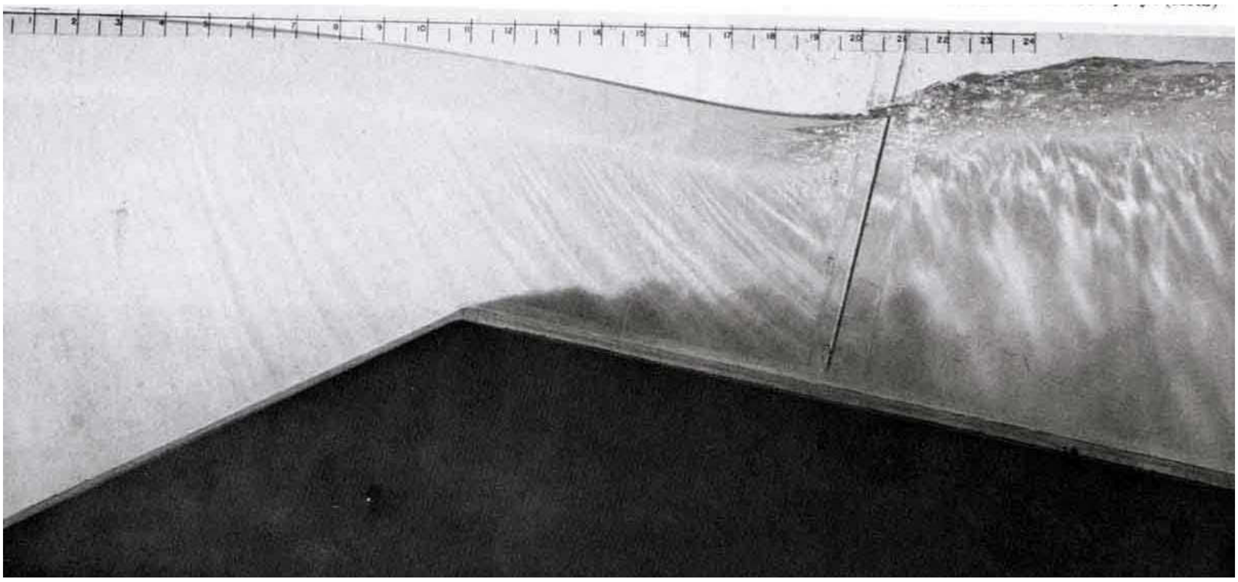


Plate 12 Two dimensional triangular profile weir - drowned flow conditions
Source: HR Wallingford

Flat-V triangular profile weirs

ISO 4377:2012 describes the design and performance specifications for flat-V triangular profile weirs, see the Appendix.

The flat-V weir was developed from the two-dimensional weir in order to extend the range of flows which could be measured with consistent accuracy. Two-dimensional weirs lose accuracy when flows are very low because of a) the difficulties in measuring small heads and b) the difficulties of building very precise crest profiles in the field. The flat-V weir concentrates low flows towards the location of the lowest crest elevation and maintains significant heads down to relatively low flows.

Plate 13 Laboratory testing of a flat-V weir
Source: HR Wallingford

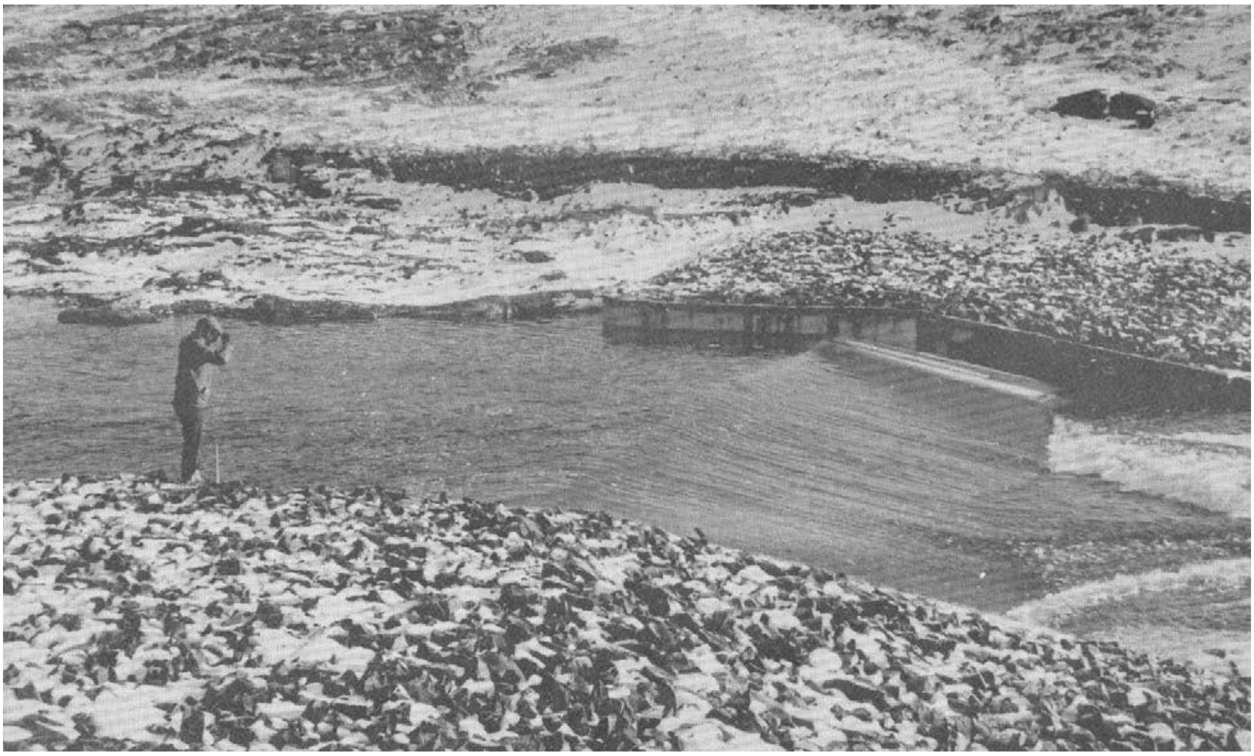


Plate 14 Flat-V weir on the River Tees at Cow Green, Northumberland
Source: Author

Long-throated flumes

ISO 4359:2013 describes the design and performance specifications for long-throated flumes, see the Appendix.

A long-throated flume is a flow measurement structure formed by making a constriction in an open channel. The constriction always involves a narrowing of the channel but may, in addition, involve a hump to raise the invert. By making the constriction sufficiently severe and long it is possible to induce critical flow conditions within the constricted, parallel section. This makes it feasible to calculate the relationship between head and discharge purely from sound and well established theoretical considerations.

These flumes are very versatile and are widely used in laboratory and field applications. They provide high accuracy and can be used in a wide range of situations including those where the flow contains suspended or bed-load sediments.

The ISO Standard covers rectangular, U-shaped and trapezoidal throated flumes all of which have their own unique head discharge relationships.

Plate 15 Trapezoidal long-throated flume on the River Meden at Church Warsop, Nottinghamshire
Source: R W Herschy

Broad-crested weirs

ISO 3846:2008 describes the design and performance specifications for the broad-crested weir, see the Appendix.

The broad-crested weir, which is sometimes referred to as the rectangular profile weir, takes the form of a simple rectangle in terms of its longitudinal profile.

Advantages of this type of weir include:

1. The weir is simple to construct and install
2. The weir can be made up of pre-cast units which result in robust and economical field installations

Disadvantages include:

1. The weir has a variable coefficient of discharge which varies with flow and upstream water level

2. The upstream edge of the crest is vulnerable to damage which affects the performance characteristics of the weir

Parshall and SANIIRI flumes

ISO 9826:1992 describes the design and performance specifications for Parshall and SANIIRI flumes, see the Appendix.

The Parshall flume was developed in the United States by Ralph L Parshall in the 1920s and is widely used. It is not a long-throated flume and hence is not amenable to theoretical analyses. However, Parshall spent years calibrating flumes of differing sizes and by the 1950s he had developed depth-flow relationships for flumes with throat widths from 75mm to 15m. Parshall flumes are sized by throat width and conform to standardized dimensions (**Parshall R L.** (1950) *Measuring water in irrigation channels with Parshall Flumes and Small Weirs*).

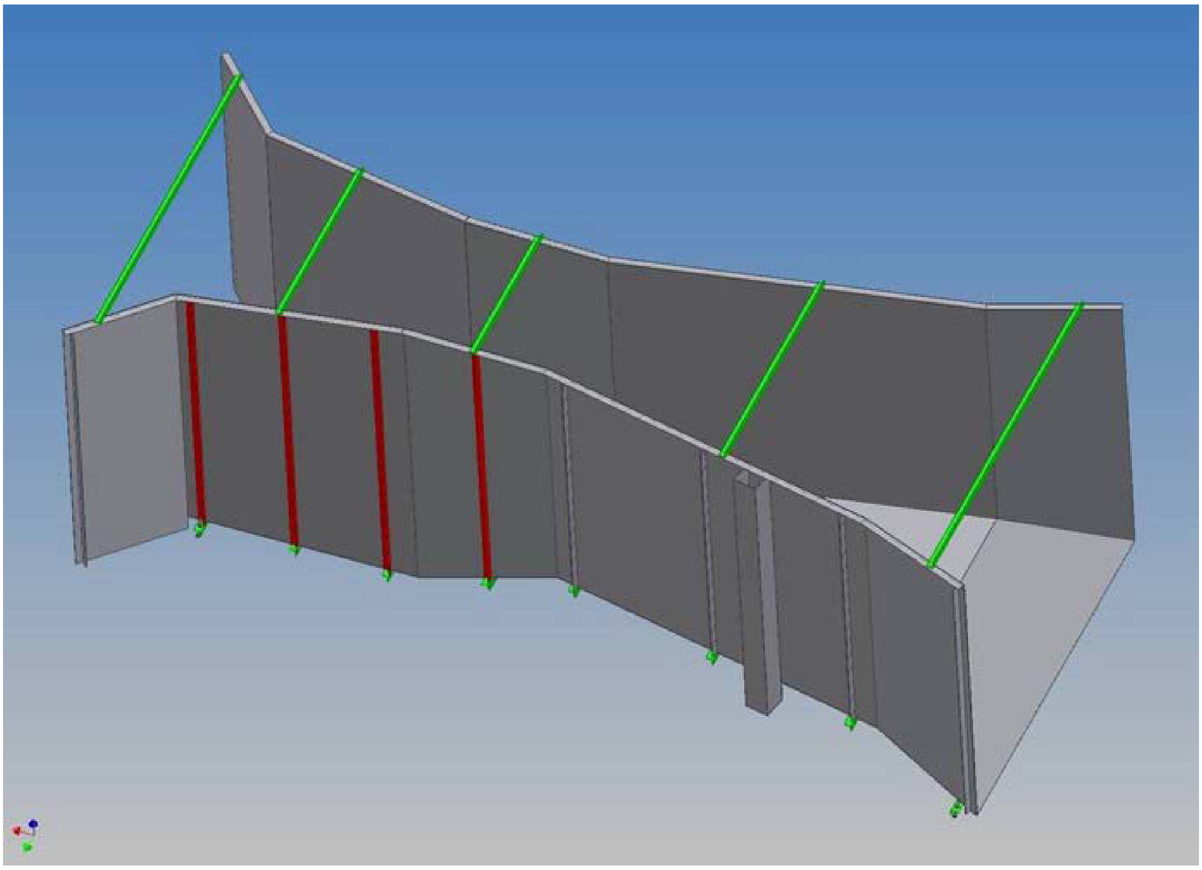


Plate 16 Geometry of the Parshall flume
Source: http://www.papay.sk

SANIIRI flumes were developed and are widely used in the countries formerly within USSR.

Compound gauging structures

ISO 14139:2000 describes the design and performance specifications for compound gauging structures, see the Appendix.

Compound gauging structures represent a further way of extending the range of flows which can be measured with consistent accuracy. Two or more flow measurement structures are placed side by side across an open channel with divide piers between each section to make sure that each individual section behaves in accordance with its established two dimensional performance. The individual structures are placed at different levels so that only the lower ones operate at low river flows.

It is not economic to measure heads at each individual crest section but laboratory research has indicated how a single head measurement at one of the crest sections can be applied to each of the other crest sections.

Most compound weirs are formed by a series of two dimensional triangular profile weirs set between divide piers but the ISO Standard does not restrict the user to this.

Plate 17 Compound gauging structure on the Senqunyane River at Marakabei, Lesotho
Source: Author

Underflow and radial gates

ISO 13550:2002 describes the design and performance specifications for underflow and radial gates, see the Appendix.

Underflow and radial gates are generally used to control upstream water levels. They are predominantly used to release water from dams, either to provide a regulated flow to the downstream reach or to draw water levels down in the upstream reservoir in anticipation of future inflows. The opening beneath the gates can be rapidly adjusted to provide a wide range of discharges.

In canals, underflow gates perform a similar function but they generally sit on a flat channel invert as opposed to a curved crest profile. The Standard concentrates on this type of application.

Plate 18 Radial gates at Gitaru Dam on the Tana River, Kenya
Source: Author

Fishpasses

ISO 26906:2009 describes the design and performance specifications, from a hydrometric perspective, for certain types of fishpass, see the Appendix.

Flow measurement structures can, under some circumstances, inhibit the upstream movement of fish. For this reason there are environmental pressures to either a) remove the structure or b) provide a fishpass alongside the structure. With this in mind, recent research has been carried out in the United Kingdom, commissioned by the Environment Agency, to establish the hydraulic performance of its preferred type, the Larinier fishpass (**White W R, Iredale R and Armstrong G.** (2006) *Fishpasses at flow measurement structures*). The results are included in the ISO Standard along with research findings relating to a type of fishpass often used in the Netherlands.

These fishpasses have now become dual purpose in that they facilitate the passage of fish but also enable the hydrometric function to be preserved. When set alongside a flow measurement structure they form an additional section of what has become, or is already, a compound gauging structure.

Plate 19 Larinier fishpass on the River Frome at Louds Mill, Dorset
Source: G Armstrong

3.2.3 Dilution gauging

ISO 9555 Parts 1, 3, and 4:1995 describe the use of tracer dilution methods for the measurement of steady flows, see the Appendix. ISO/TR 11656:1993 provides additional advice.

The dilution method provides a one-off measure of discharge. The measurement may be used to calibrate a nearby gauging station or it may be used for other purposes. The method is capable of giving good accuracy when used in favourable flow conditions but the range of such conditions is limited.

The dilution method involves the addition of a suitably selected tracer to the flow. As the tracer is taken downstream from the injection point, turbulence within the flow disperses it and at some point the tracer becomes fully mixed with the flow. The greater the flow, compared with the quantity of tracer injected, the greater is the level of dilution of the tracer. A measurement of the new concentration of the tracer is taken at a downstream location where full mixing is deemed to have taken place. The discharge can be determined from the rate and concentration of the tracer when injected and the concentration of the tracer at the downstream measuring point.

The tracer may be added as a continuous flow and this is known as the constant rate injection method. The alternative is the gulp or sudden injection method. The way the results are analysed differs between the two methods (**Herschy R W.** (1985) *Streamflow measurement*).

Mixing of the tracer is an important element in dilution gauging and has a significant impact on the accuracy of the discharge measurement. The most favourable conditions are those found in steep streams with high levels of turbulence.

Many tracers have been used for dilution gauging, including radioactive isotopes. However, recent concern for the environment and also health and safety aspects have now severely reduced the number of authorised chemicals and dyes.

3.2.4 Ultrasonic methods

ISO 6416:2004 describes the measurement of discharge by the ultrasonic (acoustic) method, see the Appendix.

Ultrasonic gauging stations were first established in the United Kingdom in the 1970s.

In this method acoustic flight paths are set up diagonally across an open channel at one or more elevations within the flowing water. The flight paths are typically set at about 45 degrees to the direction of flow. Times are measured for acoustic pulses to traverse this oblique path in both directions. Pulses travelling against the flow take longer than those travelling with the flow and this difference can be converted into flow velocity.

Some installations have a single flight path, others have multiple flight paths at different elevations. The former tend to be less accurate than the latter because of velocity variations with depth. In both cases the measured mean velocity is multiplied by the cross-sectional area of flow to evaluate discharge. The cross-sectional area is determined from measured water levels and bed and bank surveys.

Accurate values of discharge can be achieved where the cross-section is stable and where the range of water levels does not cause distortions in the measured mean velocity. Accuracy can reduce in the following circumstances:

1. Where water levels are subject to major changes with time
2. Where there is a high load of suspended sediments as this condition affects the transmission of the acoustic pulses
3. Where there is seasonal weed growth which affects the velocity distribution and, possibly, the transmission of pulses near to the bed
4. Where there is thermal stratification which can deflect the acoustic flight path

Plate 20 An early ultrasonic gauging site on the River Thames at Sutton Courtenay, Oxfordshire
Source: CEH Wallingford (Photo, H Gunston)

3.2.5 Electromagnetic methods

ISO 9213:2004 is the Standard which describes the electro-magnetic method of measuring discharge in open channels, see the Appendix.

Electromagnetic methods are used more commonly for determining discharge in closed conduits and pipes. However, there are a few installations which measure free surface flows, usually placed in man-made rectangular open channels where the cross-section is well defined and stable.

The electromagnetic method involves the measurement of water velocity and is based on Faraday's Law, well known to the students of electrical theory. A magnetic field is induced in a moving conductor, in this case water, and the generated emf (voltage) across the moving conductor is a measure of its velocity.

Electromagnetic flow gauging installations have an external coil surrounding the cross-section at which the discharge is to be determined and sensors placed diametrically opposite each other, at the perimeter of the cross-section, to measure the induced emf. This is then converted to velocity and multiplied by the cross-sectional area to yield discharge.

Difficulties often arise in field installations because:

1. It is hard to create a uniform and consistent magnetic field in the near-rectangular cross-sections typically found,
2. Variations in water level cause changes to the cross-sectional area of the moving conductor.

These difficulties often mean that the electromagnetic installations are calibrated by alternative techniques such as current metering.

Technical, maintenance and health and safety issues mean that there are only a modest number of operational electromagnetic stations for measuring free surface flows.

3.2.6 Volumetric and weighing techniques

In the laboratory it is often necessary to measure flows to a greater accuracy than can be achieved by the methods described in Sections *3.2.1* to *3.2.5*. This can be done by using volumetric or weighing techniques. Often these weighing or volumetric techniques are used in the laboratory to calibrate flow measurement structures such as weirs or fishpasses.

The set up consists of a test flume (channel) in which the device to be calibrated is placed. The flume has an inflow which is highly regulated, usually by the incorporation of a constant head tank in the water supply system, and this provides constant, steady flow conditions. The outflow from the flume is where the precise flow measurement takes place. Flow normally re-circulates through the system, but when a measurement of the flow is required, the outflow is deflected for a known length of time either to:

1. A volumetric tank which has been very precisely surveyed in terms of its level to volume relationship or
2. A weighing tank which is connected to an accurate weighing system.

The time for which the flow is diverted and the weight or volume of the diverted flow give a direct measure of the flow rate. The precision of this process is usually an order of magnitude higher than is expected for the device being calibrated.

Plate 21 Laboratory flume with volumetric flow measurement facilities
Source: HR Wallingford

4 Archives of surface water runoff information

4.1 Organisations which maintain archived material

The World Meteorological Organization (WMO) is a specialized agency of the United Nations. Its stated role is to provide information on the state and behaviour of the Earth's atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources. WMO had a membership of 191 Member States in January 2013.

In the United Kingdom, the Centre for Ecology and Hydrology (CEH), Wallingford, manages the National River Flow Archive. CEH works in collaboration with the measuring authorities, which include the Environment Agency and the Water Utilities, and endeavours to maximise both the quality and utility of the hydrometric data under its stewardship.

The international situation is a little more fragmented.

4.2 National data

United Kingdom rivers remained largely un-gauged until the latter half of the 20th century. The stimulus was a realisation in the 1950s that the United Kingdom needed to be more self-sufficient in food production and this would need a better understanding of the water resources available, and the distribution of those resources. The Water Resources Act of 1963 included the setting up of the Water Resources Board (WRB), later to become the Water Data Unit (WDU) within the Department of the Environment (DoE), with a remit to monitor all the main rivers in the United Kingdom. WRB had powers to approve and to provide grant aid for hydrometric schemes. It also had a remit to commission research and this focussed largely on the development of design and performance data for a series of "Standard" weirs and flumes, many of which are described in this ROCK.

This national initiative produced a rapid growth in the monitoring network such that by the early 1970s outflows from almost 70% of the land area of the United Kingdom could be monitored.

Currently the network comprises around 1500 flow measurement stations and this includes around 700 flow measurement structures. The location and spatial density of the stations are influenced by variations, within the United Kingdom, of climate, topography, geology, land use and patterns of water utilisation.

4.3 International data

One useful database is kept by the Global Runoff Data Centre within the German Federal Institute of Hydrology in Koblenz, Germany. The centre operates under the auspices of the World Meteorological Organisation (WMO) and its core objective is to support research on climate variability and global climate change.

The Global Runoff Data Base (GRDB) was initially built on an early dataset collected in the 1980s by WMO. This initial dataset of monthly river discharge data over a period of several years around 1980 was then supplemented by the UNESCO monthly river discharge data collection 1965-85. Today the database has been enlarged considerably and comprises discharge data for approaching 9000 gauging stations from over 150 countries worldwide.

The database is available to organisations carrying out hydrological research and the application procedure is available on the internet.

Figure 4 gives an indication of the current coverage of this runoff information.

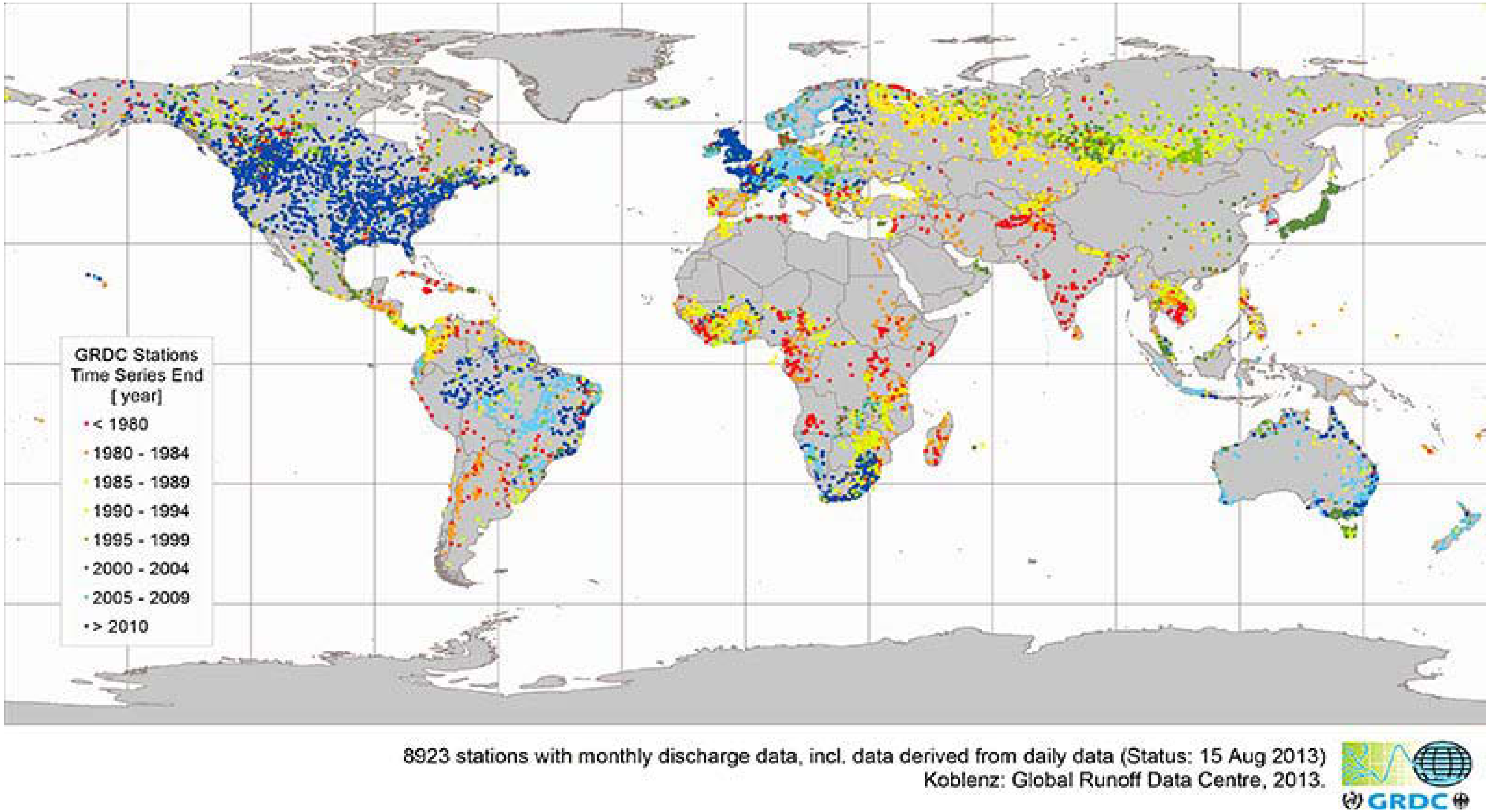


Figure 4 Global runoff database, German Federal Institute of Hydrology
Source: http://www.bafg.de

5 Other related issues

5.1 Telemetry

Telemetry is the science and technology of automatic measurement and transmission of data by wire, radio, satellite or other means from remote sources to central receiving stations for recording and analysis. Telemetry can also be a two way process whereby information is also transmitted outwards from the central station(s) to the remote sensors giving instructions on the nature of the measurements or actions required.

Telemetry is used in many fields including communications, flight testing, hydrometry, intelligence gathering, medicine/healthcare, meteorology, retail services, space exploration and many others.

Focussing on meteorology and hydrology, responsibilities in the United Kingdom rest with the Met Office and the Environment Agency.

Remote stations provide continuous measurements of:

1. *Rainfall at particular sites using mainly tipping bucket rain gauges.* There are approximately 750 gauges in operation in the United Kingdom.
2. *Rainfall over a wider area using radar.* There are 10 radar sites across England and Wales which provide radar coverage at three resolutions: 5km, 2km, 1km. Radar images show precipitation movement, patterns and intensities.
3. *River levels and flows*. The network consists of approximately 1500 river level and river flow sensors.
4. *Coastal gauges*. Around 100 coastal gauges record tidal levels.

The routine measurements from remote stations are stored centrally and help to build up long term databases which give greater understanding of climatic conditions and any changes thereto. These databases are heavily used, not only in water resource and flood protection studies, but also in the design of engineering works which impinge on water courses.

A more immediate use of telemetry relates to the speed of transmission of the large quantities of information that it provides. For example, flood forecasting has become far more reliable and the speed of telemetry makes it possible to warn potential victims in advance, thereby saving the cost of damages and, in extreme circumstances, loss of life.

5.2 Uncertainties

In parallel with the development of performance specifications for flow measurement methods, and flow measurement structures in particular, there have been efforts to develop rigorous approaches to the expression of uncertainty. The subject is complex and only an outline of the essentials can be covered by this ROCK.

Early versions of Standards which were developed in the 1970s and 1980s included a unified method for assessing the overall uncertainty in discharge. Two types of error were identified, *random* and *systematic*. The multiple sources of these uncertainties were combined using the root mean square method to establish an "overall" uncertainty. These uncertainties were expressed at the 95% confidence level, as is common in engineering practice.

More recently ISO has produced a new methodology (**International Standards Organisation (ISO).** (1993) *Guide to the expression of Uncertainty in Measurement (GUM)*). The GUM approach is based on the forward linearized probability propagation method and is a general document which is intended to apply in many fields of measurement. In the context of this ROCK, the GUM approach has been used to develop a guide which is more focussed on free surface flows, see ISO/TS 25377:2007 *Hydrometric Uncertainty Guidance* (HUG) as listed in the Appendix. In this Standard the uncertainties are expressed at the 68% confidence level.

Neither the early nor the more recent method for the estimation of uncertainty is perfect. The early method combined systematic and random errors in order to estimate overall uncertainty, a process lacking in mathematical rigour. The GUM/HUG approach effectively overcomes this difficulty by assuming that systematic errors can be eliminated by multiple, careful measurements of any particular parameter, a dubious presumption.

An alternative approach, namely the use of stochastic sampling (Monte Carlo simulation) techniques, has more recently been proposed (**Tyler K D.** (2004) *Improved estimation of uncertainty in flow measurement at sewage treatment works*).

There remain three principle difficulties for practising engineers with uncertainty estimation associated with flow measurement in open channels:

1. There is confusion regarding the confidence levels to be used. Early Standards used the 95% confidence level (commonly used by engineers) and the newer revisions use the 68% confidence level (commonly used by scientists). Assuming the errors are Gaussian, computed uncertainties at the 95% confidence level are approximately double those at the 68% confidence level.
2. In the new GUM/HUG approach, straightforward systematic errors are not detectable by the advocated method. For example, if the level of the datum pin at a gauging structure changes due to settlement, and this goes unnoticed, the resulting systematic error in head measurement will not be detected by any amount of statistical analysis.
3. Many of the numerical values for individual uncertainties given in the Standards have not been determined from the results of comprehensive scientific test programmes. In some cases they have been subjectively agreed by experts, in others they are taken on trust from the manufacturers of measurement equipment.

Despite all these difficulties older ISO and BSI Standards are gradually being updated to comply with the ISO GUM/HUG approach.

6 Ongoing research and development

6.1 Remote control surveys

In recent years remote controlled boats have been developed to carry out surveys on lakes, rivers, estuaries and in coastal waters. The boats can carry a range of instruments, including Acoustic Doppler Current Profilers (ADCPs).

The boats are designed with a V-shaped hull to give optimal manoeuvrability and minimal air entrainment beneath the ADCP, ensuring high quality data collection. Their size is such that they can be easily transported and launched. The land-based remote control typically provides a maximum range in excess of 200m and radio transmissions provide data communications with onshore computing facilities.

The number of tasks which can be carried out by remote controlled boats fitted with ADCPs are numerous:

1. Using the ADCP to provide depth information, the bed levels of lakes and reservoirs can be surveyed quickly and economically to give general information on volumes, and specific information on sediment deposition. The former is useful for water resource planning, whilst the latter may provide useful information for the calibration and verification of numerical models of sedimentation.
2. Some units also have the capability of measuring sediments in suspension which is an additional aid to numerical modelling.
3. In estuaries and coastal waters, navigation channels can be surveyed to check available water depths and routine surveys may provide data such as littoral drift along the coastline.
4. Using the power of the ADCP to quickly measure velocities has opened up opportunities for river gauging and also for providing data for numerical models of broader expanses of water.

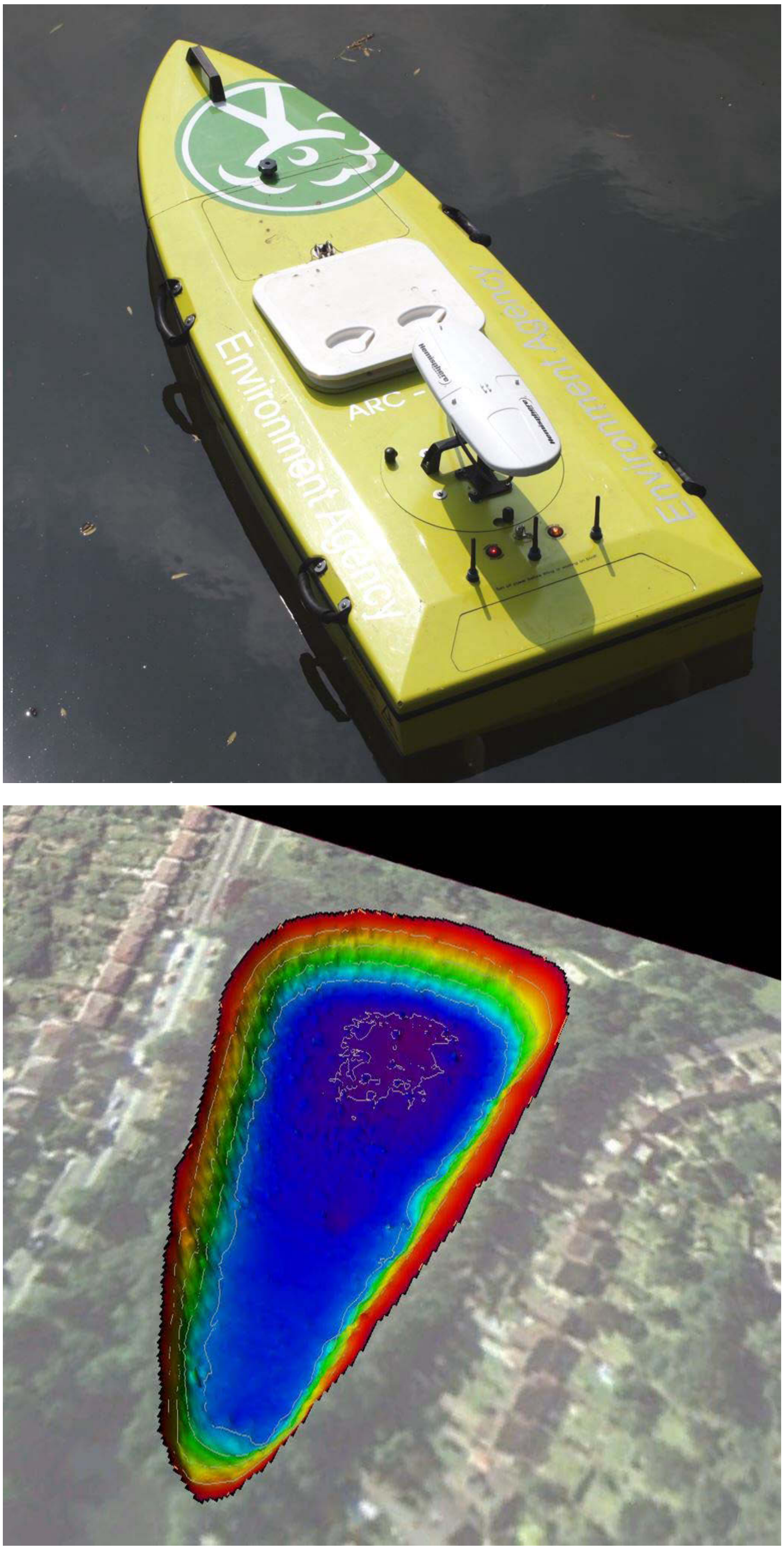


Plate 22 Remote control survey vessel and example reservoir survey
Source: HR Wallingford / Environment Agency

References

Ackers P., White W. R., Perkins J. A. and Harrison A. J .M. (1978) *Weirs and flumes for flow measurement.* John Wiley and Sons, 350pp, ISBN 0 471 99637 8.

Bos M. G. (1975) *Flow measurement structures.* Publication No. 20, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands.

Crump E. S. (1952) *A new method of gauging stream flow with little afflux by means of a submerged weir of triangular profile.* Proceedings of the Institution of Civil Engineers, Part 1, pp223-242.

Escarameia M., Marias F., White W. R. and Iredale R. (2013) *Enabling accurate flow gauging at weirs with Larinier fishpasses.* Paper No. 81, Smart Rivers Conference, Liege, Maastrict.

Food and Agriculture Organization of the United Nations (FAO). Water Resources, Development and Management Service. (2013) *AQUASTAT Information System on Water in Agriculture: Database.* Available on-line at: www.fao.org.

Herschy R. W. (ed.) (1978) *Hydrometry.* John Wiley and Sons, 511pp, ISBN 0 471 99649 1.

Herschy R. W. (1985) *Streamflow measurement.* Elsevier Applied Science Publishers Ltd, 553pp, ISBN 0 85334 327 6.

Herschy R W (ed.) (1999) *Hydrometry.* John Wiley and Sons Ltd, 376pp, ISBN 0 471 97350 5.

International Commission on Large Dams (ICOLD) (2007) *Dams and the World's Water.* Copyright CIGB-ICOLD. Available on-line at: www.icold-cigb.org.

International Standards Organisation (ISO). (1993) *Guide to the expression of Uncertainty in Measurement (GUM),* ISO, Genève, Switzerland.

Parshall R. L. (1950) *Measuring water in irrigation channels with Parshall Flumes and Small Weirs.* Soil Conservation Circular No. 843, U. S. Department of Agriculture.

Tyler K. D. (2004) *Improved estimation of uncertainty in flow measurement at sewage treatment works*, PhD thesis, University of Hertfordshire, 320pp.

White W. R. (1975) *Field calibration of flow measuring structures*. Proceedings of the Institution of Civil Engineers, Paper No 7821, Part 2, 59, pp429-447.

White W. R. (2001) *Standard Specifications for Flow Measurement Structures.* Proceedings of the Institution of Civil Engineers, Water and Maritime Engineering. Vol. 148, Issue WM3.

White W. R. (2010) *World water: resources, usage and the role of man-made reservoirs.* Review of Current Knowledge (ROCK). Foundation of Water Research, Marlow, United Kingdom, 60pp.

White W. R. (2013) *The role of water in the production of energy.* Review of Current Knowledge (ROCK). Foundation of Water Research, Marlow, United Kingdom , 45pp.

White W. R., Iredale R. and Armstrong G. (2006) *Fishpasses at flow measurement structures*. Proceedings of the Institution of Civil Engineers, Water and Maritime Engineering. Vol. 159, Issue WM3.

White W. R and Samuels P. G. (2011) *Floods: alleviation, protection, response and risk management.* Review of Current Knowledge (ROCK). Foundation of Water Research, Marlow, United Kingdom, 60pp.

Appendix

International Hydrometric Standards

Title of Standard	Number
Parent Committee ISO/TC 113 Hydrometry	
Hydrometry -- Vocabulary and symbols	ISO 772:2011
Measurement of liquid flow in open channels -- Moving-boat method	ISO 4369:1079
Liquid flow measurement in open channels -- Flow measurements under ice conditions	ISO 9196:1992
Measurement of liquid flow in open channels -- Measurement in meandering rivers and in streams with unstable boundaries	ISO/TR 9210:1992
Measurement of liquid flow in open channels -- Tracer dilution methods for the measurement of steady flow -- Part 1: General	ISO 9555-1:1994
Measurement of liquid flow in open channels -- Tracer dilution methods for the measurement of steady flow -- Part 3: Chemical tracers	ISO 9555-3:1994
Measurement of liquid flow in open channels -- Tracer dilution methods for the measurement of steady flow -- Part 4: Fluorescent tracers	ISO 9555-4:1994
Hydrometry -- Field measurement of discharge in large rivers and rivers in flood	ISO 9825:2005
Measurement of liquid flow in open channels -- Mixing length of a tracer	ISO/TR 11656:1993
Hydrometric uncertainty guidance (HUG)	ISO/TS 25377:2007
Sub-committee ISO/TC 113/SC1 Velocity area methods	
Hydrometry -- Measurement of liquid flow in open channels using current meters or floats	ISO 748:2007
Liquid flow measurement in open channels -- Slope-area method	ISO 1070:1992 Amd. 1997
Measurement of liquid flow in open channels -- Part 1: Establishment and operation of a gauging station	ISO 1100-1:1996
Hydrometry -- Measurement of liquid flow in open channels -- Part 2: Determination of the stage-discharge relationship	ISO 1100-2:2010
Hydrometry -- Measurement of liquid flow in open channels under tidal conditions	ISO 2425:2010
Hydrometry -- Measurement of discharge by the ultrasonic (acoustic) method	ISO 6416:2004
Measurement of liquid flow in open channels -- General guidelines for selection of method	ISO/TR 8363:1997
Measurement of liquid flow in open channels -- Stage-fall-discharge relationships	ISO 9123:2001

Measurement of liquid flow in open channels -- Determination of the wetline correction	ISO/TR 9209:1989
Hydrometry -- Measurement of free surface flow in closed conduits	ISO/TR 9824:2007
Determination of volume of water and water level in lakes and reservoirs	ISO/TR 11330:1997
Hydrometric determinations -- Unstable channels and ephemeral streams	ISO/TR 11332:1998
Measurement of liquid flow in open channels -- Computing stream flow using an unsteady flow model	ISO/TR 11627:1998
Measurement of liquid velocity in open channels -- Design, selection and use of electromagnetic current meters	ISO/TS 15768:2000
Hydrometry -- Guidelines for the application of acoustic velocity meters using the Doppler and echo correlation methods	ISO 15769:2010
Hydrometry -- Acoustic Doppler profiler -- Method and application for measurement of flow in open channels	ISO/TR 24578:2012
Sub-committee ISO/TC 113/SC2 Flow measurement structures	
Hydrometry -- Open channel flow measurement using thin-plate weirs	ISO 1438:2008 Cor.2008
Hydrometry -- Open channel flow measurement using rectangular broad-crested weirs	ISO 3846:2008
Liquid flow measurement in open channels by weirs and flumes -- End-depth method for estimation of flow in rectangular channels with a free overfall	ISO 3847:1977
Flow measurement structures -- Rectangular, trapezoidal and U-shaped flumes	ISO 4359:2013
Hydrometry -- Open channel flow measurement using triangular profile weirs	ISO 4360:2008
Hydrometric determinations -- Flow measurement in open channels using structures -- Trapezoidal broad-crested weirs	ISO 4362:1999
Measurement of liquid flow in open channels by weirs and flumes -- End-depth method for estimation of flow in non-rectangular channels with a free overfall (approximate method)	ISO 4371:1984
Liquid flow measurement in open channels -- Round-nose horizontal broad-crested weirs	ISO 4374:1990
Hydrometric determinations -- Flow measurement in open channels using structures -- Flat-V weirs	ISO 4377:2012
Liquid flow measurement in open channels by weirs and flumes -- V-shaped broad-crested weirs	ISO 8333:1985
Hydrometric determinations -- Flow measurements in open channels using structures -- Guidelines for selection of structure	ISO 8368:1999
Measurement of liquid flow in open channels -- Parshall and SANIIRI flumes	ISO 9826:1992
Measurement of liquid flow in open channels by weirs and flumes -- Streamlined triangular profile weirs	ISO 9827:1994

Hydrometric determinations -- Flow measurements in open channels using structures -- Use of vertical underflow gates and radial gates	ISO 13550:2002
Hydrometric determinations -- Flow measurements in open channels using structures -- Compound gauging structures	ISO 14139:2000
Hydrometry -- Fishpasses at flow measurement structures	ISO 26906:2009
Sub-committee ISO/TC 113/SC5 Instrumentation	
Hydrometry -- Velocity-area methods using current meters -- Collection and processing of data for determination of uncertainties in flow measurement	ISO 1088:2007
Hydrometry -- Rotating-element current meters	ISO 2537:2007
Hydrometry -- Direct depth sounding and suspension equipment	ISO 3454:2008
Hydrometry -- Calibration of current meters in straight open tanks	ISO 3455:2007
Hydrometry -- Echo sounders for water depth measurements	ISO 4366:2007
Hydrometry -- Water level measuring devices	ISO 4373:2008
Hydrometric determinations -- Cableway systems for stream gauging	ISO 4375:2000
Liquid flow measurement in open channels -- Position fixing equipment for hydrometric boats	ISO 6420:1984
Measurement of liquid flow in open channels -- Equipment for the measurement of discharge under ice conditions	ISO/TR 11328:1994
Measurement of liquid flow in open channels -- Method of specifying performance of hydrometric equipment	ISO 11655:1995
Hydrometry -- Measuring river velocity and discharge with acoustic Doppler profilers	ISO/TS 24154:2005
Hydrometry -- Hydrometric data transmission systems -- Specification of system requirements	ISO/TS 24155:2007
Sub-committee ISO/TC 113/SC6 Sediment transport	
Hydrometry -- Functional requirements and characteristics of suspended-sediment samplers	ISO/TS 3716:2006
Measurement of liquid flow in open channels -- Methods for measurement of characteristics of suspended sediment	ISO 4363:2002
Measurement of liquid flow in open channels -- Bed material sampling	ISO 4364:1997 Cor. 2000
Liquid flow in open channels -- Sediment in streams and canals -- Determination of concentration, particle size distribution and relative density	ISO 4365:2005
Hydrometry -- Methods for assessment of reservoir sedimentation	ISO 6421:2012
Liquid flow measurement in open channels -- Sampling and analysis of gravel-bed material	ISO 9195:1992
Hydrometry -- Measurement of liquid flow in open channels -- Methods of measurement of bedload discharge	ISO/TR 9212:2006
Hydrometric determinations -- Measurement of suspended sediment transport in tidal channels	ISO 11329:2001

Sub-committee ISO/TC 113/SC8 Groundwater	
Hydrometric determinations -- Geophysical logging of boreholes for hydrogeological purposes -- Considerations and guidelines for making measurements	ISO/TR 14685:2001
Hydrometric determinations -- Pumping tests for water wells -- Considerations and guidelines for design, performance and use	ISO 14686:2003
Manual methods for the measurement of a groundwater level in a well	ISO 21413:2005
Hydrometry -- Measuring the water level in a well using automated pressure transducer methods	ISO/TR 23211:2009

Review of Current Knowledge