Monitoring the Water Cycle -- state of the art and future needs


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Monitoring

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Legislation has increased the need for water quality information systems in the entire water cycle. **Ingmar Nopens, Kris Villez, Leiv Rieger** and **Peter Vanrolleghem** shed light on the current situation and requirements for the future.

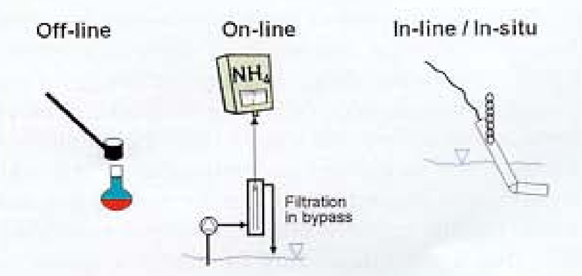

Figure 1. Definition of off-line, on-line and in-situ (or in-line).

With the European Water Framework Directive (WFD) high on the agenda, Europe faces the challenge of guarding or restoring the ecological quality of its rivers. The same holds true for the US, where the Total Maximum Daily Load (TMDL) approach has gained considerably increased attention in recent years. Moreover, in many other countries very similar legislation is on its way or is already being implemented. The condition of our rivers is a major public concern as it becomes an increasingly important source of drinking water.

To constructively tackle this challenge, a thorough analysis of the entire (urban) water cycle, ranging from sewer systems, wastewater treatment systems, ground and surface waters to drinking water systems, is required, as all these systems are interconnected. In order to perform such an integrated analysis, good quality and high frequency measurements are crucial. Hence, the water community will more than ever face the need for thoroughly-designed monitoring networks providing information on the whole urban water cycle. Handling and integrated analysis of huge amounts of data and guaranteeing sufficient data quality are the main challenges for the future.

Evolutions in monitoring the water cycle

Initially, water systems are monitored using individual sampling points visited on a regular (typically monthly) basis. This approach can be regarded as the current state-of-the-art. Due to the enormous work load resulting from this, (automated) monitoring stations were developed and investigated in the 1990s (for example Beck et al., 1998, van Griensven et al., 2000). Nowadays, one can observe that the use of this type of monitoring has found its way into most subdomains of the water cycle (Strobl et al., 2006).

The latter has evolved to the implementation of monitoring networks. However, it can not yet be regarded as being common practice. This is most probably due to the implementation problems encountered, which lead to a lack of trust in the system and, hence reluctance to further invest in and maintain it. Practical problems observed are typically related to the high expectations of those systems, their complexity and vulnerability. Often, systems are set up without a concept to deal with data quality issues and without collecting the required meta-data, two crucial aspects of monitoring. Meta-data (information about the data, e.g. location, time, equipment type and status, site description) is a crucial aspect to data interpretation but often forgotten, hence leading to uninterpretable datasets and subsequently to so-called data graveyards.

But what is the incentive for such high measuring frequency (hourly instead of monthly) and why is the information currently gained insufficient? There are several reasons for this and they can be found throughout the different subsystems of the water cycle. Peak discharges occurring in sewer systems lead to overflows and these must be monitored, logged and reported. Wastewater treatment systems face more stringent legislation, where the emphasis moves toward peak discharges (for instance, German

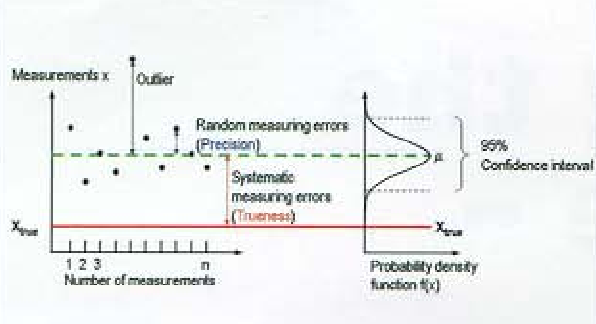

Figure 2. Differentiation between systematic (expressed as trueness) and random (expressed as precision) errors (Rieger et al, 2005).

legislation evaluates on a two-hourly basis). In rivers, there is increasing awareness of short-term effects (CSOs, eco-hydraulics, hydromorphology, algal blooms, ammonia toxicity, intake of drinking water systems and so on). On top of that, global climate change leads to a more energetic atmosphere and an increased frequency of extreme events (intense rains), leading to more peak discharges, overflows, and intense run-off, leading to sudden impacts on river water quality.

An issue closely related to this increased frequency is obviously the availability of suitable sensors, as these form the backbone of a monitoring network. The required sensors should be low maintenance relation to the achievable benefit. Currently, three types of measurement system can be identified: off-line, on-line and in-line/in-situ (Figure 1). In terms of measurement frequency, the latter two are clearly favoured. On-line analysers have the advantage of allowing auto-calibration routines to be implemented, whereas in-situ sensors perform their measurements directly in the liquid without the need for time-consuming and error-prone pumping and filtration. An increasing trend in the use of in-situ probes can be observed due to the reduction of maintenance (Pressl et al., 2005). Also, the short response time, which is an important source of control errors, is greatly reduced in comparison with classical on-line analysers equipped with a filtration unit that is also often the cause of a significant amount of downtime.

Data quality considerations

In chemical engineering (and more specifically statistical process control), monitoring is regarded as a lot broader than merely sampling a system (as it was interpreted in environmental engineering); it also includes data quality evaluation. In water systems too, data quality deserves special consideration as the high frequency with which we can nowadays generate data sets (for instance by using in situ probes connected to automated measuring stations) leads to data graveyards if proper data quality is not assured: indeed, what is the use of truly large databases if one cannot trust the data inside them because there is no time to have them evaluated in

Data quality evaluation can indicate whether a sensor may need maintenance.

3rd International IWA Conference on Automation in Water Quality Monitoring - AutMoNet2007, 5-7 September 2007, Gent, Belgium

This autumn the third specialised conference on water quality monitoring is being held in Ghent, Belgium. This conference deals, among other issues, with the aspects addressed in this article. All details concerning the conference can be found at http://biomath.ugent.be/AutMoNet2007/

The main theme of AutMoNet2007 is monitoring and sensor technology in the water cycle including both (networks of) data collection devices / methods and quality assurance / interpretation methods. It should be a conference that, while rightly focusing on sensors and sensor networks, deals with the entire continuum of: designing robust and more intelligent sensors for field deployment, design of sensor networks, sensor / network supervision and fault detection, validation / QA of data, database management, data interpretation, signal processing and data assimilation, information, models, control, and decision-making.

The conference should be attractive for the whole diversity of water systems: surface waters, groundwater, wastewater treatment plants, sewer systems, drinking water, supply networks etc.

it is no longer even possible for a human operator to perform such data quality assurance. This data-drowning syndrome will certainly get even worse with the up-coming trend for monitoring networks.

There are two major tasks in data quality evaluation: first, the detection of errors in existing data sets and second, guaranteeing a certain data quality in (or near) real-time. Whereas the first task is looking back trying to reconcile historical data, the second task is looking forward and is a prerequisite to deal with the huge databases we are creating by using continuously measuring devices at various locations in the urban water cycle. The main step is to detect systematic errors (see Figure 2). The second step is to quantify the uncertainties (trueness, precision and response time) of every single sensor to be able to use the data taking the unavoidable uncertainties into account.

Experience shows that there is major need for a monitoring concept that can be used by operators with a minimum of monitoring effort but with a high probability of detecting systematic errors. Guaranteeing data quality (or more specifically high trueness) needs the following crucial steps:

- measurements: signals and meta-data (data about data)
- monitoring: detection that there is a problem
- diagnosis: localisation of the problem and quantification (trueness and precision)
- control: manual or automated action based on predefined rules.

While monitoring tools concern the simple question of whether the data quality is sufficient for the intended purpose, diagnosis aims at the identification of a problem based on a given set of symptoms. Given a diagnosis, action can be taken, automated or not.

Tools for monitoring and diagnosis can be of an inductive or deductive nature. Methods of an inductive nature are based on empirical evidence about the nature of measured variables and are by definition based on past observations. Simple, uni-variate methods for monitoring include Shewhart and CUSUM charts. Other, more complex monitoring methods are often based on multi-variate methods such as principal component analysis (PCA), partial least squares (PLS) or independent component analysis (ICA) (Rosen et al, 2003; Yoo et al, 2004).

Inductive diagnosis can be conceived by classifier (supervised learning, such as discriminant analysis) or cluster (unsupervised learning, such as k-nearest neighbour clustering) models. More advanced methods may be based on case-based reasoning, allowing recognition of a previously-encountered problem.

Quantification of the uncertainty

In addition to a monitoring concept for detecting and dealing with systematic errors, the uncertainties of the continuously-measuring devices should be quantified during field operation (Rieger et al, 2005). Information about the trueness and precision of the measuring system under field conditions helps to adapt operating strategies more effectively to the relevant processes and permits sophisticated operating concepts to be applied. Moreover, the monitoring concept can help to define guidelines for evaluating the uncertainties involved in monitoring effluent quality. This will greatly increase the acceptance of the measuring devices and of continuous effluent-quality monitoring.

Pro-active maintenance

Data quality evaluation also allows us to find out whether a sensor may need maintenance (for instance, because it is detected that some fouling has occurred) and one can act proactively in this way (that is, we maintain the sensor while it still gives good data such that it can continue to do so), rather than reactively (for example, when the fault has led to a sensor not giving good data any more).

Integrated system analysis - where do we go from here?

To summarise, for the time being we have to deal with an increasing amount of data due to the increasing use of continuously-measuring devices. Data handling, integration, visualisation and analysis have become a real challenge for engineers, and concepts for daily engineering practice are not yet available. Data management and quality control are major problems and new tools should be developed. The different parts of the urban

Automated monitoring is not yet common practice but is nonetheless well established.
Picture credit – IMW-project.

water cycle are often monitored separately and an integrated analysis is therefore a complex and time-consuming task.

Standardised monitoring platforms including high frequency measurements and data quality verification algorithms can be very beneficial here. However, these should still have enough flexibility to deal with different monitoring needs or different types of sensors. The main challenge is to guarantee reliable and accurate measurements over the lifetime of the devices. Plug-and-play sensors, and data with a quality label to each value, are the directions we need to head in the future.

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