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ITU-T L.1500 series – Requirements for water sensing and early warning systems

ITU-T L-series Recommendations – Supplement 15

Supplement 15 to ITU-T L-series Recommendations

Supplement to ITU-T L.1500 series
Requirements for water sensing and early warning systems

Summary

Supplement 15 to ITU-T L-series Recommendations provides a general overview of the requirements for water sensing and early warning systems. This Supplement illustrates the different technologies for sensing water quality indicators, in addition to early warning systems. The Supplement also demonstrates the most commonly measured water parameters and associated sensing technologies.

History

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Supplement to ITU-T L.1500 series
Requirements for water sensing and early warning systems

1 Introduction

The increasing worldwide contamination of water sources with thousands of industrial and agricultural chemical compounds is one of the fundamental environmental challenges facing global societies. Almost 89% (6.1 billion people) of the total global population had access to an improved water source in 2010. However, approximately 884 million people of the global population were still relying on unimproved drinking water sources. Provision of improved water sources in urban areas remained at 83% between 1990 and 2008.

Furthermore, this is linked to over 35% of all deaths in developing countries. The World Health Organization (WHO) cites waterborne illnesses as a major factor in 1.8 million deaths each year of which 88% are children in developing countries.

Many water sources are polluted with microbiological organisms from the disposal of excreta, impairing human health through waterborne diseases such as diarrhoea, cholera, trachoma, schistosomiasis and others. Water-related vector-borne diseases, such as malaria, are also a major health concern.

Different water sources and aquatic systems that receive contamination from industrial waste and sewage treatment plants, storm water systems, and run-off from urban and agricultural lands need to be assessed via reliable, accurate and effective techniques. The assessment system can provide early warnings with the obtained water quality data, thus necessary actions and proper control can be taken in time to protect the quality of water sources. It is very important to supervise the quality of water resources through effective water sensing and early warning systems.

2 Scope

Supplement provides a general overview of the requirements for water sensing and early warning systems. This Supplement illustrates the different technologies for sensing water quality indicators, in addition to early warning systems. The Supplement also demonstrates the most commonly measured water parameters and associated sensing technologies.

3 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

AHP	Analytic Hierarchy Process
BOD	Biological Oxygen Demand
CAP	Common Alerting Protocol
COD	Chemical Oxygen Demand
ISO	International Organization for Standardization
ITS	Intelligent Transport System
KPI	Key Performance Indicator
LED	Light-Emitting Diode
MS	Mass Spectrometry
ORP	Oxidation-Reduction Potential

SSC	Smart Sustainable Cities
SWB	Subjective Well-Being
SWM	Smart Water Management
TEN	Trans-European Network
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TR	Technical Report
TS	Technical Specification
TSS	Total Suspended Solids
TTC	Telecommunication Technology Committee (TTC) of Japan
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UN-Habitat	United Nations Human Settlements Programme
UV-Vis	UltraViolet-Visible
WG	Working Group
XML	Extensible Markup Language

4 Overview

4.1 Water quality parameters

Water resources are constantly subject to ever increasing risks of pollution, thus water quality must be closely supervised to ensure that it responds fully to safety requirements associated with its different uses. A water system is very complicated and there are many parameters which influence water quality. These parameters are the basis for water sensing as water quality indicators.

Environmental water quality assessments are based on the analysis of the physical, chemical and bacteriological parameters of the water. Examples for the physical characteristics include temperature, conductivity and turbidity. Chemical parameters are: pH, oxygen, alkalinity, nitrogen and phosphorus compounds, while bacteriological contaminants look for the abundance of certain biological taxa. Monitoring could also include tests for toxins and direct measurements of pollutants such as heavy metals or hydrocarbons. It has been reported that in daily use there are up to 70000 known and emerging chemicals that might be present in various water resources, including for drinking water production.

Notably, approximately 860 active compounds are currently formulated in pesticide products. The chemical and physical properties of these pesticides can differ significantly which deem them relevant to be detected by various analytical methods. For example, they might include heteroatoms such as halogens, phosphorous, sulphur or nitrogen.

Quality indicators, especially in waste water include the biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) and total suspended solids (TSS).

Most natural waters contain small quantities of organic compounds. Aquatic microorganisms consume some of these organic compounds as food by oxidizing the organic compounds, thus releasing energy used further for growth and reproduction. The problem is that these microorganisms' microbial metabolisms consume dissolved oxygen in the water, which might threaten aquatic life if the rate of dissolved atmospheric oxygen does not compensate for the oxygen depletion process. The BOD represents the amount of oxygen required for the microbial metabolism of the organic compounds in the water and is used as an indicator of the degree of organic contamination of water.

The presence of nutrients (e.g., nitrates and phosphates) and heavy metals (e.g., lead) in water is a serious threat to human health. Phosphorus is widely used as an agricultural fertilizer and this can be found most notably in agricultural runoffs. It can also be found in domestic detergents. Phosphates can generally be grouped within three broad classes: orthophosphates, condensed phosphates (pyro-, meta- and poly-) and organic phosphorus depending on the nature and source of the discharge. Phosphates in water cause eutrophication, a severe threat to marine life. Nitrate fertilizers on the other hand can have a threatening effect on human health since they can be reduced to nitrite by bacteria in the stomach and furthermore become incorporated into carcinogenic N- nitrosamine compounds.

Heavy metals, on the other hand, such as zinc, lead, copper, mercury and nickel are common in the earth's crust. Some, in trace amounts, are even essential to human health. However, due to natural erosion, runoff from industrial and other sources, and corrosion in water-bearing pipes, contaminate the water sources and water supplies to toxic levels.

The most commonly used surface water quality parameters are shown in Table 1. These parameters are generally adopted by many countries or international associations such as WHO, EU, US EPA and Chinese National Standard.

Table 1 – Most common water quality parameters for general designated use categories

Physical parameters	Conductivity, temperature, total dissolved solids (TDS), TSS, turbidity, oxidation-reduction potential (ORP)
Chemical parameters	pH, BOD, COD, dissolved oxygen, ammonia nitrogen, arsenic, chloride, cyanide, fluoride, nitrate, sulfate, total phosphorus (TP), total nitrogen (TN), aluminium, antimony, dadmium, chromium, copper, iron, lead, manganese, nickel, mercury, selenium, zinc, oil (extracted from petroleum ether), volatile phenol, benzo(a) pyrene, anionic surfactant, permanganate index, TOC
Biological parameters	Escherichia coli, coliform bacteria, EPT (ephemeroptera, plecoptera and trichoptera) index

4.2 Meters and sensors

Meters and sensors are currently being intensively applied to regulate different activities of water distribution systems such as hydraulic pressure and flow, water quality, head losses, and water and energy consumptions. The major aim of water utilities is to convey water from one place to another effectively with a minimal compromise to its quality and quantity.

Water quality sensors help to detect and address problems related to the quality of water before affecting consumers. Water quality monitoring inside the distribution or the network system helps in addressing problems and providing related operational management activities. An application of different water quality sensors provides verified information that leads to informed decisions related to the observed water quality change. An advanced water quality sensor measures the water pH, dissolved oxygen, temperature, turbidity, salinity, and conductivity.

In May 2007, the European Parliament proposed increasing from 33 to 61 the toxic products covered by European legislation on water quality. Forty-five of these were classified as priority substances and should no longer be used by 2015. There is an acute need in high sensitive low cost on-line sensors that are able to detect the excess of pollutants established by the official water quality regulations. As an example, the EU pesticide standard is set at 0.1 micro grams/L.

In order to detect multi-contaminants simultaneously, multi-parameter water quality sensor panels, are mainly used in finished water, i.e., in water which has been treated and is ready for consumption. The authors have demonstrated typical parameters and techniques used in these monitors along with the differences and limitations between the different sensing methodologies as shown in Tables 2 and 3 respectively.

Table 2 – Most commonly measured water parameters and associated sensing technologies

Parameter being measured	Sensing technology
Aluminium	Colorimetry; atomic absorption spectrometry
Antimony	Atomic absorption spectrometry
Ammonia	Colorimetric (manual; Nessler's reagent; automated; Berthelot reaction); ion selective electrode
Chlorine	Colorimetric; membrane electrode; polarographic membrane; 3-electrode voltametric method
Conductance	Conductivity cell; annular ring electrode; nickel electrode; titanium or noble metal electrode
Dissolved oxygen	Membrane electrode; 3-electrode voltametric method; optical sensor
Ions (Cl-, NO3-, NH4+)	Ion-selective electrodes
ORP	Potentiometric; platinum or noble metal electrode
pH	Titration with sodium hydroxide; proton selective glass bulb electrode, proton selective metal oxide; ion sensitive field effect transistor (ISFET)
Phosphates	Manual or automated colorimetry
Temperature	Thermistor
TOC	UV-persulfate digestion with near infrared detection or membrane conductometric detection of CO2
Turbidity	Optical sensor; nephelometric (light scattering) method

Table 3 – Status of current techniques in monitoring waste water quality and their limitations

Parameter	Technique	Limitations
BOD	Non-specific sensor array (electronic nose)	Relationship is source/site specific and time dependent further development needed
BOD, COD	Oxidation by hydrogen peroxide with UV light	Limited range and long (~55 min) measurement times, range and correlation are source dependent
OD, COD, TOC, TSS, nitrates and anionic surfactants	UV spectral measurements and multivariate calibration	Sample handling is problematic, acquisition of reference spectra and calibration necessary for samples of different origin
BOD, nitrates, (TOC and COD)	Optical scattering (fluorescence)	Still in infancy, research needed, fluorescence affected by pH and temperature, correlation with BOD is plant sensitive.
BOD	UV adsorption (280 nm)	Poor sensitivity, uses only one wavelength, interferences from particles and toxic metals

Table 3 – Status of current techniques in monitoring waste water quality and their limitations

Parameter	Technique	Limitations
COD, TOC	UV adsorption	Immerged sensor (fouling), influence of suspended particulate material
RQ value	Off-gas analysis (CO2 and O2)	Does not distinguish C-oxidation from N-removal, only big changes in nitrification activity can be monitored
COD, NH4, NO3	Artificial neural network + multi sensor (pH, temp, conductivity, redox potential DO, turbidity)	Approximate estimation, training needed, problems in case of sudden changes in waste water composition, reliable for a short period only

4.3 Water sensing and early warning system

It is essential to provide scientific and technical bases for improved water surveillance capable of global and rapid detection of pollutants from accidents or malevolence in order to protect surface waters. Effective water sensing and an early warning system is the key point of ensuring the water resources safety and sustainable use. When there is a sudden abnormal change in water quality, the on-site monitoring units can detect this abnormality and the system can present early warnings as soon as possible, determine the measures to be taken based on the conditions so implementation of these measures can be done promptly. An advanced system can even give precautions based on the change of sensing data before any serious accidents happen. This kind of programme can lead to substantive benefits, as their actual cost is very low compared to the economic and social impacts of hazards which are not detected early enough to undertake adequate actions.

Early warning is "the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response", and is the integration of four main elements (from International Strategy for Disaster Reduction, United Nations, 2006):

1. Risk knowledge: Risk assessment provides essential information to set priorities for mitigation and prevention strategies and designing early warning systems.
2. Monitoring and predicting: Systems with monitoring and predicting capabilities provide timely estimates of the potential risk faced by communities, economies and the environment.
3. Disseminating information: Communication systems are needed for transmitting the monitoring data and delivering warning messages to the potentially affected locations to alert local and regional governmental agencies. These messages need to be reliable, synthetic and simple for the authorities and public to understand.
4. Response: Coordination, good governance and appropriate action plans are a key point in effective early warning. Likewise, public awareness and education are critical aspects of disaster mitigation.

The basic idea behind water sensing and early warning systems is that the earlier and more accurately short- and long-term potential risks associated with natural and human-induced hazards can be predicted, the more likely the disasters' impact on society, economies and the water environment can be mitigated and managed. The success of the entire system relies on every one of the four main elements listed above. For example, accurate warnings of hazards could not be made without accurate water-sensing data and effective risk assessment, while it will have no impact if the population is not prepared or if the alerts are received but not disseminated by the agencies receiving the messages.

Effective water sensing and early warning systems embrace the following aspects: water monitoring and sensing data communicating; risk analysis and predicting location and intensity of the disaster; alerts communicating to authorities and to those potentially affected; and responding to the disaster. The complete system has to address all aspects. Figure 1 shows the operational aspects of the water sensing and early warning system.

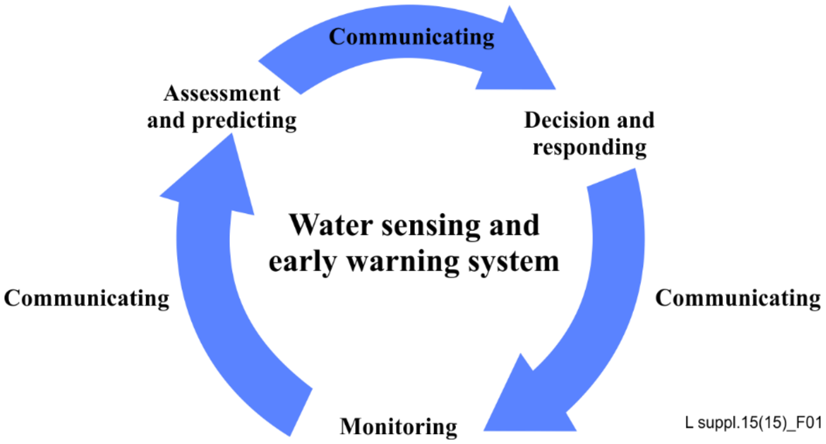

Figure 1 – Water sensing and early warning system operational aspects

5 Current sensing technologies

Accurate and timely water sensing is the starting point of an early warning system. Traditional methods of monitoring water quality require scientists to gather water samples at different monitoring sites on a timely basis and complete analyses in a lab, which consumes huge manpower needed to cover large areas of the water environment. Also the time-delay of measured results is significant which may not provide warnings of hazards in time. Various technologies were developed for measuring water quality parameters on-site automatically. The two major categories are based on optical methods and electrochemical methods. Optical methods usually measure the optical response changes related to the chemical or physical response of components in water. Electrochemical methods are usually based on the electrochemical reactions of chemical components in water and related electrical response changes. Other methods include mass spectrometry, electromagnetic waves, ultrasonic waves, etc.

5.1 Optical sensing technologies

Optical techniques for chemical and physical analysis have been widely used for water quality monitoring, and are authorized internationally as the official analytical method by the US EPA, Chinese GB Standards, Japanese Industrial Standards, etc. The basic principle is based on the characteristic light transmission, absorption or fluorescence spectrum of a chemical species being measured in order to determine its concentration or identity, e.g., UV-Vis (ultraviolet-visible) spectrophotometry, IR (infrared) spectrometry, ion chromatography and spectrofluorimetry. The impact of the recent revolution of optoelectronics is significant in reducing cost and improving the performance of optical components by the application of new materials and structures, along with new concepts in sensors technologies. Existing optical and spectroscopic techniques can be adapted using new optical components, such as fibre optics and optoelectronic devices, to form new miniaturised and low-cost sensors and optical instruments for water monitoring.

5.1.1 UV-Vis spectrophotometry

Standard spectrophotometry is the quantitative measurement of the reflection or transmission properties of a material as a function of wavelength, which is considered the main method for detection of many chemical species such as: ammonia, chlorine, chromium, iron, nitrate, phosphorus, sulfate. This technique is based on Beer-Lambert's law, which is the linear relationship between absorbance and concentration of an absorbing species. The general Beer-Lambert law is usually written as:

$$A = \lg \frac{I_0}{I} = \varepsilon \cdot l \cdot c$$

Where A is the measured absorbance, I is the light intensity after it passes through the sample and I_0 is the initial light intensity, ε is the wavelength-dependent molar absorptivity coefficient, l is the path length, and c is the analyte concentration.

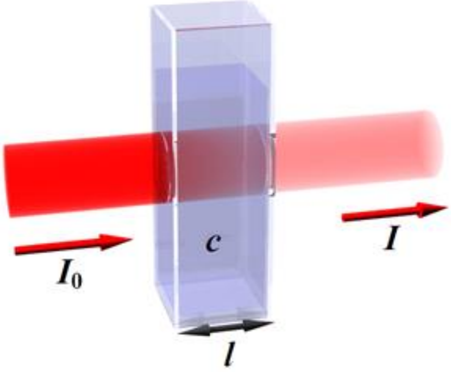

Figure 2 – Diagram of light absorbance

Spectrophotometry uses photometers that can measure a light beam's intensity as a function of its colour (wavelength). The most common spectrophotometers are used in the UV-Vis regions of the spectrum, and some of these instruments also operate into the near-IR region as well.

In this technique, a photo sensor measuring the wavelength of a distinct colour (e.g., blue) which results from a chemical reaction between the analyte species and special reagent is used. The concentration of the resultant dye indicates the concentration of the analyte species in the sample.

In the past UV-Vis spectrometric applications were often based on visual observation and direct comparison of the UV-Vis spectra, which required special training and skill sets, in addition to the equipment and samples-handling procedures. With the advancement of modern optoelectronics, photomultiplier and photodiodes are used in spectrometers to measure the light beam's intensity directly, thus making it possible to do online and continuous monitoring of a water environment.

Figure 3 shows an example of a commercial online colorimetric analyzer based on UV-Vis spectrometry. This instrument has three major operating components: a linear peristaltic pump to precisely control the volume of incoming samples and reagents; a colorimeter with a seal-free, solid-state mixing system that includes a self-cleaning stir bar; a supply of reagents (indicator and buffer). A zero reference point is established with the first sample in the cycle by measuring blank absorbance. This compensates for the sample's colour intensity and turbidity before the measurement is made. Then, indicator and buffer reagents are added to the sample while a magnetic stirrer mixes the solution and the sample changes colour. A compact colorimeter then measures the light transmitted through the sample. The measured colour intensity is compared to a reference standard. Finally, the sample cell is flushed with a new sample so that the cycle can repeat itself with the setting time intervals.

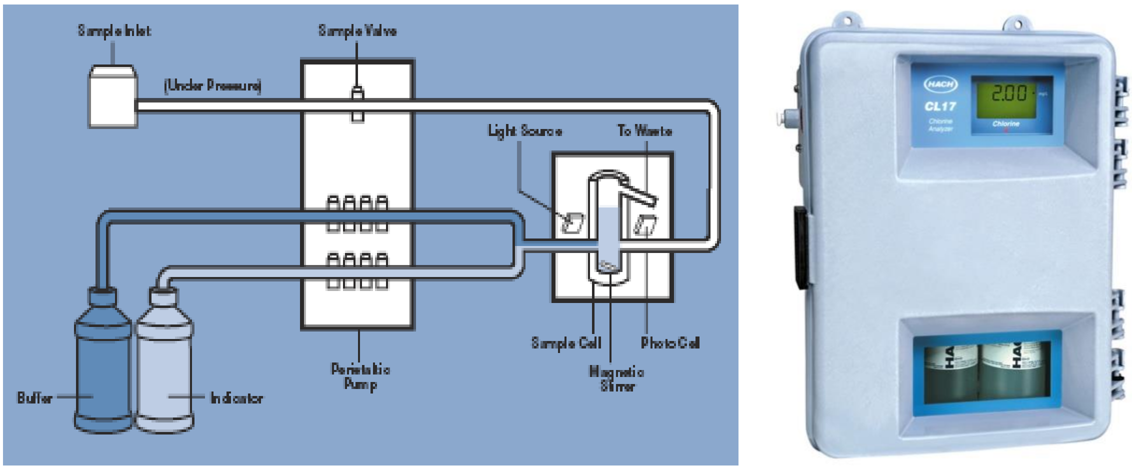

Figure 3 – Principle of operation of a commercial colorimetric water analyzer

UV-Vis spectrometry is based on non-contact measurement with light intensity, so it is convenient to design structures with better isolation protections used in a water environment. Its advantages also include high selectivity and sensitivity. However, most of UV-Vis spectrometry instruments measure the light intensity through the reaction of a specific indicator with the water sample, which requires continuous consumption of chemicals at a designated added amount. This increases the complexity of automated measurement instruments and long-term operational costs as well.

5.1.2 Fibre optic sensors for real-time water quality monitoring

Fibre optic sensors are used in combination with the UV-Vis methods for detection of water contaminants. Fibre optic systems are particularly suitable for harsh and difficult to reach places.

In a specific arrangement, light-emitting diodes (LEDs) have been employed in conjunction with these sensors for environmental monitoring. Common analytes for these LED-based sensors are nitrate/nitrite, ammonia, phosphorus, cations/metals and anions. LED-based chemical sensors have been developed for in situ monitoring of a variety of analytes with particular focus on phosphate and nitrate/nitrite/ammonia. The sensors mainly consists of three parts: light source, optrode (fibre optic) and detector. The main part of the sensor, the so-called optrode, contains an appropriate indicator which changes its optical properties in dependence on the analyte. In most cases, it is necessary to use an indicator because the analyte does not give or exhibit changes of optical properties. When the light source is matched to the analytical wavelength of the indicator, the best sensitivity of the sensor is achieved. The detector, usually a photodiode, converts the optical signal into an electric signal to be processed electronically. For example, a multi-parameter fibre optic probe was designed to test drinking water. The probe consists of pH, temperature and calcium ions sensors, which are based on measuring the absorbance changes of an appropriate reagent. The sensors are combined in a form of the head made from Teflon. LEDs are used as light sources and they are matched to maximum absorbance of the reagents.

In an alternative setup, an optic fibre is suitably doped to produce luminescence when exposed to an excitation light source. In principle, glass fibres are either doped with a rare earth metal or activated with a transition metal. Polymeric fibres are doped with a dye. The design and selection of the fibre determines the peak wavelength of the output illumination; options exist to span the UV-Vis-NIR spectrum. And the coating of the fibre determines the sensitivity and selectivity of the sensor.

5.2 Electrochemical sensing technologies

Electrochemical methods, such as amperometric, potentiometric and conductometric sensing approaches are widely used in the measurement of pollution in water. Electrochemical sensors change their properties as a result of interaction with the component being measured. The species of interest are either oxidized or reduced at the working electrode causing a transfer of electrons, thus generating a measureable signal. This change can be digitized and recorded as a change in the output signal which can further be mapped to an output voltage, current, change in conductivity, capacitance or dielectric constant or any parameter that gives a noticeable sensor response. They have the important advantages of not requiring chemical consumables and also provide a truly continuous read-out of concentration because they can be used in flow-through mode. Less maintenance is required than the optical method, such as the colorimetric method.

Amperometric detection is based on the measurement of current when a potential is applied to the working and reference electrodes of the system. Generally, the amperometric method detects the concentration of a chemical species by measuring the current between a pair of electrodes in response to an applied voltage. According to Faraday's law, the total charge is directly proportional to the amount of species undergoing a loss (oxidation) or gain (reduction) of electrons, while the current is the change in electric charge as a function of time.

$$I = \frac{dQ}{dt} = nF\frac{dk}{dt}$$

where Q is the total charge generated in coulombs, n is valence number of the species, F is Faraday's constant (96487 coulombs/mol), and k is number of the species undergoing oxidation or reduction in moles, which is proportional to its concentration[*].

Amperometric sensing technologies are very sensitive with high selectivity. They are often used for real-time water quality monitoring because of low maintenance requirements and a fast response. Figure 4 shows an example of a commercial amperometric sensor probe and meter for chlorine measurement in water developed. It can measure chlorine continuously with a low limit of detection, 5 µg/L. Since the sensor probe is usually placed in contact with the water sample and electrochemical reactions take place at the electrode-electrolyte interface, the lifetime of a sensor probe is often a serious issue, while the drift of measurement results also becomes serious in many cases. Timely calibration is required for this kind of sensor.

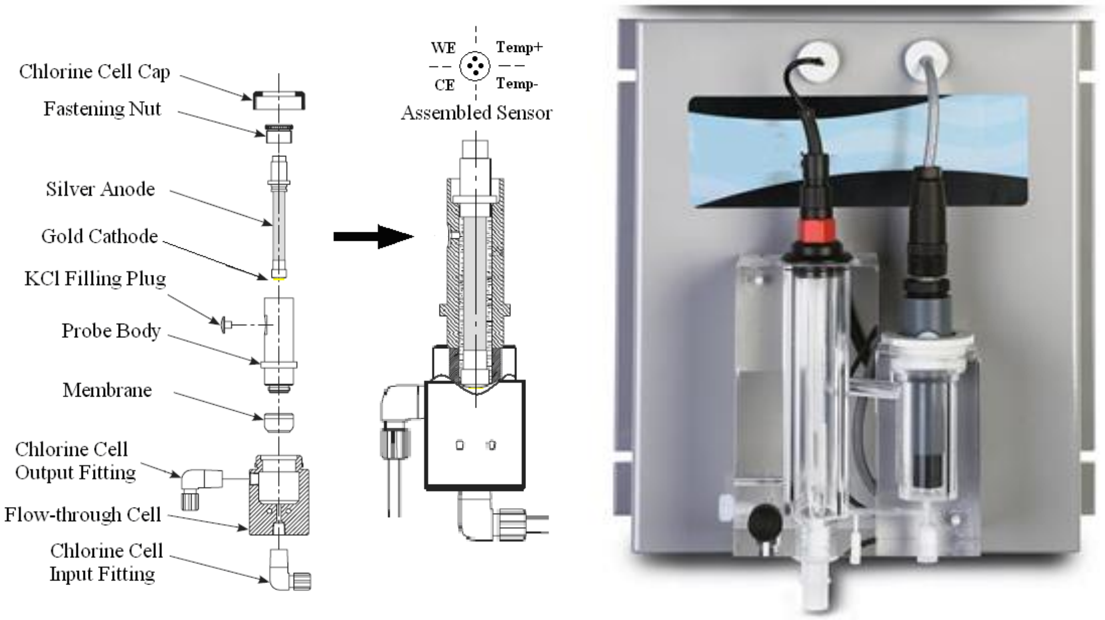

Figure 4 – Example amperometric sensor probe and meter

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[*] For a low concentration electrolyte, 1 ppm≈(1000*molar mass* moles/L).

Potentiometric detection is also attractive since it possesses numerous advantages when considering the development of real-time sensing technologies, as the recording instrumentation is cost-effective and highly portable. The sensor usually consists of two electrodes, one working electrode and one reference electrode. For such a redox reaction

$$O + ne^{-} \Leftrightarrow R$$

where O and R are the oxidized and reduced forms of the analyte. The potential of the electrode *E* is defined as the potential difference between the electrode and the bulk electrolyte. Electrode potentials can be used to establish the concentration of the analyte species at the electrode surface according to the Nernst equation:

$$E = E^{\circ} + \frac{RT}{nF} \ln \frac{C_O}{C_R}$$

Where E° is the standard potential for this redox reaction, C_O and C_R are the concentrations for O and R at the electrode surface. By measurement of the electrode potential, the concentration of specific chemicals can be obtained.

Compared to amperometric measurement, there is no current flow through the electrode and only electrode potential is measured. Thus the sensor structure is usually simpler and easier to fabricate. Many ion-selective electrode based on potentiometric detection are used for online monitoring water parameters, such as pH, chloride, fluoride, nitrate and metal ions.

5.3 Mass spectrometry for water micro-pollutants

Mass spectrometry (MS) is an analytical chemistry technique that helps identify the amount and type of chemicals present in a sample by measuring the mass-to-charge ratio and abundance of gas-phase ions.

In a typical MS procedure, an electron is ejected from the molecules by the ionizing electron beam and passed through an electrical field to accelerate them to a uniform velocity. These ions are then passed through a magnetic field. Moving charges are deflected by a magnetic field, with low mass ions being defected more than heavy mass ions. The force is constant because they all have a single charge but momentum is greater for the heavier ions. These ion positions are recorded as they strike the detector and a spectrum with mass on the x-axis is recorded. Mass spectra give information on the molecular weight, formula and the substructures that are present.

Liquid chromatography mass spectrometry (LC-MS) is often used in water analysis. Based on the combination of chromatography and mass spectrometry, LC-MS is a powerful technique that has very high sensitivity and selectivity and thus, is useful in many applications. Its application is oriented towards the separation, general detection and potential identification of chemicals of particular masses in the presence of other chemicals (i.e., in complex mixtures), e.g., natural products from natural-products extracts, and pure substances from mixtures of chemical intermediates. The typical application of LC-MS in water analysis includes analysis of pesticide residue, organic components, microcystins and various toxins.

5.4 Sensors based on sound and electromagnetic field interaction

5.4.1 Ultrasonic measurement

Ultrasonic and radar sensors are used whenever there is a risk of damage or burial to in-situ instruments or where silt is a problem. These sensors are highly accurate, robust and low powered and offer many advantages. Ultrasonic and radar level sensors have no moving parts and provide a non-contact method of measurement. Radar sensors can have large operating ranges (>60 meters), however they are more often used in flood warning systems since they can be mounted high up to provide continuous data even in the most extreme flood events. Figure 5 presents a typical commercial water quality station.

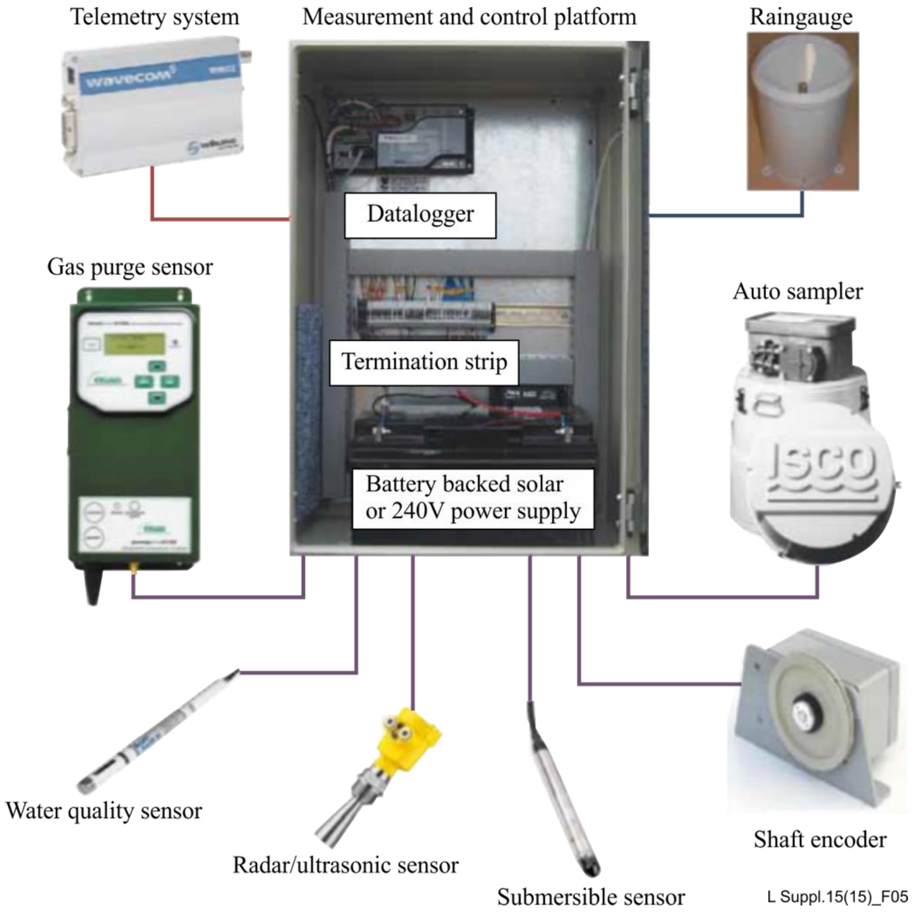

Figure 5 – Typical water quality station equipment

In principle, the ultrasonic technique is a non-destructive and non-invasive method capable of the rapid characterization of systems, which are concentrated and optically opaque. Ultrasonic technique is sensitive to particles with a radius of between about 10 nm and 1000 mm. The propagation of ultrasound in a fluid is affected by its density, compressibility, temperature and composition.

5.4.2 Electromagnetic waves sensor

One of the most successful attempts to use electromagnetic sensing as a method for the detection of nitrates and contamination in natural water sources have been recently reported, where the combination of meander and interdigital planar electromagnetic sensors for monitoring the level of contamination in water sources were used.

Two types of meander and interdigital planar electromagnetic sensors combined in series are used. An external function generator is used to provide an alternating 10 Volt peak-to-peak sine waveform signal. The sensor consists a spiral meander planar turns surrounding (each turn is distanced at 0.5 mm) the interdigital sensor. The sensor is connected to the function generator which provides the signal. A magnetic field is created around the meander sensor while an electric field is generated within the region of the interdigital sensor. Thus, the combination of magnetic and electric fields forms an electromagnetic field which passes through material under test and changes the impedance of the sensor.

Electromagnetic waves sensors are still at an early stage; however, they provide a very promising technique for detecting waste and anomalies in water systems.

5.4.3 Microwave sensing

Microwave sensing is a novel technology which has been successfully used as a sensing method for various industrial applications including water solution concentrations, water level measurements, other applications in the healthcare industry, and process operations monitoring.

The principle of sensing properties of water and its composition relies on the ability of the electromagnetic waves to penetrate (in the GHz region) the water and interact with it subject to its properties. Contaminations can change the permittivity of the water which in turn will affect the attenuation and reflection of the electromagnetic waves in the water sample.

5.5 Further challenges and possible solutions in developing real-time water monitoring platform

To achieve adequate simultaneous detection of various water parameters, the current industry trend is to use a sensor array containing more than one type of sensor. Requirements include the need for robustness, reliability, energy efficiency, high sensitivity and selectivity and high accuracy; to be able to detect low level of traces with high confidence level and minimum sample preparation than before, to allow the detection of minute quantities of pollutants with high confidence and minimum sample preparation.

It is usually required to map the spatial and temporal distribution of pollutants and locate them automatically. Distributed sensor networks can be used to achieve this purpose. However, an extra layer of control is needed to guarantee the seamless fusion of the sensor data. One major concern that hinders the sustainability of stationary water sensors, is the issue of bio-fouling. Accordingly, efforts in developing non-invasive techniques and mobile sensing methods, in addition to mitigation against bio-fouling issues need to be addressed.

Real-time monitoring of waste water quality provides a potential opportunity. However, associated with these techniques, are the needs for efficient powering and wireless connectivity that can resist channel impairments.

The advancement of microelectronics and microsystem devices brings great opportunities for improving water monitoring techniques and platforms. They usually come with advantages like low power consumption, small size, integrated control and data processing unit, wireless communication capabilities. For example, opto-chemical sensors or optodes are an attractive alternative to current electrochemical or electronic devices in terms of monitoring water, which is a suitable tool for the detection of a large number of chemical parameters. Optochemical sensors for parameters like oxygen, pH, carbon dioxide, and ammonia are reportedly available in the market or nearing the point of commercialization.

6 Early warning systems

Water monitoring is just the first step of an early warning process, which provides the input information for the entire system. This information gives the possibility of taking action to make predictions and initiate mitigation or security measures before a catastrophic event occurs. When monitoring and predicting systems are associated with communication systems and response plans, they are considered early warning systems.

To be effective, warnings must be timely to provide enough lead-time for responding; be reliable, so that those responsible for responding to the warning will feel confident in taking action; and simple, in order to be understood. Timeliness often conflicts with the desire to have reliable predictions, which become more accurate as more observations are collected from the monitoring system. Thus, there is an inevitable trade-off between the amount of warning time available and the reliability of the predictions provided by the system. An initial alert signal may be sent to give the maximum amount of warning time when a minimum level of prediction accuracy has been reached. However, the prediction accuracy for the location and size of the event will continue to improve as more data are collected by the monitoring part of the system network. It must be understood that every prediction, by its very nature, is associated with uncertainty.

Because of the uncertainties associated with the predicted parameters that characterize the incoming disaster, it is possible that a wrong decision may be made. Two kinds of wrong decisions may occur: missed alarm (or false negative), when mitigation action is not taken when it should have been or false alarm (or false positive), when mitigation action is taken when it should not have been.

Finally, the message should communicate the level of uncertainty and expected cost of taking action but it should also be stated in simple language so as to be understood by those who receive it. Most often, there is a communication gap between specialists who use technical and engineering language and the system users who are generally outside of the scientific community. To avoid this, these early warnings need to be reported concisely, in layman's terms and without scientific jargon.

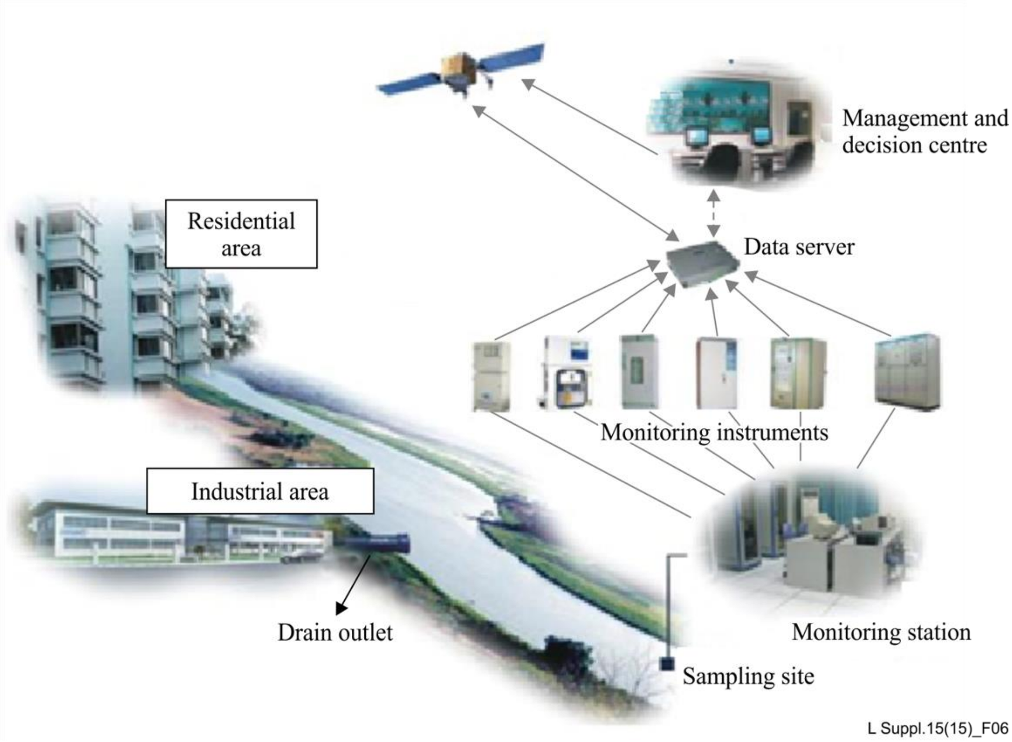

Figure 6 – Typical water sensing and early warning system

6.1 Predicting and decision making

It is very common that measurement is difficult, but obtaining the correct result and making valid predictions is even more difficult. Current early warning systems often utilize technologies such as geographic information system (GIS), neural network models, chemometrics, etc., to make warning predictions with the obtained water monitoring data.

The complexity of datasets obtained in water quality monitoring, which is required for the application of advanced chemometric and natural computing techniques, is preferentially combined in a system of database management tools, and tools to process heuristic knowledge. Such systems are referred to as data mining for which software is becoming readily available. The complexity and large amount of water environmental data is a real challenge to the chemometrician and environment professionals.

There are three main types of chemometric multivariate techniques: classic linear statistical analysis including multivariate statistics, multivariate regression approaches for time dependent variables, and geostatistical approaches for space dependent variables, neural network approaches, and fuzzy logic approaches. These tools are available for specific demonstrations in the field of water quality monitoring either for time dependent or space dependent parameters. The range of application fields is large and the parallel development of sensor arrays of spectral signal sensors increases the interest of these efficient numerical tools. To derive virtual or integrated parameters directly available for decision making, from large and complex datasets, the optimal combination of phenomenological, statistical, neural and fuzzy approaches seems very attractive for future research and development in the field of measurement and testing or in the field of advanced technologies.

To improve the performance of early warning systems, a performance based decision making procedure needs to be based on the expected consequences of taking action, in terms of the probability of a false or missed alarm.

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It is most useful where teams of people are working on complex problems, especially those with high stakes, involving human perceptions and judgments, whose resolutions have long-term repercussions. It has unique advantages when important elements of the decision are difficult to quantify or compare, or where communication among team members is impeded by their different specializations, terminologies or perspectives.

Decision situations to which the AHP can be applied include:

- Choice – The selection of one alternative from a given set of alternatives, usually where there are multiple decision criteria involved.
- Ranking – Putting a set of alternatives in order from most to least desirable.
- Prioritization – Determining the relative merit of members of a set of alternatives, as opposed to selecting a single one or merely ranking them.
- Resource allocation – Apportioning resources among a set of alternatives.
- Benchmarking – Comparing the processes in one's own organization with those of other best-of-breed organizations.
- Quality management – Dealing with the multidimensional aspects of quality and quality improvement.
- Conflict resolution – Settling disputes between parties with incompatible goals or positions.

The applications of AHP to complex decision situations have numbered in the thousands, and have produced extensive results in problems involving planning, resource allocation, priority setting, and selection among alternatives. Other areas have included forecasting, total quality management, business process re-engineering and quality function deployment.

6.2 Communication of information

An effective early warning system needs an effective communication solution. It should have two main components: communication infrastructure hardware that must be reliable and robust, especially during a disaster; and appropriate and effective interactions among the main actors of the early warning process, such as the scientific community, stakeholders, decision makers, the public, and the media.

Redundancy of communication systems is essential for disaster management, while emergency power supplies and back-up systems are critical in order to avoid the collapse of communication systems after a disaster occurs. In addition, to ensure the communication systems operate reliably and effectively during and after a disaster occurs, and to avoid network congestion, frequencies and channels must be reserved and dedicated to disaster relief operations.

Many communication tools are currently available for warning dissemination, such as short message service (SMS), e-mail, radio, TV and web services. Information and communication technology (ICT) is a key element in early warning, which plays an important role in disaster communication and disseminating information to organizations in charge of responding to warnings and to the public during and after a disaster.

Currently, the decentralization of information and data through the World Wide Web makes it possible for millions of people worldwide to have easy, instantaneous access to a vast amount of diverse online information. This powerful communication medium has spread rapidly to interconnect our world, enabling near-real-time communication and data exchanges worldwide. According to the Internet World Stats database, as of December 2011, global Internet users were documented at 2.3 billion people. Thus, the Internet has become an important medium to access and deliver information worldwide in a very timely fashion. In addition, remote sensing satellites now provide a continuous stream of data. They are capable of rapidly providing authorities at every level, and the general public with high-quality and scientifically credible information in a timely fashion.

The dissemination of warnings often follows a cascade process, which starts at the international or national level and then moves outwards or downwards in scale to regional and community levels. Early warnings may activate other early warnings at different authoritative levels, flowing down in responsibility roles, although all are equally necessary for effective early warning.

Standard protocols play a fundamental role in addressing the challenge of effective coordination and data exchange among the actors in the early warning process; they aid in the process for warning communication and dissemination. The common alerting protocol (CAP), really simple syndication (RSS) and extensible markup language (XML) are examples of standard data interchange formats for structured information that can be applied to warning messages for a broad range of information management and warning dissemination systems.

The advantage of standard format alerts is that they are compatible with all information systems, warning systems, media, and most importantly, with new technologies such as web services. CAP, for example, defines a single standard message format for all hazards, which can activate multiple warning systems at the same time and with a single input. This guarantees consistency of warning messages and would easily replace specific application-oriented messages with a single multi-hazard message format. CAP is compatible with all types of information systems and public alerting systems (including broadcast radio and television), public and private data networks, multilingual warning systems and emerging technologies such as Internet web services and existing systems such as the U.S. National Emergency Alert System and the National Oceanic and Atmospheric Organization (NOAA) weather radio. CAP uses XML, which contains information about the alert message, specific hazard event, and appropriate responses, including the urgency of action to be taken, severity of the event, and certainty of the information.

6.3 System policy

For early warning systems to be effective, it is essential that they be integrated into policies for disaster mitigation. Good governance priorities include protecting the public from disasters through the implementation of disaster risk reduction policies. It is clear that natural phenomena cannot be prevented, but their human, socio-economic and environmental impacts can and should be minimized through appropriate measures, including risk and vulnerability reduction strategies, early warning, and appropriate action plans. Most often, these problems are given attention during or immediately after a disaster. Disaster risk reduction measures require long-term plans and early warning should be seen as a strategy to effectively reduce the growing vulnerability of communities and assets.

The information provided by early warning systems enables authorities and institutions at various levels to immediately and effectively respond to a disaster. It is crucial that local government, local institutions and communities be involved in the entire policy-making process, so they are fully aware and prepared to respond with short and long-term action plans.

The early warning process, as previously described, is composed of four main stages: water monitoring and sensing data communicating; risk analysis and predicting location and intensity of the disaster; alerts communicating to authorities and to those potentially affected; and responding to the disaster. Within this framework, the short- and long-term actions plans, laid out based on risk assessment analysis, are the realm of institutional and political actors. The system acquires a technical dimension in the monitoring and predicting phase, while in the communication phase, early warning involves both technical and institutional responsibility. The response phase then involves many more sectors, such as national and local institutions, non-governmental organizations, communities and individuals.

Below is a summary of recommendations for effective policies within the early warning process:

Prediction is insufficient for effective decision making

Prediction efforts by the scientific community alone are insufficient for decision making. The scientific community and policy makers should outline the strategy for effective and timely decision making by indicating what information is needed by decision makers, how predictions will be used, how reliable the prediction must be to produce an effective response, and how to communicate this information and the tolerable prediction uncertainty so that the information can be received and understood by authorities and the public. A miscommunicated or misused prediction can result in costs to society. Prediction, communication and use of the information are necessary factors in effective decision making within the early warning process.

Develop effective communication strategies

Wishing not to appear 'alarmist' or to avoid criticism, local and national governments have sometimes kept the public in the dark when receiving technical information regarding imminent threats. The lack of clear and easy-to-use information can sometimes confuse people and undermine their confidence in public officials. Conversely, there are quite a few cases where the public may have refused to respond to early warnings from authorities, and have therefore exposed themselves to danger or have forced governments to impose removal measures. In any case, clear and balanced information is critical, even when some level of uncertainty remains. For this reason, the information's uncertainty level must be communicated to users together with the early warning.

Establish proper priorities

Resources must be allocated wisely and priorities should be set, based on risk assessment, for long- and short-term decision making, such as investing in local early warning systems, education, or enhanced monitoring and observational systems. In addition, decision-makers need to be able to set priorities for timely and effective response to a disaster when it occurs based on the information received from the early warning system. Decision-makers should receive necessary training on how to use the information received when an alert is issued and what that information means.

Clarify responsibilities

Institutional networks should be developed with clear responsibilities. Complex problems such as disaster mitigation and response require multidisciplinary research, multi-sector policy and planning, multi-stakeholder participation, and networking involving all participants of the process, such as the scientific research community (including social sciences aspects), land use planning, environment, finance, development, education, health, energy, communications, transportation, labour, and social security and national defense. Decentralization in the decision making process could lead to optimal solutions by clarifying local government and community responsibilities.

Collaboration will improve efficiency, credibility, accountability, trust, and cost-effectiveness. This collaboration consists of joint research projects, sharing information, and participatory strategic planning and programming.

Establish and strengthen legal frameworks

Because there are numerous actors involved in early warning response plans (such as governing authorities, municipalities, townships, and local communities), the decision making and legal framework of responsibilities should be set up in advance in order to be prepared when a disaster occurs.

7 Conclusions

Water is one of the basic elements supporting life and the natural environment, a primary component for industry, a consumer item for humans and animals and a vector for domestic and industrial pollution. Effective water monitoring and an early warning system would bring great economic and social benefits to humanity.

This Supplement summarized the requirements for building water sensing and early warning systems. The market needs for future water sensing and early warning systems are greater confidence in the data, better reliability, better sampling, lower skill requirements, lower cost of ownership, valid and timely prediction of possible hazards, better communication of data and warning information, etc.

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