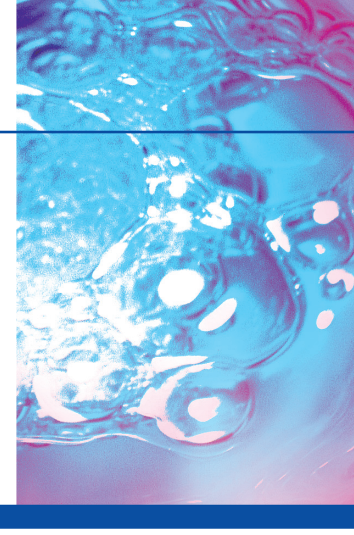

Water Quality Monitoring
FOR ENVIRONMENTAL MANAGEMENT

WATER/
Wastewater

Author Details

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Water quality of lakes and rivers encompasses a wide variety of attributes, not all of which may be obvious on a first encounter. A reasonably complete list includes:

- Temperature
- Dissolved solids. This includes a wide range of substances. Interest is usually in those substances having biological significance, including oxygen, nutrients (particularly NO_3^-, NO_2^-, P and K) or toxic species, but may also encompass measurement of substances which will allow the geochemical signature of the water to be determined and hence provide clues to its origin.
- Electrical conductivity
- Suspended sediment. This may be a pollutant in its own right, but also a vector for other chemicals, such as heavy metals, which bind to the particles. By studying the mineralogy of the suspended sediment, the origin can often be determined.
- Turbidity
- Colour
- Biological Oxygen Demand
- Dissolved oxygen
- Partial pressure of carbon dioxide
- pH
- Alkalinity
- Redox potential
- Microbes and viruses
- Microfauna & microflora
- Macrophytes and macrofauna

The appropriate definition depends heavily on the purpose for which one needs the information and will, typically, encompass a combination of several of these factors. Several of the items mentioned above are, themselves, composites of a number of possible candidates. For instance, there is an almost infinite number of chemicals which may be dissolved in water and also very many different biological organisms which could be present in the water.

It is necessary, therefore, to focus on particular applications and / or technologies to make the task of writing this article manageable.

Time Dependent Factors

The processes affecting the concentration of many substances in rivers (dissolution, mobilisation, dilution, etc.) are such that they often vary significantly faster than the flow does. On the other hand, biologically-mediated processes (e.g. algal blooms) respond to weather and seasonal factors, usually on a much slower timescale. It is clear, therefore, that an appropriate sampling regime needs to be tailored to the site-specific conditions and objectives for which the data is being collected.

Sensor Technologies

As interest in water quality measurement increases, so the number of online sensors which are available for continuous *in situ* monitoring has increased rapidly over the last 15 years. Mostly, the sensors are essentially the same as used for laboratory measurements, although there has been a move towards modification of these to suit field conditions (low power consumption and more rugged construction, for instance) and some entirely new sensors are starting to appear specifically for field applications.

It would be impossible to describe all the sensors available for such a diverse range of applications, but a selection appears below

Dissolved Oxygen

The most common sensor uses the well-established Clark cell principle. Whilst several manufacturers offer reliable sensors for use under field conditions, they mostly suffer from the need for recalibration and change of membrane typically every two weeks. Some manufacturers have addressed this problem and claim extended operational periods by the use of a wiper or other measures. Because the Clark cell consumes oxygen, problems occur with oxygen depletion by the membrane in lakes and slow-moving rivers, making it necessary to stir the water artificially. This often consumes precious power. An alternative methodology, based on fluorescence, has recently been introduced by a few manufacturers and is claimed to overcome these problems. Time will tell whether this promise is realised.

Turbidity

Turbidity is important in its own right, as it controls light transmission through the water and hence has a direct effect on any organisms living in the water. However, it is also used as a surrogate for suspended sediment in the water. In general, the higher the suspended sediment load, the greater the turbidity. The relationship is not, however, unique and depends on the size distribution of the particles as well as their optical characteristics and degree of aggregation. By combining an estimate of suspended sediment concentration with a measure of flow at the same point, the total flux of suspended sediment can be estimated. This methodology is also applicable to chemical species.

Electrical conductivity and dissolved solids

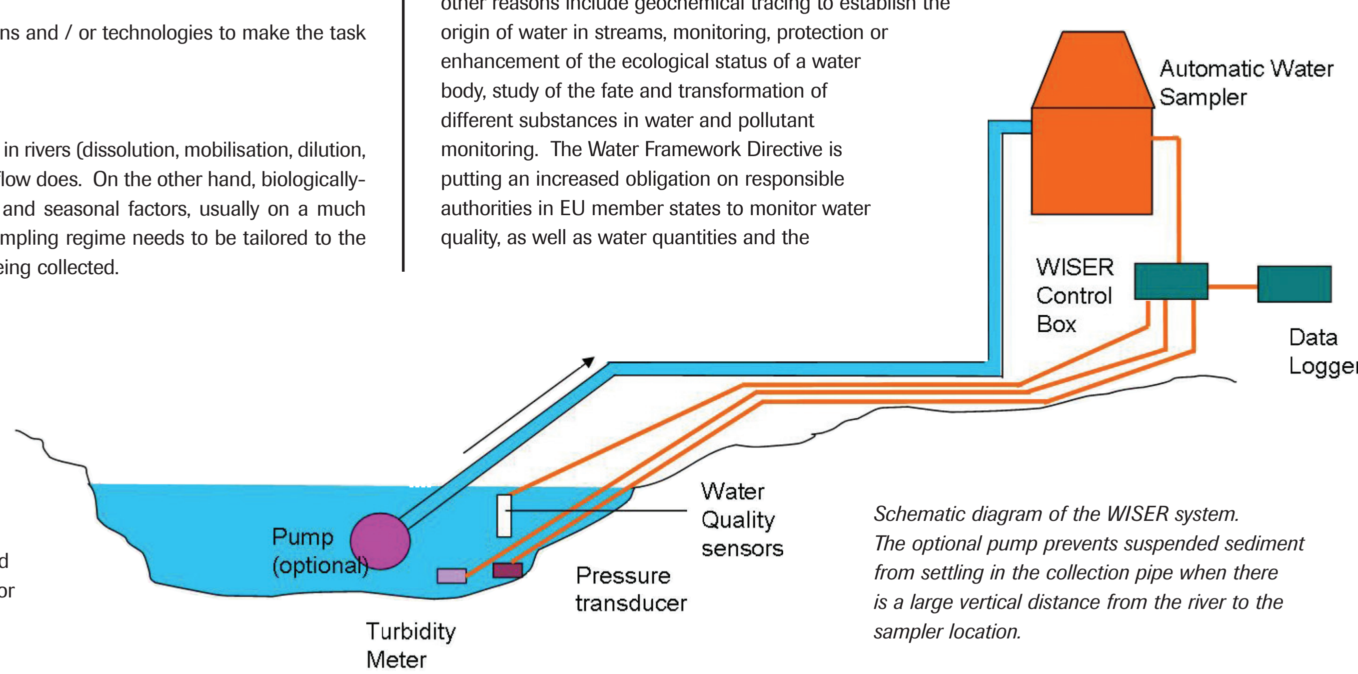
Sensors based on the well-known four-point or ac bridge methods at ~1 kHz are used routinely for measurement of electrical conductivity in conductivity cells. Problems often occur in water with low ionic strength ($<\sim$ 5 mS m^{-1}), common in upland rivers in hard rock areas. Electrical conductivity depends strongly on temperature and is usually expressed, therefore, as the conductivity at a particular reference temperature (normally 25° C). Temperature measurement is, therefore, essential to allow the correction to be made. The content of dissolved solids is usually estimated from electrical conductivity, although this depends on the chemical species dissolved in the water, especially their valency. A rule of thumb that the amount of dissolved solids in mg l^{-1} is approximately equal to 67 times the electrical conductivity in μS m^{-1} at 25° C works well in many situations, but for accurate work, a specific relationship must be derived.

Multi-parameter probes

Over the last decade, multi-parameter water quality probes have become very popular, with at least a dozen manufacturers worldwide offering basically similar products. These integrate a number of different sensors onto one, normally cylindrical, housing, incorporating electronics and, often, a data logger. The most basic suite of sensors is usually pH, temperature, electrical conductivity and dissolved oxygen, but an ever-expanding list of other sensors is available, which include turbidity, chlorophyll, redox potential and several different chemicals.

The need for water quality measurements

As noted above, there are many motivations for measurement and monitoring of water quality. Perhaps protection of public health springs most readily to mind, but other reasons include geochemical tracing to establish the origin of water in streams, monitoring, protection or enhancement of the ecological status of a water body, study of the fate and transformation of different substances in water and pollutant monitoring. The Water Framework Directive is putting an increased obligation on responsible authorities in EU member states to monitor water quality, as well as water quantities and the



Schematic diagram of the WISER system. The optional pump prevents suspended sediment from settling in the collection pipe when there is a large vertical distance from the river to the sampler location.

ecological state of the water.

Because of the large variety of different potential variables to measure, there is an almost endless series of possibilities for measuring water quality. Because of this, some people take an approach which seeks to measure an integrated "health" factor based on toxicity to some specified target population, rather than to make detailed measurement of specific substances. This is clearly useful if there is a good correlation between the chosen measure and, say, danger to public health or to another target population. For scientific research, on the other hand, this broad brush approach is often of limited utility and detailed measurements of specific parameters are usually required.

CEH DEVELOPMENTS

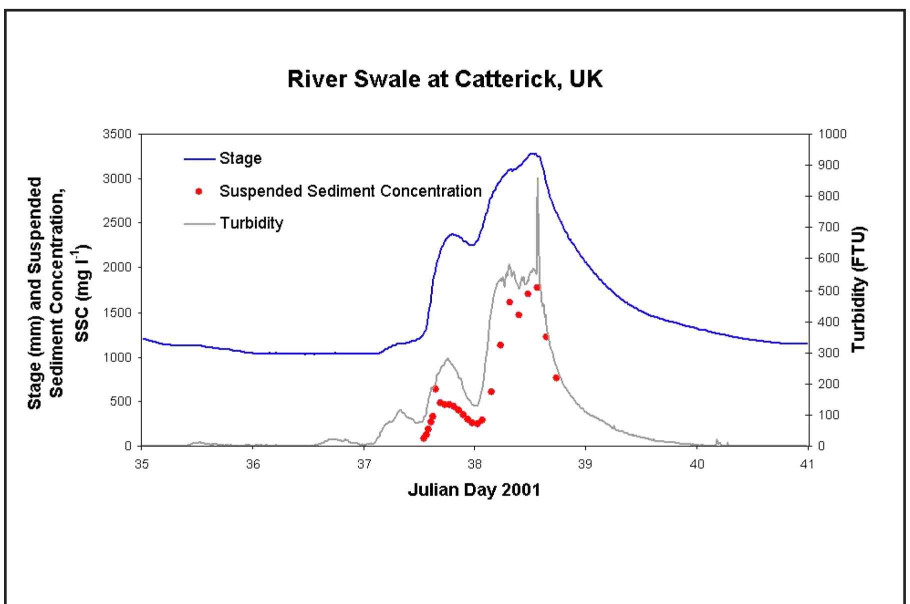
The Centre for Ecology and Hydrology (CEH) has a need for water quality measurement and monitoring in a variety of programmes touching on problems relating to water supply for public consumption, ecological studies and fundamental studies of in-river and in-lake processes. Some of the approaches are described below.

A WISER system installed in the field. The sensors are mounted inside and on the surface of the black plastic pipe. The data logger and automatic water sampler is inside the green cabinet.

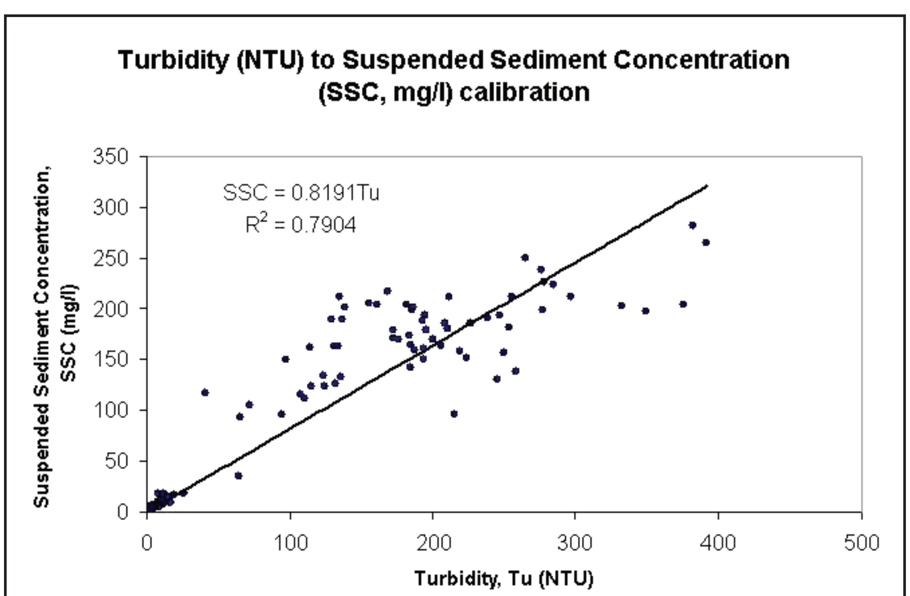
WISER – Intelligent sampling

Despite the ever-expanding range of online sensors available, there are many substances which scientists need to measure, for which there are no suitable sensors. Taking a sample from the river or stream and transporting it back to a laboratory for analysis is the only option in such cases. Samples are also required for quality assurance and calibration purposes. As noted above, the variation of concentration is extremely rapid in many rivers, with, in quiescent periods, very often only small amounts of the substance of interest being present. When an event occurs, however, concentrations can reach high levels very quickly.

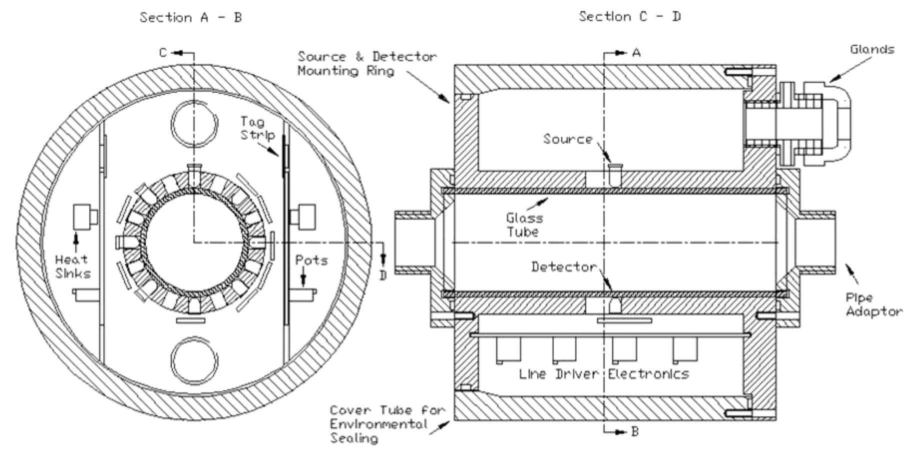
The CEH WISER (Wallingford Integrated System for Environmental Monitoring in Rivers) is designed to cope with this characteristic by waiting until an event occurs before starting a sampling cycle designed to collect samples over the peak of the event. This ensures that maximum value can be obtained from each sample. No samples are collected during quiet periods, when concentration is low and of little interest, but as soon as an event occurs, a program in the data logger initiates a sampling sequence. Samples are taken rapidly at first, and then less frequently as the concentration changes reduce on the falling limb of the hydrograph. On a small stream, the sampling frequency may initially be 15 minutes, reducing in stages to, perhaps, hourly. On a large river, these intervals would be longer. Should an event, and hence sampling sequence, be initiated but not sustained, then the program will abort the sampling.



Example data from the River Swale in N Yorkshire, showing the much more rapid variation of turbidity with time than that of river flow, particularly on the falling limb of the hydrograph.



Example plot of suspended solids concentration v turbidity measured on the River Term in Shropshire.



Arrangement of light sources and sensors in the suspended sediment version of OPTIMO. Each radial position can accommodate a LED light source or PIN diode detector. Water is pumped through the glass tube in the centre of the sensor head.

As well as a data logger and automatic water sampler, the system has several online sensors. The number of these is flexible, as is their function. Typically, they will include a pressure transducer to record water level, a turbidity meter and a multi-parameter water quality probe. Triggering of the sampling sequence is possible from the output of any of the online sensors, although using water level has proved most successful so far.

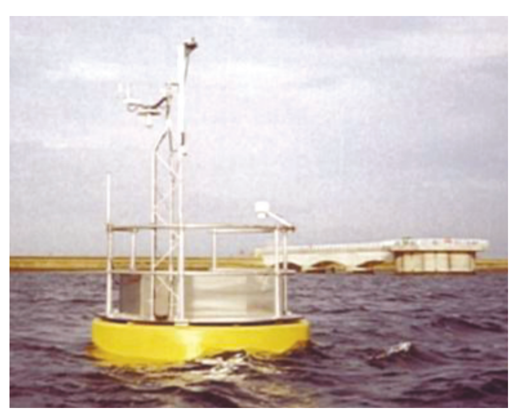
Over 50 units have been constructed, with many having been employed in the NERC LOIS, URGENT, LOCAR and CHASM programmes. The system has proven to be robust and economical. All devices used are low power consumption and can be run from solar panels and sealed lead acid batteries. Connection of a GSM telephone link has proved to be very useful, so that operators can know whether the sampler bottles are full and make a decision on whether it is necessary to visit. This cuts down on wasted visits and avoids missing events because there are insufficient empty sample bottles remaining.

OPTIMO

OPTIMO (Optical Technology for Intelligent Monitoring Online) is the result of a European Union-funded collaboration, led by Loughborough University, to develop economical monitoring technology based on multi-angle, multi-wavelength optical scattering using cheap light sources (LEDs) and sensors (PIN diodes). The version for water treatment works and suspended sediment in rivers is described here. Other versions have been produced for colour and process monitoring of wine production and olive oil processing.

Because optical scattering by suspended particles depends on a large number of characteristics of the particles, including size, optical characteristics and shape, there is no unique relationship between suspended sediment load and turbidity (which is usually determined at 90° scattering using an infra-red source – 860nm according to ISO 7027, but often in the range 780 – 900 nm). By increasing the number of scattering angles and wavelengths employed, OPTIMO has many more channels of information available. These can be used to resolve the ambiguities introduced by the above-mentioned factors and also allow for some particle size information to be recovered.

Testing is at an early stage, but preliminary results are encouraging. In the water treatment works application, impressive sensitivity has been demonstrated, the OPTIMO signals showing much earlier signs of low levels of particulates in water when the filter is backwashed than traditional turbidity meters. In the river application, correlation against the WISER turbidity meter shows good agreement at one site.



Photograph of a CEH buoy system on a water supply reservoir.

Lakes

Lake monitoring presents different problems from those in rivers. Rates of change may not be so rapid, but stratification is important, making the need for measurement as a function of depth important. The size of lakes also means that measurement from the bank is not usually an option. The solution is usually to deploy a buoy, with instruments both on top and slung underneath. Power is clearly a serious issue, although solar panel area is not often at a premium and theft and vandalism problems are reduced considerably from those on land-based systems. Communication can be accomplished conveniently by a short-range radio link to the shore, which is relatively economical on power, with a more powerful GSM unit to relay data back to base.

Growth of algal blooms can be studied from such a system. Fluorescence is the preferred method for continuous monitoring. Different species of algae fluoresce at different wavelengths, so that it is possible, in principle, to monitor the development of different groups of algae. A full spectrometer would be prohibitively expensive, but success has been achieved using a series of filters placed in front of a photomultiplier with a xenon flash lamp to provide short wavelength illumination.

The Future

The range of possible determinands is so great that it is inevitable that the surface of this subject has only been scratched. To avoid overwhelming both those making the measurements and those seeking to use them, more attention will need to be paid to the objectives for which the measurements are wanted. The observation strategy can then be tailored to the data analysis. The scattergun approach will, however, become increasingly less viable. Similarly, volumes of data can easily get out of hand and attention needs to be paid to efficient data handling strategies, visualisation and collecting data only at those times when there is something of real importance to measure.