

IMPROVEMENT OF WATER QUALITY SURVEILLANCE WITH THE DEVELOPMENT OF A NEW APPROACH: INTEGRATED CONTROL OF PHYSICO-CHEMICAL AND BIOLOGICAL SENSORS RESPONSES

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1. Definition of the problem area

Water quality resources must be closely supervised to ensure that they respond fully to safety requirements associated with its different uses. Yet water in general is constantly subject to ever increasing risks of pollution, concurrently more stringent quality requirements are imposed on water for human consumption for example. Several thousand xenobiotic substances may be expected to be found in a river although most of them are in very low concentration and sometimes undetectable through routine analytical methods. It is essential to provide the scientific and technical bases for improved water surveillance capable of global and rapid detection of pollutants from accidents or malevolences in order to protect surface waters (aquatic life, drinking water resources).

The cost of monitoring programmes is really low compare to the economic and social impacts of pollution which are not detected early enough to undertake adequate action.

2. Current solutions and limitations

Continuous surveillance of river water quality has recently attracted growing attention. Water and effluent quality measurement is routinely based on the analysis of random samples. Spot samples are collected periodically and transported for laboratory analysis. Not only is the evaluation of the results problematic for the periods in between the sampling events, but due to financial and analytical constraints, only a limited number of compounds can be detected chemically. Although continuous monitoring is possible for some chemical parameters, it is widely accepted that routinely used chemical monitoring and analysis methods only detect a limited fraction of the toxic compounds that may be present. In addition, physico-chemical surveillance does not take into account interaction phenomena.

To cope with this situation, a new solution relies on the use of biological sensors allowing a wide monitoring spectrum. These biological systems indicate that a harmful condition exists, even when the compound cannot be detected analytically by routine monitoring programmes. Each organism has its specific sensivity towards certain pollutants but also towards environmental conditions. Since changing natural conditions may affect the parameters measured, knowledge of such effects is needed to improve data analysis and evaluation.

On the other hand, there is a wide range of reported lethal and sublethal concentrations for different organisms deduced from laboratory tests, yet there is much confusion as to how this knowledge should be integrated into water quality research. When comparing various investigations on the performance of biological early warning systems and biosensors, differences in the outcome have frequently been observed.

In relation to this problem, this research project aims to develop a multi-system approach in the continuous monitoring of natural waters (and/or effluents). It concerns physico-chemical and biological multi-sensors where information will be analysed in a common way by an expert system. Each type of organism, possibly each species, will have a specific sensitivity for various pollutants and/or for pollutant mixture (see figure 1). For example, herbicides will be better detected by algae (Pandard et al., 1993), anti-fouling agent by bivalves (Jenner et al., 1989). For this reason, a priority research action will be to develop a combination of the various types of organisms (which will result in the extension of the range of detected pollutants) in parallel with the analysis of physico-chemical sensors information. As to the biological approach, various types of organisms can be used as fish, bivalves, daphnia, algae, bacteria, ... and also different responses will be analysed as behaviour, physiology, biochemical changes, ... (Kramer and Botterweg, 1989; Thomas, 1997; Van der Schalie, 1986). This will also involve biosensors that use immobilized enzyme cells, mitochondrial and tissue biocatalysts, antigen-antibody inhibitor reactions, ... (Tran-Minh, 1991).

In fact, the idea is to provide the scientific and technical bases for improved water surveillance capable of rapidly indicating quality deterioration. It is also aimed to integrate several physico-chemical data available from common sensors (pH, temperature, suspended matter, dissolved oxygen, ...) with information of the biological early warning systems and biosensors using several organisms and biological components in a multi-sensor approach. The nature of the retained sensors has to be related to a vulnerability study.

3. Current state of the art

The usefulness of the two approaches (physico-chemical and biological) to assure reliable monitoring of water quality is now generally recognised (Wallwork and Ellison, 1983; Botterweg et al., 1989). Scientific literature abounds in biological early warning systems and biosensors the diversity of which is attested not only by the variety of biological reagents used but also by the number of principles developed (Thomas, 1996; Thomas and Terver, 1994). Some biomonitors record the respiration activity by measuring the oxygen concentration in very different test organisms, such as bacteria (Solyom, 1977), algae (Geller and Mäcke, 1977), invertebrates (Heinis and Swain, 1986). Several monitors evaluate the light emission of bacteria (Bulich, 1979), the photosynthetic activity (Pandard and Vasseur, 1992) or the fluorescence production (Benecke et al., 1982) of algae. Other examples include the use of crustacean locomotion (Knie, 1988), mussel valve activity (Kramer et al., 1989), of fish behavioural (Besh et al., 1977; Poels, 1977), physiological (Morgan and Kühn, 1974) and electric responses (Rauch, 1980; Thomas et al., 1996) in the development of early warning systems. In spite of the proliferation of biomonitoring systems (see Table 1), much remains to be done in terms of research to grapple with a number of existing problems.

Crucial among these is the determination of water quality thresholds and pollution detection time in keeping with drinking water quality standards. In addition, the various biological monitoring systems are at different development levels with not always a validation in situ. For the sake of reliability, it is also crucial to distinguish between biological responses caused by normal variations of environmental parameters and those caused by the presence of toxic substances. For example, the influence of temperature variations on biological information is a common problem facing all biological early warning systems. Like this, Bulich (1979) and Vasseur et al. (1986) use the light output of luminescent bacteria for determining the toxicity of water samples. It was shown that light emission is temperature dependent and consequently it was necessary to control very precisely the water temperature. The same problem appears in poikilothermic electric fish, as *Apteronotus albifrons* (Gymnotiformes). In these organisms, we can exploit the Electric Organ Discharge Frequency, a physiological response affected by the water temperature (Thomas et al., 1997). In this context, the development of methods integrating several physico-chemical and biological sensors could be a promising means and proposes a completely new approach as an integrated early warning system.

4. Further research needs

The outcome of the further research would be the creation of a highly sensitive monitoring approach (with physico-chemical and biological sensors) for aquatic environment quality surveillance. It will aim specially at improving biological early warning systems which are required by national and international commissions and organizations for the implementation of monitoring programmes. This is all the more important since the number of new chemical products put on the market increases year by year (Chemical Abstracts).

As to the scientific, technical and economic arguments, several points can be listed:

- only a limited number of compounds can be detected with physico-chemical sensors;
- there is a complementarity of physico-chemical and biological approaches;
- detection of possible effects of complex mixture of pollutants to different species, for a global approach;
- detection of sudden changes in river water quality and safeguarding waterwork intakes against toxic events;
- a relatively cheap method of broad-spectrum detection with the biological approach;
- the reliability of a multi-system approach.

The information provided by such an integrated method can also be useful for the maintenance of the general system. Local authorities, water agencies and national environmental authorities have already expressed their interest for such a project. On the other hand, biological monitoring is a relatively cheap method of broad-spectrum detection which can support early warning and survey programmes of organizations such as the International Rhine and Danube Commissions, ...

Figure 1 : Comparison of the sensitivity of biosensors applied to water quality control (modified after Osbild et al., 1995).

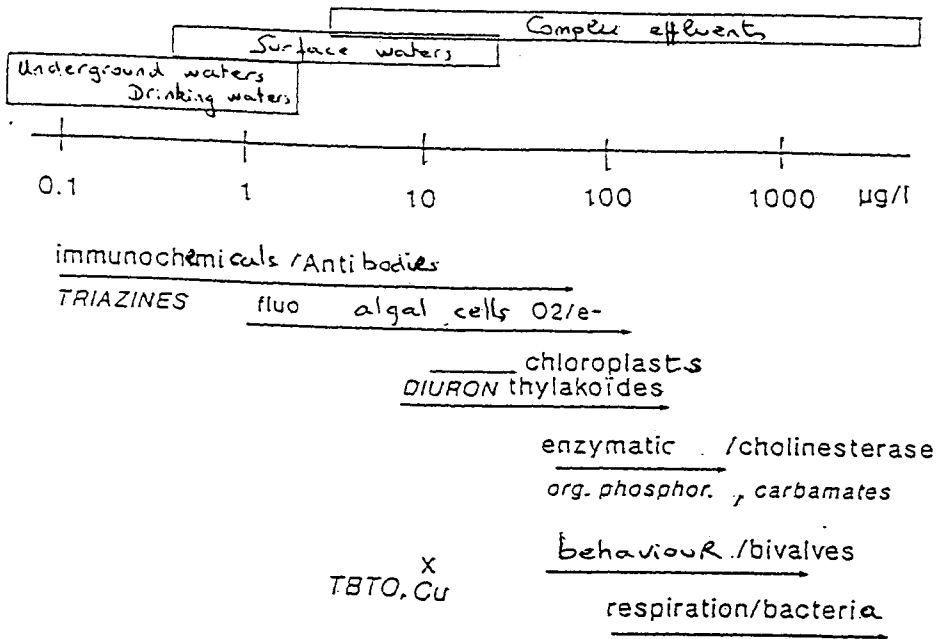


Table 1 : Overview of the automated biological early warning systems or biosensors (modified after WIR Bund / Länder - Projektgruppe "Wirkungstest Rhein", 1994).

Biological reagents	Test systems	Biological components or test organisms	Test parameters
ENZYME	Enzymatic biosensors	Tyrosinase Cholinestérase Cytochrome oxydase Acétylcholinestérase Butyrylcholinestérase	Enzyme activity Enzyme activity Enzyme activity Enzyme activity Enzyme activity
ANTIGEN-ANTIBODY	Immunosensors		
BACTERIA	Toxiguard Biox 1000T Toxalarm Stiptox-norm EuCyano bacteria electrode ROD TOX Lumino 2000 RBT Biotoximeter Auto-Microtox	Biofilm Biofilm Pseudomonas putida Pseudomonas putida Escherichia coli Activated sludge Photobacterium phosphoreum Photobacterium phosphoreum Photobacterium phosphoreum Photobacterium phosphoreum	Respiration: O ₂ consumption Respiration: O ₂ consumption Respiration: O ₂ consumption Respiration: O ₂ consumption Respiration: electron transport Respiration inhibition Inhibition of nitrifying ability Light emission Light emission Light emission Light emission
ALGAE	FluOx test system Biosens algae toximeter IFW fluorometer DF algae test Biotoxitel EuCyano bacteria electrode	Chlamydomonas reinhardii Chlamydomonas reinhardii Chlamydomonas reinhardii Chlamydomonas reinhardii Chlorella vulgaris Synechococcus sp.	Photosynthesis: fluorescence and O ₂ development Photosynthesis: spontaneous fluorescence Photosynthesis: spontaneous fluorescence Photosynthesis: delayed fluorescence Photosynthesis Photosynthesis: electron transport
HIGHER PLANTS	Protoplast biotest	Vicia faba	Photosynthesis: O ₂ development

Biological reagents	Test systems	Biological components or test organisms	Test parameters
ANIMALS	Dynamic daphnia test Dreissena monitor Mosselmonitor Aqua-Tox Control Fish warning test Behavioural fish test WRc fish monitor Gymnotox	Daphnia magna Dreissena polymorpha Dreissena polymorpha Leuciscus idus melanotus Leuciscus idus melanotus Leuciscus idus melanotus Oncorhynchus mykiss Apteronotus albifrons	Swimming activity Valve movement Valve movement Swimming activity Swimming activity Swimming behaviour Ventilation: gill beat frequency Electric organ discharge frequency

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