Second Generation Water Monitoring Using Biological Early Warning Systems and Biological Assays

Currently water monitoring is performed according to EU Directives and National laws and is organised in temporal sampling and analysis of contaminants. Over several decades a wide range of tools, commonly called biosensors, have been developed for monitoring water quality. These devices can produce an early warning, a precocious alarm that can be used for sampling the "same" water that produces the warning; furthermore, this water sample can be used for biological assays, including biomarkers and ecotoxicology tests that provide extremely useful information on classification of pollutants.

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Biological early warning systems

Changes in the behaviour or properties of on-line biological early warning systems (BEWS) may indicate the sudden occurrence of a pollutant not detected by conventional, analytical warning systems (ILSI, 1999).

The goal of an early warning monitoring system is to reliably identify low probability/high impact contamination events (chemical, microbial or radioactive) in source water or distribution systems, in time to allow an effective local response that reduces or avoids entirely the adverse impacts that may result from the event (ILSI, 1999).

In long-term monitoring, the water quality is usually well known and so in this case expensive analysis costs may not prove to be cost effective; conversely, funding of early warning system could be effective.

As stated by ILSI (1999), the ideal EWS has these requirements:

1. Provides warning in sufficient time for action
2. Cost is affordable
3. Requires low skill and training
4. Covers all potential threats
5. Is able to identify the source
6. Is sensitive to quality changes at regulatory levels
7. Gives minimal false positive or negative responses
8. Is robust
9. Is reproducible and verifiable
10. Allows remote operation
11. Functions year-round

One single device alone, may not provide a good early warning system. In particular, requirements 1, 5 and 6 are very difficult to have together and 7, 9 and 11 are difficult to have with a biosensor. Requirement 1, 3, 8 and 10 need an engineering development, whereas 2 is only possible if the technologies are widely used in a public organisation having a leading role in and managing an early warning system network (EWSN). A EWSN may be useful for homogeneous environments such as for rivers and coastal areas.

Biosensors

A biosensor is an instrument that continuously records an organism's behavioural and/or physiological response, and evaluates changes that could indicate pollution in the environment. These systems have several advantages and have been developed to fulfil any monitoring needs for a wide range of organisms. Furthermore because biosensors directly measure toxic effects, it provides an important tool to use in association with chemical monitoring technology. Biological measures of water quality can detect unexpected materials and evaluate the toxic effect of multiple chemicals. (EPA, 2001).

Epidemiological studies of drinking water will always address mixtures of agents and are unlikely to be able to identify which specific components of a mixture are associated with any adverse effect that might be identified (ILSI, 2002).

Depending on expected pollutants, biosensors can use the most suitable organism, as fish, bivalves and crustaceans are more sensitive to different classes of chemicals. Every organism provides a specific behavioural response to pollution, such as a change of position and movement in fish or a long closure of valves in bivalves.

View of instrument and accessories (left – ph. DeltaConsult®) and top view (right – ph. Brunelli) of Mosselmonitor®

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For example, the Dutch Mosselmonitor® is a biosensor that uses bivalves (Anodonta sp. in freshwater or Mytilus galloprovincialis in brackish water) for a qualitative detection of water quality; the frequency of movements of the animal is recorded and elaborated upon (Allan et al, 2006; USEPA, 2005). This instrument has been designed in Europe and other similar instruments have been designed elsewhere (ILSI, 1999).

A range of real-time toxicity monitoring instruments using living organisms, for example; daphnia, algae and fish, are commercially available from the German BBE Moldaenke®, DaphTox II®, Algae Toximeter® and Fish Toximeter®, using the respective organisms.

Water monitoring system using biological early warning systems

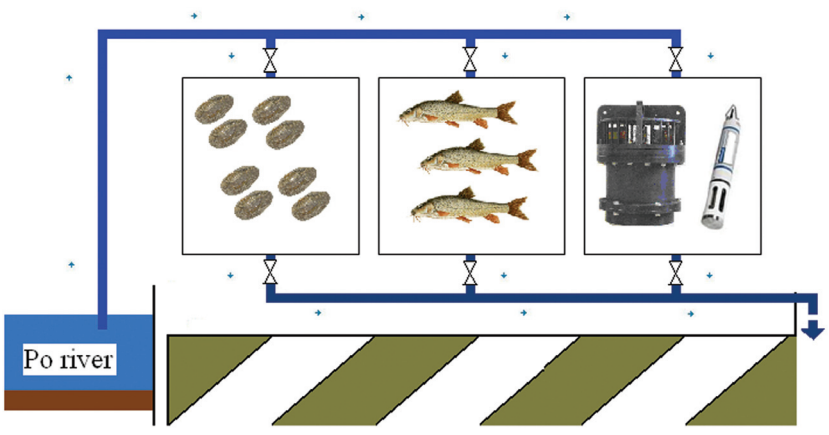
This water monitoring system using a biosensor, a probe for measurement of physio-chemical parameters, an electronic controller and a water-sampler. Exposure of fish or other organisms is also useful for testing an organisms' health status. This set-up has been designed in order to provide a full capability in water monitoring. During my 10year experience, I used Mosselmonitor®, as biosensor (valve opening measurement every 10"), Hydrolab® DataSonde®, as probe (one recording per hour: temperature, dissolved oxygen in % and mg/L, and pH), Logosens® as datalogger (data/alarm evaluation every 5') and ISCO® 6700 as water-sampler. When an alarm occurs, the datalogger enable the water sampler to send an SMS to an operator for sampling analysis. Data and alarm are available on a remote PC, using the GSM module installed with Logosens.

Although highly effective, this is only one of the many possible set-ups and for every application a suitable combination of one or more biosensors as well as instruments and facilities should be carefully evaluated.

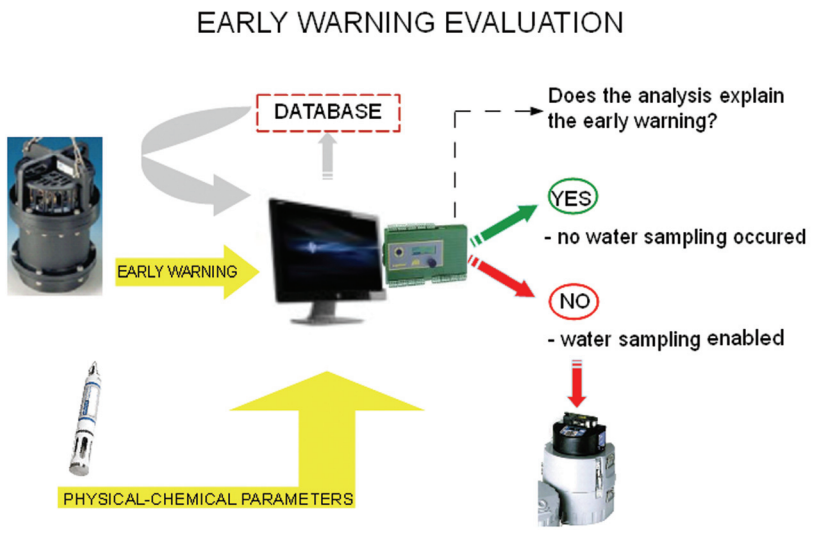
The functioning of biosensors should be recorded in every new location and disturbances, as well as anthropic "noise", should be acquired during the "monitoring station's calibration", in order to not include these in the evaluation of alarm.

The data acquisition, storage and processing have to be performed by an automatic device using software for data and alarms management. The procedure for "early warning evaluation" is designed on the basis the type of water body (river, lagoon, lake, and sea), type of water (freshwater, brackish water, seawater) and target of monitoring (food production, drinking water surveillance). The early warning evaluation is shown in the following figure.

DaphTox II® (left) and Fish Toximeter® (right).



The set-up for the monitoring of the Po river in Italy.



Biosensors and automatic water quality instruments for example; probes for T, DO, produce a sample of the same water that produced the alarm. The water sample will be analysed in a laboratory.

Biological assays

The water sample provided by early warning system is highly probable to include pollutants. As for the target of monitoring, several assays can be performed: biomarkers, ecotoxicology and bioaccumulation. There are a wide range of categories of assays and here a brief introduction is provided.

Biomarkers are short term effects on biological system, able to quickly provide information on the presence of pollution into the water. The biomarkers can be investigated on the same species hosted in the biosensor, as well as on other organisms. Ecotoxicology includes methodologies for evaluation of toxicity of the sample of water in 12, 24, 48 or 96 hours (acute test) or several days (chronic test). The assay can be designed for use on several organisms.

Bioaccumulation means of chemical analysis of tissue and organs of fish, bivalve or other animals, in order to measure the accumulation of pollution going through the food chain. Often these tests use muscle and liver, because these are easy to sample (muscle) and are widely related to exposure to pollutants (liver).

These three methodologies provide a full range of tools for evaluation of short-term and long-term effects on organisms, as well as providing huge information on environmental quality.

The choice of residential organism (bivalve) or an easy technical solution (caged fish) aims to improve the level of investigations and to improve the link between results of biological assays and ecological status of environment.

Applications

The proposed approach was widely tested in the basin (70,000 km^2) of Po river, the longest (650km) Italian river that has 141 tributaries and flows into Adriatic sea, south, to Venice. Applications were developed for drinking water surveillance, aquaculture and biodiversity conservation, both in river waters and coastal brackish lagoons.

A more reliable evolution of this system, is its use in a mobile laboratory; all devices are installed in a 6m long container and the water inlet/outlet are managed depending on application. This solution can be located in every monitoring site and also far from power lines! In addition this can be managed remotely (Brunelli, 2011).

BOX 1: How to design your monitoring system

water:	☐ freshwater	☐ brackish	☐ seawater
target of monitoring:	☐ drinking water	☐ aquaculture	☐ biodiversity conservation
human activities:	☐ low	☐ medium	☐ high
links with public authorities:	☐ yes	☐ no	
links with universities or EPA:	☐ yes	☐ no	
consulting:	☐ yes (design)	☐ yes (monitoring strategy)	☐ no
training:	☐ required	☐ not required	

BOX 2: Financing your new monitoring system

This kind of monitoring system is an innovation for many European areas. The use of this system can be funded in the framework of EU projects on environmental and/or innovative solutions, also in association with public bodies or universities. Where applicable, this approach can be used for an improvement of sustainability of food productions (aquaculture) and in public-private partnerships (water cycle management).

Literature

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