Use of real-time data in environmental monitoring: current practices

A. Gunatilaka and J. Dreher
Verbundplan GmbH, Consulting Engineers, Parkring 12, A-1011 Vienna, Austria
(E-mail: gunatilakaA@Verbundplan.at; dreherJ@Verbundplan.at)

Abstract Water quality monitoring in Europe, especially in transboundary water courses has made steady progress during the last decades through establishment of international commissions. The main activities of these commissions include protection and management of the catchment, sustainable use of the river and establishment of Accident Emergency Warning Systems (AEWS). The latter could be effectively accomplished only through real-time monitoring. Concurrently real-time data have been found important for the monitoring of potable water intake points, wastewater treatment plants, estuaries and in aquaculture. With the recognition of the diversified demand, there are a number of questions to be answered such as: (1) are we satisfied with the existing monitoring systems? (2) is standardisation of the measuring instruments a necessity? (3) do we have foolproof systems for data capture and transmission? (4) are there adequate procedures to analyse vast amount of data generated? We have to answer these questions urgently as the demand for real-time monitoring has been drastically increased.

Keywords Data handling; early warning; groundwater; on-line measurements; on-line sensors; transboundary rivers

Introduction

In European rivers continuous chemical and biological monitoring dates back to the sixties and seventies (Kramer and Botterweg, 1991; Gunatilaka and Diehl, 2001). There have been a number of on-line monitoring systems deployed along the water courses that provided ample opportunities for field testing, resulting in the emergence of some robust chemical and biological sensors and they are reviewed in detail in Butterworth et al. (2001). These on-line sensors differed from commonly used sensors in wastewater treatment plants having a lower limit of detection which were required to satisfy the environmental regulators, for natural water investigations. The impact of the micro-electronic development in the past two decades contributed strongly to further advancement of sensor technology for real-time monitoring, data collection and data transmission. However, the sensors – our link to the real world – are clearly still the weakest part of the monitoring and control in a measuring chain (Lynggaard-Jensen et al., 1996).

The availability of powerful tools from biochemistry, molecular biology and genetics have contributed to development of sensitive and specialised biosensors (Wilderer et al., 2002; Nielsen et al., 2000; Janata et al., 1998). Research and development has stimulated development of series of novel on-line sensors which are quite promising and different to conventional sensors are reviewed in Butterworth et al. (2002). Cosnier (1999) has reviewed the immobilisation of biomolecules on polymerised films for commercial development of miniaturised biosensors. Increased reliability requirements have stimulated research into non-invasive sensor techniques using laser technology, fluorescence and optical sensors. These have the advantage of being prone to bio-fouling, free from electromagnetic interference and of being less susceptible to corrosion. To put these developments into practice and to the final emergence as reliable on-line sensors is a long way ahead. The users expect from the on-line sensors reliability, reproducibility, stability,
robustness, precision, self-cleaning, low maintenance requirements, auditable performance and validity of data, all at low cost. The potential for improvement is vast when sensors can provide accurate, continuous on-line information, as reliable data are fundamental to river basin management (RBM). Based on three implemented projects, some of these contrasting issues are discussed in this paper.

**International treaties and AEWS**

Water quality monitoring of international rivers has always been a difficult task in Europe, but great strides have been made through the establishment of international commissions such as the International Commission for the Protection of the Rhine (ICPR) and the recently founded Danube River Protection Convention (DRPC). On-line monitoring has been introduced in most of the large rivers in Europe and they served as cornerstones in setting up trans-boundary monitoring between cross border countries and best exemplified by the Rhine.

In the nineties with the establishment of the New Independent States (NIS) in Europe and together with redefined borders in East European countries, the number of international river boundaries increased rapidly. In 1992 in Helsinki, Water Framework Directive of the European Commission under the auspices of United Nations Economic Commission for Europe (UNECE), established the Convention on Protection and Use of Trans-boundary Watercourses and International Lakes. The convention was set up as a framework for management of nearly 115 major trans-boundary rivers and 20 international lakes. This came into effect in 1996 and under the UNECE Water Convention, the Task Force on Monitoring and Assessment has drafted the “Guidelines for Water-Quality Monitoring and Assessment of Trans-boundary Rivers”. Among other measures on-line monitoring stations will be established on either sides of the boundaries for compliance and regulatory monitoring, and AEWS as a control measure between the bordering countries with the aim of improving human and environmental health. The necessity for vigilant transboundary control was shown by the recent Danube accidental spills: one in Hungary (26.05.1998) where pesticide (β-cipermetrin, 6 kg) was released into the river from a chemical industrial plant (rkm 1621.8; Pintér, 1999) and in another in Romania (30.01.2000), with leakage of nearly 100,000 tons of cyanide-laden sludge (Baia Mare, gold mine tailings) in the river through Szamos and Tiza tributaries. Both accidents led to large fish kills and unprecedented ecosystem damage.

Trans-boundary water pollution is a widely recognised environmental problem in Central and Eastern Europe. A key objective of the EU environmental policy for the future is the protection of water resources which can be achieved only through active monitoring programs. Such improvements are already visible in the Rhine and in the upper Danube (Germany and Austria), but monitoring efforts were initiated three decades back (Gunatilaka and Diehl, 2001). A newly assembled Danube AEWS of the Rhine model has been in operation since 1997 and today effective early warning systems in both rivers can deal with short and sudden contamination (Pintér, 1999). Aiming at a sustainable water policy, the European Union pursues transboundary river management, as the ICPR practices for the Rhine, to be established for the whole of Europe.

**Standardisation**

More and more industries, controlling bodies, regulatory authorities and international organisations are now using real-time monitoring as an effective tool to monitor the aquatic environment. During the past decade there has been a steady increase in the demand for real-time monitoring chains and peripheral equipment. Therefore standardisation of commercially available on-line sensors/ analysing equipment for water analysis has become an
important requirement. They are needed by the users including law enforcing authorities to compare the results of measurements from variant sources, carried out with instruments produced by different manufacturers. If there are no standardised sensors used in monitoring, harmonising of representative databases will be an impossible task. Harmonised databases can secure data accuracy, prevent redundancies and will be a great asset to both regulatory organisations and other users.

At present this task of comparing instruments from different manufacturers is difficult due to the lack of proper documentation and the non-existence of standard test protocols. At present there are no validation schemes or standards that address user needs with respect to instrumentation for on-line water quality monitoring. The result is that instrument manufacturers and suppliers set their own specifications based on the available technology. Another shortcoming is that most of the on-line instruments which are sold are not field calibrated and tested. Rivers are dynamic systems and the sensors are exposed to completely different matrices than the laboratory calibration medium or physical conditions (e.g. fluctuations in flow, high sediment loads, floods). The first action in this direction was the ETACS (European testing and assessment of comparability of on-line sensors/analysers) project which was launched under the auspices of the EU research program (ETACS, 1999) that focused on on-line instrumentation used in wastewater treatment plants. The main objectives of the project were: (1) to develop a test protocol for validation of on-line sensors and analysers, (2) the practical testing (with field tests) for establishing a final test protocol and (3) acceptance of the test protocol by all concerned parties (instrument manufactures, suppliers and relevant authorities) to be presented as a European standard. These objectives will guarantee the quality assurance of on-line water quality measurements that are used for real-time process control as well as regulatory environmental monitoring which incorporate two main aspects of the validation procedures: (1) laboratory documentation of the instrumentation performance to check the technical data given by the producer, (2) documentation of the reliability of results obtained by the users during field operations. The ETACS project was completed in 1999 and it is encouraging to note that the final report has become the basis for the preparation of an ISO standard for standardising of on-line sensors and analysing equipment for water quality (ISO/TC 147, 2001). In the near future this can be a useful tool for harmonisation of environmental databases.

The results of the project have led to defining the criteria of the instrumentation and test procedures which are helpful to both instrument makers as well as users. According to the outcome, the following main features are taken into consideration in describing an on-line measuring chain: the deployment of the on-line sensor, sampling procedure, sample pre-treatment, method of measurement, principle and the type of determination. Thus the characteristics of the selected on-line measuring chain will depend on the combination of sensors that are been used for the type of application. Typically the measuring chain starts at the sample input (measuring medium) and ends at the electrical signal output from the sensor (usually 4–20 mA). The validation schemes for on-line sensors and analysers include the following performance characteristics: selectivity and specificity, range, linearity, sensitivity, limit of detection, limit of quantification, ruggedness, accuracy, precision, repeatability and reproducibility, response time, dead time and rise time, and up time (effective operation time). In the future the above criteria should guide both instrument manufactures and users in accomplishing their respective goals. Finally for successful real-time monitoring, the sensors developed have to be accurate and dependable.

**Data transfer and acquisition**

As continuous monitoring systems generate large amounts of data there is a demand for advanced computer hardware and the software has to be able to handle a number of
magnitudes larger data sets. At present some compensations have been made by using expensive industrial standard software based on SCADA (Supervisory Control and Data Acquisition) standards. The functions of SCADA systems for environmental monitoring include: (1) collection of on-line measurement data, (2) surveillance of the measuring chain including operations and (3) process control and other relevant operations. The future needs are to develop simpler routines which are accurate but cost effective for worldwide applications. Earlier statistical processing of the data was neglected in the measuring devices and the SCADA systems due to delays caused by long data processing procedures. These limitations have been overcome by the fast development of microprocessors and the introduction of 32-bit operating systems which provide more computer capacity for the processing of data. This gave the possibility for refinement of software sensors in incorporating more complicated modelling and time series evaluation than those that were included as standard in most industrial SCADA systems. These timely improvements led to development of computerised, true real-time process control systems using the SCADA systems as front ends (Harremoës et al. 1994) and many operations are now using second or third generation of SCADA.

In environmental monitoring a SCADA application generally involves a number of process-controlled, semi-intelligent input and output devices (I/O) monitoring and controlling equipment from one or several monitoring sites distributed across a large geographical area. SCADA systems communicate with the installed on-line sensors consecutively on a regular basis to provide up-to-date information on the measurements. The information retrieved from these I/O devices is ingested into a central computer for processing (SCADA host) with measured data and the incoming alarms and other relevant messages stored in a database. Where SCADA equipment is in remote or harsh environments the connection to the SCADA system may be via radio, satellite or digital mobile telephone. The combination of different communications systems, networks and tasks to be performed by a SCADA system are typically only limited by the type of equipment and software sensors developed for an application.

Some of the SCADA systems installed for environmental monitoring operations function according to the following sequence: (1) the sensor located at a remote monitoring site measures the physical or chemical parameters sending a signal (analog) to the local remote terminal unit (RTU) through an interface, (2) the interface calculates the corresponding value using a device-specific function (3) the value is stored in the local database of the RTU, (4) it is transmitted to the Master Station when the RTU is next polled, (5) if there is a repeater, data are transmitted from the RTU to the radio modem at the Master Station host, passing through the repeater, (6) the values are stored in the database at the Master Station and are made ready to be displayed on an easy to read graphical display, (7) the values are compared against the alarm limits, (8) the status indicator reflects the present alarm conditions. For real-time water quality and quantity monitoring operations discussed below, specially designed SCADA software sensors were used to accommodate user requirements.

**Systems installed and their performance**

**Groundwater management in metropolitan Vienna**

The fully automated groundwater management system for 2nd and 20th districts of Vienna (30 km² area) has been in operation for seven years. This system has been installed during the construction of the Freudenau hydropower plant on the Danube River in Vienna to prevent undesirable changes in the groundwater quality and quantity, and as a precaution a 13 km long, 12 to 40 m deep double-walled sealing system was constructed along the right bank of the river discussed and reviewed in detail in Gunatilaka and Dreher (1996, 2001).
The groundwater management is accomplished through the operation of 25 pairs of extraction and infiltration wells located on either side of the sealing walls. For controlling the groundwater flow, appropriate software sensors have been developed and are in use for daily routines in scheduling pumping sequences for the extraction and recharging wells. The direct infiltration of contaminants from the Danube is prevented through real-time control of the water quality and regular monitoring in an elaborate net of groundwater wells. A total of seven on-line monitoring stations are used for the continuous monitoring of water quality (chemical and biological), of which three are equipped for groundwater monitoring and the rest for direct river water quality control. A unique feature of the operation is that in the case of an accident or the presence of a pollution plume (detected through continuous analysis routines) installed alarm systems will prevent pumping of a contaminated bank filtrate in the aquifer.

The data acquisition system for the groundwater management system is comprised of the following elements: (1) pressure sensors for water level measurement (without local data storage), (2) analysers for detection of nutrients, BTEX and hydrocarbons, biomonitoring are equipped with data processing units (PC) and local memory for data retrieval (hard disk), (3) sensors for measurement of physical water quality parameters are with local displays, (4) industrial remote terminal unit (RTU from SAT®) is capable of event-dependent data transmission, (5) data transfer by means of optical cable network and (6) the power is supplied from the national grid. The system as a whole is an expensive installation but it is part of a hydropower plant control network which is using the same SCADA/SAT® system for plant control and power distribution.

**Telemetric flood control for the Umbeluzi River, Mozambique**

The main source of water in Mozambique is surface water but the most important river basins are shared with neighbouring countries and nearly 60% of the water originates in countries located in the upstream regions. Integrated river basin management (RBM) is a challenge in such shared water courses where monitoring systems are burdened with trans-boundary political issues. The Telemetric Flood Control for the Umbeluzi River included on-site sensors, telemetric equipment, software sensors and hardware in the control centres for flood control and reservoir management. The telemetry and data acquisition system comprised of: (1) pressure sensors and rain gauges connected to RTU by special interfaces, (2) RTU with data logger for local data storage and data control, (3) event dependent alarm triggering, (4) radio modems and directional antennas for data transmission, and (5) power is supplied from solar energy. Integration of the monitoring stations from Swaziland over the border was an important task for the project. It was accomplished through new data collection equipment installed by the Southern African Development Council (Hydrological Cycle Observation System SADC-HYCOS, for details see Dreher, 2002). Internet facilities that have been installed at the Pequenos Libombos Dam and at the Control Centre, permit easier access to the data collected in the monitoring stations in Swaziland. These data can be reached via the satellite communication system from SADC-HYCOS, illustrating an important and implicit contribution to the advances in data capture and communication technology. Satellite imagery from METEOSAT could be analysed via Internet web sites which provide rough estimation of the meteorological weather conditions.

The data transmission and acquisition alternative selected here is cheaper and more cost effective than the equipment used for the groundwater management system for Vienna as we shifted from a costly optical cable network to radio modems, and from an industrial SCADA to a simpler software sensor based on SCADA standards (IEEE, 1994). Open software application systems have been developed to allow flexibility for adaptation and extension. Solar panels as an energy source were an inevitable requirement as the water...
quantity and climate monitoring stations were installed in remote mountainous terrain. Data transmission is secured through standard protocols and repetitive polling of each monitoring station by the host and system performance is reliable and satisfactory. The data is stored and can be visualised in the Master Station on the PC, which performs the dual tasks of supervisory control and a data acquisition system.

**Water quality and pollution control in Brantas River, East Java, Indonesia**

The Brantas Basin is approximately 12,000 km² in area and has a very high population density of 1,263/km² (Java 865/km²). The urgent need for drinking water, food, shelter and recreational areas, and dangers of increasing eutrophication and acute pollution (industrial, municipal) are current problems for the population living in the Brantas catchment. Since 1990, a professional river basin management organisation PJT (Jasa Tirta Public Corporation) is the manager of the Brantas river basin. The Indonesian Institute of Science (LIPI) in co-operation with PJT has implemented a water quality and pollution control program using real-time data (Gunatilaka, 2001).

The on-line water quality and water quantity control systems include the following main components: (1) water quality monitoring: 23 on-line monitoring stations for continuous monitoring of water quality; (2) water quantity monitoring: 14 stations for stage and precipitation measurements to strengthen the existing monitoring net with 53 stations, (3) basin wide telemetry system for the transfer of real-time data to a central station using a network comprising of both radio and ISDN transmission systems, (4) central databank, Hydrological Information System (HIS) and a Decision Support System (DSS). Open software application systems have been specially designed to allow flexibility for adaptation and extension. The telemetry and data acquisition system comprised of: (1) special interfaces that connect physical–chemical sensors, nutrient monitors, pressure sensors and rain gauges to the RTU, (2) RTU with data logger for local data storage and data control, (3) event dependent alarm triggering, (4) ISDN net, radio modems and directional antennas are used for data transmission, (5) power supply is either from the national grid (water quality monitoring stations) or through solar panels (for water quantity and weather stations which are at remote locations). The basin wide data acquisition and transmission alternative selected is a surrogate hybrid system (combination of radio and ISDN transmission) different to earlier systems with the main aim of making it cost effective by incorporating a simpler specially developed standard SCADA software sensor. Data transmission is secured through standard protocols and can be visualised in the Master Station, similar to earlier examples.

**Early warning and diagnostic systems**

In Europe, river bank filtrates are used as a primary drinking water source, but in larger cities in Africa and Asia surface water directly extracted from rivers serves as the main water supply. Accidental pollution which is common in most of these rivers may cause serious problems leading to closure of water intake facilities. In transboundary rivers, the downstream users are badly affected in such incidents and the need to inform them timely led to the development of sophisticated AEWS systems implemented by ICPR (Rhine) and DRPC (Danube). Similar AEWS systems are now in the planning phases or in limited operation in many ASEAN and Pacific Rim countries extending from Australasia up to South Korea.

Developments and improvements of such systems have to follow a step-by-step approach as river systems are plagued with a multitude of toxic substances that cannot be detected by the available on-line sensors in the market. Recent investigations have shown that there a large number of newly emergent contaminants in surface water as well as in
groundwater such as endocrine disrupting compounds, antibiotics, non prescription drugs and their metabolites (Kolpin et al., 2002). The AEWS for the Rhine and Danube include data-banks of more than 15,000 dangerous chemicals and over 200,000 material names. One approach to solve the problem is to use biomonitors (biosensors) to supplement chemical monitoring as they react to a wider spectrum of toxicants. At present ten recommended continuous biotest systems are now in operation in rivers in Germany using different test organisms representing different trophic levels (e.g. bacteria, algae, water fleas, mussels). Twelve stations in the Rhine catchment, both upstream and downstream, are equipped with biomonitors and some have more than one biomonitor system (18 instruments in 12 stations). Aquatic organisms integrate all of the influential biotic and abiotic parameters in the habitat, thus providing a continuous record of environment quality that resulted in developing successful Biological Early Warning Systems (BEWS) for the Rhine, reviewed in Gunatilaka and Diehl (2001) and in Gunatilaka et al., (2001).

The ICPR in 2001 completed its international alarm system by the establishment of a procedure for the handling of alarms based on biotests, supplementary to the existing system, which is based on chemical analysis and information given by the discharges. The proposed scheme is shown in Figure 1 and such a system has to be based on a well tested, foolproof alarm classification model as implementation procedures will be very costly. Online monitoring systems generate a large amount of data, and at present there are no profound automated data analyses programs developed for environmental monitoring tasks. Especially from biomonitoring systems routine data analysis are not free from “false alarms” (see Gunatilaka et al., 2001) and expert intervention is needed for final decisions. Therefore for proper functioning of combined alarm systems, development of advanced software sensors is a prerequisite.

![Figure 1](https://iwaponline.com/wst/article-pdf/47/2/53/423958/53.pdf)

**Figure 1** Alarm warning scheme for the Rhine. So far the Rhine Warning and Alarm Service relied on chemical measurements and analysis and information about emissions. Since 2001 information from both chemical as well as biological monitoring are coupled for conformation of alarms: (see ICPR, 2000. IMWC – International Main Warning Centre)
Conclusions

The real-time monitoring of water quality in rivers during the last three decades shows continuous development and as a result there are well tested, on-line sensors and analysers available in the market for measuring general water quality parameters, nutrients, metals and some organic parameters. Careful long-term testing of biomonitoring equipment over nearly a decade has led to ten reliable biosensors for routine river monitoring programs. The integration of biological and chemical monitoring in progress would lead to improvements in AEWS. However, considering the danger from newly emergent contaminants in aquatic ecosystems, the present advancements in sensor technology should be rapidly used for development of new generations of on-line sensors for the improvement of ecosystem health. As world-wide demand for on-line sensors for environmental monitoring has increased, it is necessary to develop international standards for on-line sensors and instrumentation. This will help the instrument manufacturers as well as users and at the same time will be a prerequisite for harmonisation of environmental databases. There are advances in the development of sensor technologies in many fields, but to produce reliable on-line sensors, they are required to be tested in the field as well as in accredited testing laboratories, before they are marketed and the economic impact of adopting of such products has to be emphasised. As these systems produce large amounts of data, for their proper use in environmental monitoring there is a need for the development of advanced software sensors and data analytical routines. The available computing power today is quite high and affordable. The data collection is no longer an obstacle as many users have access to advanced SCADA systems and it is possible to automate most of these routines. Finally, it is hoped that the R&D in sensor studies would produce on-line equipment where capital costs and maintenance are reduced, and eventually developing countries would have their “late comer’s advantage”. The technology developed has tremendous potential in water quality monitoring which can lead to new horizons in detection, monitoring and control technologies.

Acknowledgements

The authors would like to thank Austrian Hydro Power and Verbundplan for continuous support, P. Diehl (Rhine Water Control Station, Worms) and F.M. Butterworth (Institute for River Research International, CA USA) for developments in biomonitoring.

References


