Surveillance of Drinking Water Resources with Biosensors. Use of a Mobile Laboratory in Ferrara (Italy).

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The Po, the longest (650 km) Italian river, has 141 tributaries and flows into Adriatic sea, southern to Venice; its basin (70.000 km2) is densely populated (16 million people) and collects waters from the northern regions of Italy and includes many Natura 2000 sites. The town of Ferrara (130,000 inhabitants) is located 50 km far to the sea and its drinking water plant has 80% of water intake from the Po river. In this plant an innovative monitoring system, located into a Mobile Laboratory (ML), is built by a biosensor (Mosselmonitor®), a multi-parameter probe and a water sampler. A software elaborates data and, if an alarm occurs, enables the water-sampler. Four types of alarm have been detected, as a clear correspondence between a “noise” and a reproducible behaviour of bivalve. The good relationship between alarm and physic-chemical measured values for some types of alarm is a result of this experiment and proves the capability of this approach; in fact biosensors and automatic instruments can be used to produce a sample of the same water that produced the alarm.

On water samples many types of assay can be performed, such as biomarker, ecotoxicology and bioaccumulation, on bivalves, fishes or other organisms. All data and alarms are available by a remote control and are represented on the web. The ML has been realised in order to be able to identify variations of the quality of the water that enters into the drinking water plant (DWP) of Ferrara (Italy). The target is to improve the water monitoring by the detection of “new” pollutants (such as endocrine disruptors), supporting the monitoring of Environmental Agencies (also creating a network of automatic instruments) and the protection of health of people. The solution described, including only commercial modules, is widely replicable. The information on pollutants not included in the mandatory monitoring, are used for risk assessment on food chain and biodiversity conservation.

The project has been performed by ATO (waste and water cycle public Authority) in association with ARPA (Emilia-Romagna Regional Environmental Agency) and HERA S.p.A., the owner of drinking water plant.

Key words: EWS, biosensor, Po river, water surveillance, water quality

Introduction

The Po, the longest (650 km) Italian river, has 141 tributaries and flows into Adriatic sea, southern to Venice; its basin (70.000 km2) is densely populated (16 million people) and includes many Natura 2000 sites. The town of Ferrara (130,000 inhabitants and recognized as a UNESCO world heritage site) is located 50 km far to the Adriatic Sea and is the last town before the delta of the river. The drinking water plant is managed by HERA (a private company, with public participation), the 80% of water intake came from the Po river and the gross production is roughly 30 million m3. The ATO Ferrara is a public authority in charge for water cycle (potabilization and depuration) and waste disposal in the province of Ferrara and decides the standards for the processes and the prices of products and services.

On 2010 ATO, ARPA (Emilia-Romagna Regional Environment and Prevention Agency) and HERA have developed an innovatory system for the monitoring of water for human use and this paper presents the results of the first year of work. The research aims to monitor the river water, to detect emergency situations and, where appropriate, to sample the same water that produced the alarm. This approach has been widely used in Europe [ILSI, 1999] and USA [USEPA, 2001] and in this work we use a modern system, that includes automatic water sampling and an alert system, used to communicate to operators that a water sample has been collected.

Automated biomonitoring systems continuously record an organism’s behavioural or physiological response and evaluate change that could indicate developing toxic condition. These systems have several advantages relative to sole reliance on chemical monitoring and have been developed for a wide range of organisms and to fulfil any monitoring needs; furthermore, because automated biomonitoring systems directly measure toxic effects, they provide 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 mixtures of multiple chemicals [EPA, 2001].

Selection of an automated biomonitoring system for this project fits local regulatory and public concerns over the potential effects of contaminants on animals and humans in the Po river and in drinking water.

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 causally associated with any adverse effect that might be identified [ILSI, 2002]. Changes in the behaviour or properties of on-line biological early warning systems (BEWS) may indicate the sudden occurrence of a pollutant not detected in 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, 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].

Materials and Methods

Mobile Laboratory

A mobile laboratory (ML) has been realised in order to identify variations of the quality of the water that enters into the drinking water plant (DWP) of Ferrara (Italy). The ML support actual and
future needs in drinking water surveillance, specially for the
development of sensors and systems for the detection and health
evaluation of “new contaminants”; into the ML the variability of the
environmental conditions are reduced and then some experi-
mental variables are negligible. The ML is furnished of air condi-
tioning, several types of water supply (raw water from the river
and water after any step of the water purification process) and
can host any type or field/laboratory device. The ML is located
near the “sedimentation” step of the DWP (Figure 1), because has
been estimated to work, in long term, with the water before and/or
after this stage. As specifically said before, any type of water
can be used for monitoring and experiments and, as well,
different biological assays can be carried out simultaneously.

Figure 1: scheme of the drinking water plant of Ferrara and location of the Mobile Laboratory (reproduced by permission of HERA)

Figure 2 shows the block scheme of the ML: in different basins it
is possible to install animals (bivalves or fishes) and instruments. The water discharged by the
ML goes to purification.

Complex System
The Complex System (CS) includes a biosensor, Mosselmonitor®, a probe for measuring of water physico-chemical parameters (HydraData®), a semi-automatic water sampler (ISCO® 6700) and an electronic module (Logosens®) for data acquisition and communication [Brunelli, 2011]. This CS, hosted in a 6 meters container (the Mobile Laboratory - ML), is built with commercial components, so in other application, every item can be substituted with others or existing one.

biosensor
The Mosselmonitor (see Figure 3) is a biosensor that uses bival-
ves for a qualitative detection of water quality; the frequency of
movements of the animal is recorded and elaborated [Kramer,
1989; Kramer, 1991; Allan et al, 2006; USEPA, 2005]. The instru-
ment gives 4 types of alarms: 2 on frequency of movements (A-
amalous increase and D-anomalous decrease) and 2 on position
of animals (C-prolungated closure and G-gaping, complete
opening corresponding to death of animals).
The biosensor’s alarms are interpreted according to the applica-
tion and then to the environment (river, lagoon,...) and biota (a
specie living in salted or freshwater). Therefore a biosensor needs
particular skills for the calibration and for the interpretation of
data, in order to reduce false negative/positive. Every 10" the eight opening values are acquired by the software of the biosensor. The alarm state (0/1) is acquired every 5’ by the Logosens.

multi-parameters probe
The probe for measuring the physico-chemical parameters (temperature, dissolved oxygen in % and mg·l⁻¹, and pH) and gives basic information on the water; the device used in this work is a Hydrolab® Datasonde®. The measured values are acquired every hour by the Logosens.

datalogger and communications
A datalogger Logosens® is used for acquiring data from biosensor (alarm ON/OFF, sampling rate 5’) and data from water probe (all data, sampling rate 60’). Logosens can locally display the real time measurement of all instruments, as well of power supplies of instruments. With a GSM module is possible to download the monitoring data to a remote PC. Automatically Logosens evaluates the setted threshold of every measured parameter and NO contact and, when appropriate, enable the water-sampler and send an SMS to an operator.

Data processing
The data processing is based on the analysis of the alarm produ-
ced by the biosensor, by comparing the alarm details (e.g. type
and duration) to (1) the data acquired by the water probe and (2)
the data stored in a database. The alarm can be produced by a
natural (e.g. turbidity of the water) or anthropogenic source
(some type of pollution), but can also occurs for a sharp change
of environmental conditions (e.g. drop of temperature) or unus-
usual operation to the DWP (maintenance).

Because of this, the alarm of biosensor is classified as “early war-
ing” and makes start an evaluation; if the evaluation gives an
appropriate answer (e.g. a low $O_2$ value in water), no action is taken. On the other hand, if the analysis cannot explain the early warning, (1) the water sampler is enabled (following a programme that gives frequency and volume of the sampling) and (2) an SMS is send to experts.

The “early warning evaluation” (Figure 4) can be performed automatically and can be controlled by a remote PC. Each partner of the project can check the output of the monitoring from a restricted access web page; every page displays a common area (early warning state ON/OFF, alarm state ON/OFF, water probe values) and a custom area (on request by each partner).

The sample of water produced by the evaluation is used for laboratory’s assays (acute or chronic) on bivalve, fish and other organism, both from the population installed into the ML and from others. The laboratory’s activities are performed by ARPA Ichthyology Research Unit, Ferrara (Italy).

Results

The Complex System has produced four types of “alarm”, classified from A1 to A4; every alarm is characterized by a frequency, a width and a depth of the graph produced by the biosensor, as shown in Figure 5(a-d).

The red lines into figures 5 show the result of data evaluation using a software developed for automatic recognition of alarms. The performance of this software is very good and it is possible to recognize every type of alarm; in the future further efforts will be made to improve it.

The alarm A3 and A4 are related to the Oxygen value into the water, as proved by the Figure 6 (a, b). The trends of Figures 5a-6a and 5b-6b are clearly recognizable, even if an exact indication of data and time of measurement cannot be displayed; in fact, information on data, time of sampling and frequency of displayed data on graph, are confidential information.

In every event, the production of an alarm (1) enabled the water sampling and (2) sent the SMS to the expert; the “alert” had been successful.

Discussion

Four types of alarm have been detected, as a clear correspondence between a “noise” and a reproducible response produced by the biosensor.

Alarm A1 is produced by elevated turbidity of water produced during a flood event. A1 is detected as a series of “bumps” with a “depth” and a “width” and a frequency; those parameters have been classified and used for automatic recognition (red line in Figure 5).

Alarm A2 is produced by mechanical or vibrational stress (by humans, machines or devices). It is easy to identify and can be easily removed by automatic recognition.

Alarms A3 and A4 are due to change of dissolved oxygen (as shown in Figure 6); for A3 the $O_2$ drops rapidly, while in A4 the $O_2$ drops slowly and not with a monotonic decrease. Is useful to note that the automatic software used by the authors for classification and recognition of alarm, can detect the A3 alarm before it produces the closure of bivalve.
Conclusions

Biosensors and automatic water quality instruments can be used to produce a sample of the same water that produced an alarm. The Complex System identified some environmental crisis and produced several types of alarm: a good correspondence between causes and alarm has been detected, even if further data are necessary for a better analysis. In fact, now it is possible to understand and study the relation between the different types of noise and the signal produced by the biosensor, but further measurements have to be performed in order to improve the performance of the system. Probably, other instruments should be included into experimental set-up for improving monitoring capability, considering that the requirements for the ideal early warning system are [ILSI, 1999]:

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

It became clear that only one device cannot provide a good early warning. In particular, it is difficult to simultaneously satisfy requirements 1, 5 and 6 and it is difficult to satisfy requirements 7, 9 and 11 with a biosensor. Requirements 1, 3, 8 and 10 need an engineering development and 2 is possible only if the technologies are widely used or a public organisation has a leading role in built-up and manage an early warning system network (EWSN). An EWSN may be useful for homogeneous environment such as riverine and coastal areas.

The Mobile Laboratory (ML) is the evolution of a system used in different condition (fresh waters, internal and coastal lagoons and coastal waters) and for the first time has been used in a drinking water plant by the ATO-ARPA-HERA partnership. In 2010 the ML was working for the “calibration of the site”, as necessary phase for the use of a biosensor; this is a topic that have to be considered, as well as it is necessary to acquire a wide series of data before to be able to manage a system including a biosensor.

References


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The drinking working plant (DWP) of Ferrara is representative both of a DWP and of a riverine environment; furthermore it catches water at the end of the Po river basin and then is possible to sample a large number of substances (or compounds) and to study “new contaminants” such as endocrine disruptors. In future, several MLs can be installed along the river and its delta, for a complete monitoring of the Po river basin.