Philippine Engineering Journal (1991) XIII (1): 67 - 82

AUTOMATIC MONITORING OF WATER POLLUTION WITH EMPHASIS ON BIOLOGICAL MONITORS

Genandrialine. L. Peralta, M.S.
Assistant Professor
Environmental Engineering
College of Engineering
University of the Philippines
Diliman, Quezon City

Gonzalo S. Puga
Supervising Science Research Specialist
Philippine Nuclear Research Institute

ABSTRACT

Recent developments in the field of automated monitoring systems include state-of-the art instrumentation which makes full use of existing computer technology and automation processes in environmental monitoring. This paper will describe the various technologies in automatic monitoring of water pollution, ranging from biological to physico-chemical methods with stress on biological monitors as they are fast gaining attention from researchers worldwide, offering great promise in the future especially in developing countries.

INTRODUCTION

This paper aims to present the new developments in the field of automated monitoring systems for water pollution detection. Some studies had been undertaken in the past, and which have some semblance to present-day systems. These studies evolved either in response to an actual problem or an improvement of previous technology already in existence and utilized but with recognized limitations. In either case, the various systems are described including their applications and the setbacks experienced by the developers.

There could be other systems already developed elsewhere in the world but are not included in the discussion since we do not have access to such information.

PRINCIPLE OF AN AUTOMATED MONITORING SYSTEM

The need. The authors of a paper presenting the "SHERLOCK" automated water quality monitoring system of England [3] aptly described the need for such a system in the following paragraph:

"In general, pollution control scientists respond to pollution by reacting to visual signs such as dead fish or a discolouration of the water. To detect when these events have occurred, reliance is placed upon someone noticing the effects of the pollution and reporting it. Obviously there is a time lag inherent in this system and frequently by the time an investigation is underway the discharge causing the problem has stopped. This makes it difficult to trace the source of the pollution which can by this time be a considerable distance from the observed effect."

The monitoring system. This identified problem also suggests the necessary elements of an automated monitoring system:

1. Detection process
2. Analysis of the data
3. Generation of the necessary output.

In all of these, timeliness is of importance - an aspect which is fulfilled by automation and computers.

The detectors. The detection process can be performed either by physico-chemical means or by biological means. In the former, the sensors are physical transducers (non-living) and the analysis will report the occurrence of high concentrations of specific pollutants. Examples are the determination of water acidity by pH probes or of temperature by thermistors. In the latter, the sensors are living things. This is the same principle that the barking of dogs could mean the approach of a stranger. Floating dead fish at the surface of the water will clearly indicate the presence of a toxic pollutant but would have been too late to react to the spill that has occurred.

Each type of detection process has its own merits. In the physico-chemical system, we get information on the nature and concentration of the given chemicals or pollutants without direct knowledge on their actual biological effect (except in extreme cases such as when floating dead fishes are seen and we make the correlation). On the other hand, in the biological system the biological monitor (an organism) indicates the actual and combined effect of one or more toxic compounds without direct knowledge of the compounds' actual identity and concentration.

The analyzer. After the detection process is the data analysis process. Signals from the detector are amplified, conditioned, and processed so that the desired analysis is performed. The nature and degree of complexity of the analyses required will dictate the complexity of the instrumentation to carry them out. With the proliferation of computers, the complexity has been greatly reduced. What makes a biological monitoring system unique, though, is the resulting integration of various processes (physico-chemical, biological, or both) within and into a single unified system, which in turn, makes the necessary correlation and analysis.

The output. The output of the system could be as simple as giving a meter reading or a strip chart print-out, or in generating action-oriented signals such as an alarm. It could also be more complex such as when initiating commands are sent out, like the automatic performance of further sampling or of some actions which are previously determined as appropriate responses to certain alarm points.

REVIEW OF LITERATURE

Some of the relevant studies undertaken in the past 15 years using automated monitors were collected and are briefly described below.

Physico-chemical Monitoring Systems

There is a wide variety of sophistication in automation of water quality monitors for both industrial or river applications. The more advanced systems such as the Merlin and Sherlock from the UK, are designed to immediately identify a water pollution incident, take water samples for in situ or laboratory analysis/comparison and inform local pollution officials via telemetry links. Some of the earlier systems in 1977 in the US, started with probes or sensors that are directly connected to computers for data processing.

Biological Monitoring in Activated Sludge Treatment Process (Stover, et al., U.S., 1977) [1]

The problem. In the past, operators waited for days or hours for analytical measurements to tell them how well (or how poorly) the plant was performing. Most of these analytical tests require a long time to perform, and by the time the results are available their usefulness would then be only as historical information. Furthermore, many of the operational tests which are useful to plant operation are never performed; if some are ever performed they are not for plant operation purposes.

The proposal. The equipment and methods suggested by the authors for this purpose include on-line total organic carbon (TOC) or total oxygen demand (TOD) analyzers, respirometers, and analytical tests for adenosine triphosphate (ATP), deoxyribonucleic acid (DNA). Measurement of the TOC of the raw wastewater and of the return sludge will allow the determination of the food to microorganism (F/M) ratio in just a short time. But this, however, also requires initial correlation with TOC to biochemical oxygen demand (BOD) and TOC to volatile suspended solids (VSS). The respirometers are to be placed on-line continuously to monitor the system and identify any shock load conditions due to organics, pH, or toxic compounds. The ATP and DNA tests would be helpful in operating a treatment plant. Ideally, the biological system should be monitored on a continuous basis and proper responses made to maximize performance.

The result. It is evident from the above description of the monitoring and analytical processes and procedures that it would be highly desirable to have a system that accomplishes both automatically and with minimum operator intervention. The associated equipment should be such that even a relatively untrained operator could use them to continually monitor a biological system.

However, whether the authors' suggested system was ever developed and implemented was not mentioned in their paper. As early as the late 1970's, there was already an awareness of the real need to develop automated biological monitoring systems. The proposition of Stover, et al. is a case typifying the development of a system to solve or improve an existing process.

Automated Measurement of River Productivity for Eutrophication Prediction (Kelly, et al., U.S.A., 1977) [2]

The problem. In the words of the authors: "*The two most common forms of water quality degradation seem to be cultural eutrophication due to input of (often unspecified) nutrients and excessive oxygen demand caused by decomposing organic material produced in situ or from outside the aquatic system. These problems may be due to either point source or diffuse input (also known as nonpoint sources such as agricultural or urban runoffs), but their effects are usually noticeable over whole river/lake systems or watersheds. Measurement of both nutrient and biochemical oxygen demand (BOD) present problems with nonpoint source loading, and we feel that a direct measure of the effects of these pollutants on the whole aquatic community is desirable.*" (Underlining and parenthetical explanations supplied).

The solution. The above approach exemplifies a developmental process out of a "felt" need by the authors. They worked out the concept by using an exact solution to the oxygen or carbon-mass balance equations. The characteristic equations for oxygen-mass balance in a river are given below.

$$dx/dt = V$$
$$dc/dt = K\,(c_s - c) + P - R$$

where

c	=	concentration of dissolved oxygen (ML^{-3})
V	=	average velocity (LT^{-1})
K	=	reaeration coefficient (T^{-1})
c_s	=	saturation oxygen concentration (ML^{-3})
P	=	community photosynthetic rate ($ML^{-3}\,T^{-1}$), and
R	=	community respiration rate ($ML^{-3}\,T^{-1}$).

The solution to this equation required nearly continuous measurement of oxygen concentration and temperature (to obtain c_s), pH, and incident solar radiation to obtain K and efficiency. Accordingly, the needed transducers were an oxygen probe for oxygen concentration, a thermistor for temperature, a pH electrode for pH, and a radiometer for incident solar radiation. The raw data were then fed to a computer which calculated c values, mean daily values of gross productivity, community respiration, photosynthetic efficiency, reaeration coefficient, and the quantity (P-R) which was expressed as a Fourier cosine series. Computer routines were developed to solve them.

The result. The system was tested in five contrasting rivers and the authors claimed that it was possible, using automated recording and analysis, to derive values for net and gross daily community production, community respiration, and photosynthetic efficiency.

During the developmental process the authors encountered some problems, which are typical of new systems. One is on the availability of the needed instruments. Since no commercially available system could meet their requirements with respect to accuracy, precision, and frequency, they have to design their own monitoring system. The other is on data analysis; the raw data were fed to a computer which made the corresponding calculations and correlation. Such computerization requirements imply a high level of computer skill and literacy, both in hardware and software.

The "SHERLOCK" Water Quality Monitoring System (Swinnerton, et al., England, 1989) [3]

The system. The "Sherlock" water quality monitoring system was developed by the National Rivers Authority of England and is designed to detect pollution incident and changes in river quality, more particularly in the Wessex Rivers. It exemplifies a state-of-the-art integrated approach to pollution monitoring. Figure 1 illustrates the system.

Field instruments measure dissolved oxygen, ammonia, pH, electrical conductivity, turbidity, temperature, river flow, rainfall, and flow or no flow from piped discharges. The analog outputs of these instruments are then fed to a data logger which directly downloads the data to a microcomputer. The same information could also be directly downloaded to a portable microcomputer carried in,a car, in the field, or at home. When an output (the input to the data logger) or a combination of the outputs exceed pre-set limits, like when there is an increase in ammonia concentration or a decrease in dissolved oxygen (Fig. 2), several things are automatically initiated. Initially, an alarm signal is sent to the pollution control scientist indicating an abnormal situation; the system can then remotely be interrogated using a portable computer via a cellular telephone. Then, a sampling machine can be activated to automatically take samples over various predetermined time intervals; these samples are then manually taken to a laboratory for analysis to supplement the information captured in the data logger. Lastly, a radio signal will alert and consequently activate other strategically located sampling stations to start automatic sampling; various data are thus obtained in an integrated manner.

Among the commendable features are:

(1) the ability to interrogate the system from a car, the office, or at home without having to visit the site,

(2) the sending out of alarm signals which are received by a scientist in a distant location, who can then make the interrogation with a computer via a cellular telephone,

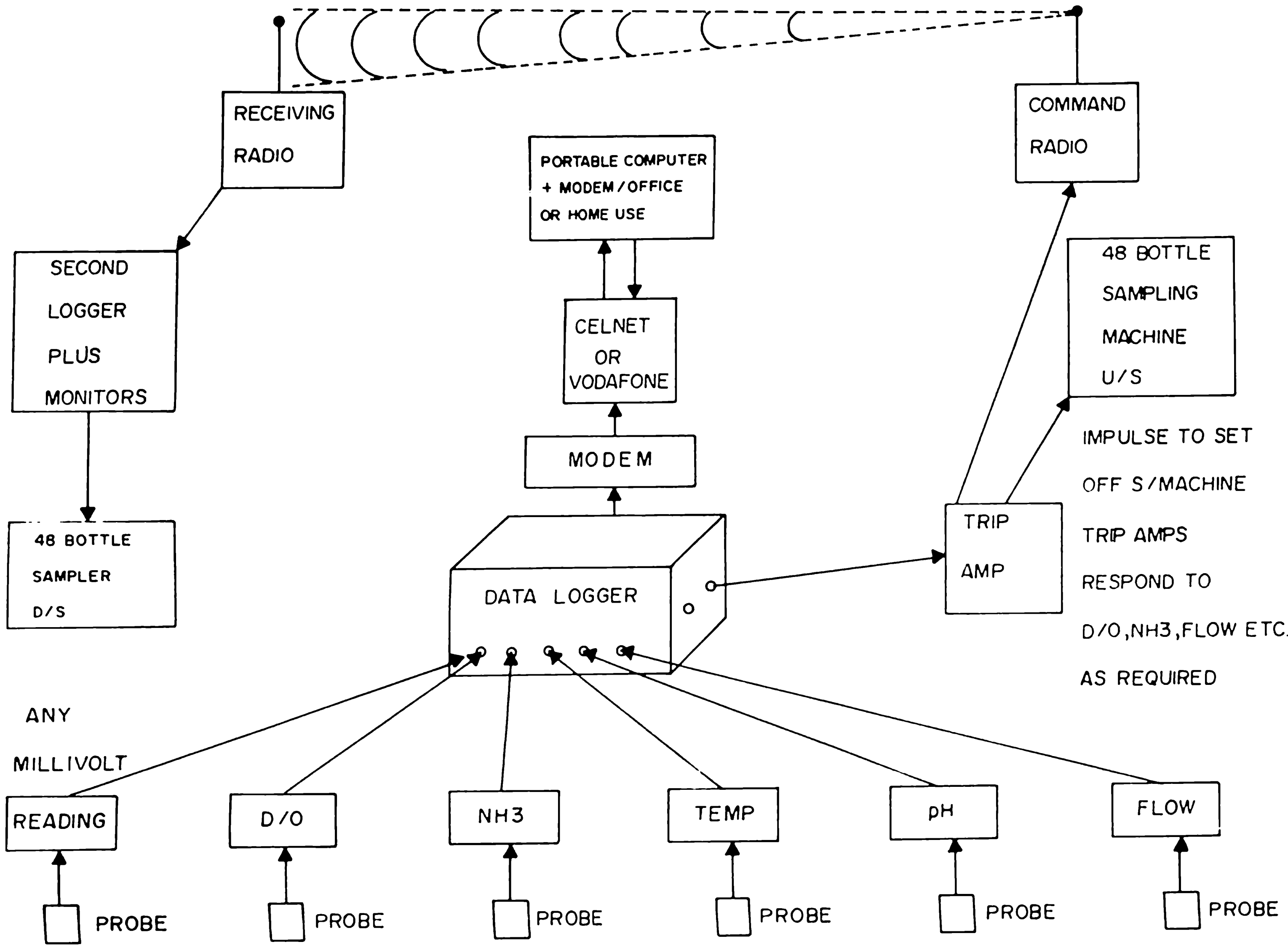

Figure 1. Schematic Diagram of "Sherlock's" Water Quality Monitoring System

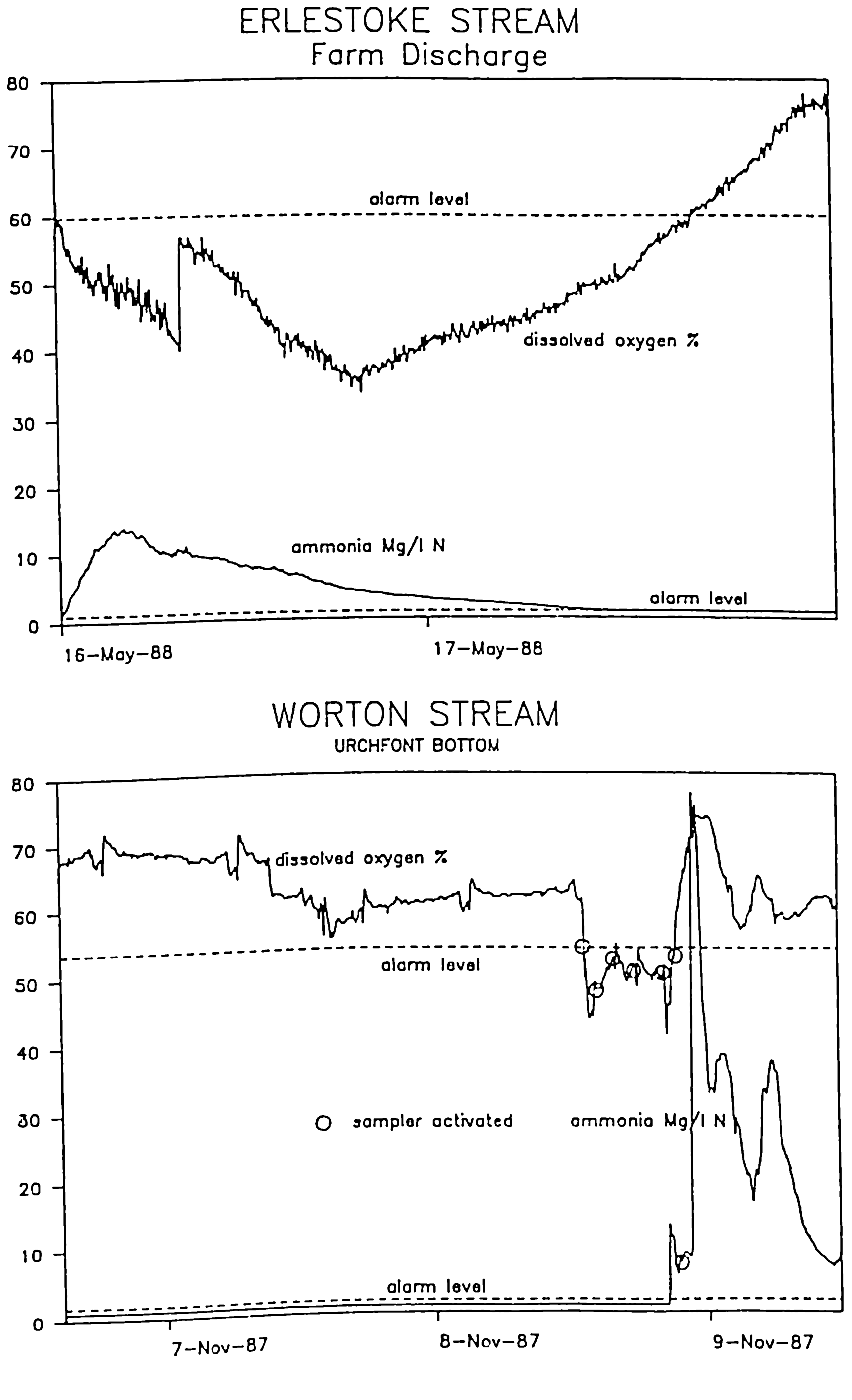

Figure 2. Graph of Monitored Dissolved Oxygen and Ammonia at ERLESTOKE and WORTON Streams

(3) the ability to automatically undertake simultaneous samplings at different locations when an alarm setpoint is reached, and

(4) the flexibility of the system due to its mobility and portability.

The results. The "Sherlock" has been successfully used in identifying problems and solving pollution incidents. In Wessex alone, more than forty investigations using this equipment had been carried out as of 1989. One documented example is the following: "*The river Avon, flowing through Hampshire has many commercial fish farms rearing trout predominantly for the table. One particular fish farm, one of the largest in Europe, was thought to have an effect on water quality detrimental to the fishery downstream. Monitoring of the watercourse confirmed that there was no significant increase in the ammonia concentration but a significant decrease and diurnal variation in dissolved oxygen was confirmed. The fish farm has now installed an aeration system to overcome these problems.*" [3]

Biological Monitoring Systems

Stover, et al., Kelly, et al. and Swinnerton, et. al., developed their concepts and systems using physico-chemical sensors. During the same period, experiments employing biological sensors were also being conducted in other parts of the world.

The use of biological subjects in the assessment of the level of pollution in a certain water system is varied. These are described below:

1. Bioassays: instead of determining the toxicity of each of the thousands of potentially toxic substances in complex effluents (which is economically not feasible) an effluent toxicity test is conducted directly with aquatic organisms.

2. **Bioaccumulation studies** : local populations are sampled for chemical analysis.

3. **Biomonitoring** : this is the least developed but the most interesting where local organisms are used as the actual sensors. The mussel monitor is a fine example. Other studies tried fishes such as Westlake with also some degree of success.

Automated Biological Monitoring System at an Industrial Site (Westlake and van der Schalie,U.S.A., 1977) [4]

The concept. Simulations in various laboratories were able to establish the efficacy of biomonitoring systems employing the respiration rates of fish to monitor industrial effluents. Using the same technique to an industrial setting, however, is an entirely different matter. G.F.

Westlake and W.H. van der Schalie attempted this task. They proposed a computerized biological monitoring system to be installed in the Celanese Corporation Plant on the New River in Virginia.

The model. Figure 3 illustrates one of the biomonitor tanks. The respiratory movements (mainly opercular), of a single fish (a bluegill) in each tank is picked up by means of a pair of stainless steel electrodes attached at the ends of the tank. These movements produced potential variations in the order of 1 to 2 microvolt. The signals were then amplified and conditioned and then fed to a microprocessor for on-site automatic analysis, computation, and some degree of automation. The system was further developed to include the capability of a minicomputer located at a central laboratory to sample the data from the microprocessor over the telephone lines. The minicomputer then performed the rest of the evaluation (Figure 4). The computer used a statistical approach to determine when the fish was respiring abnormally. When an abnormal condition is detected, a signal is sent back over the telephone line to the microprocessor which then turns on a light at the main gate of the plant initiating follow-up procedures.

The result. During the time of the report [4] the system had only been in operation for a short time and had not encountered a naturally occurring abnormality in the effluent. However, results of a short test using a simulated spill of chlorine on site were reported to be encouraging.

This project also encountered the typical problems of availability and appropriateness of instrumentation, data analysis complexities, and cost, if all the equipment were to be bought just for the project. Operating costs were found not to be great once the biomonitor was operational.

The Mussel Monitor (Kramer, et al., Netherlands, 1989) [5]

The concept. Molluscs with two shells (bivalves), like the common or blue mussel (Mytilus edulis), have been found to be good biological monitors. Under normal conditions they have their shells open for respiration and feeding most of the time; they close their shells only occasionally. However, if they are under stress, it has been shown that they close their shells for an extended period of time.

The system. Exploiting this behavior the electromagnetic induction sensor (EMIS) was developed. Figure 5 is a schematic presentation of the system. The EMIS consists of two small coils attached to both mussel shells. One coil is attached to a high frequency signal generator; this is the transmitter. The high frequency signal impressed on the first coil will cause the production of current in the other coil, called the receiver; this is the principle of electromagnetic induction. The nearer the two coils are to each other (i.e., the closer the two shells of the bivalve are to each other) the stronger will be the magnetic coupling between the two coils and the greater will be the amount of current induced in the receiver. Thus, at the two extreme positions (closed shells and open shells) the induced current will be maximum and minimum, respectively. inversion, however, was made in the output presentation; zero setting corresponds to shells closed and maximum setting to shells fully open. Figure 6 illustrates this. It can be seen in the figure that as more chlorine is added, the time that the valves are open (corresponding to the spikes in the chart) decreases. This confirms the working concept that under stress the molluscs (or mussels)

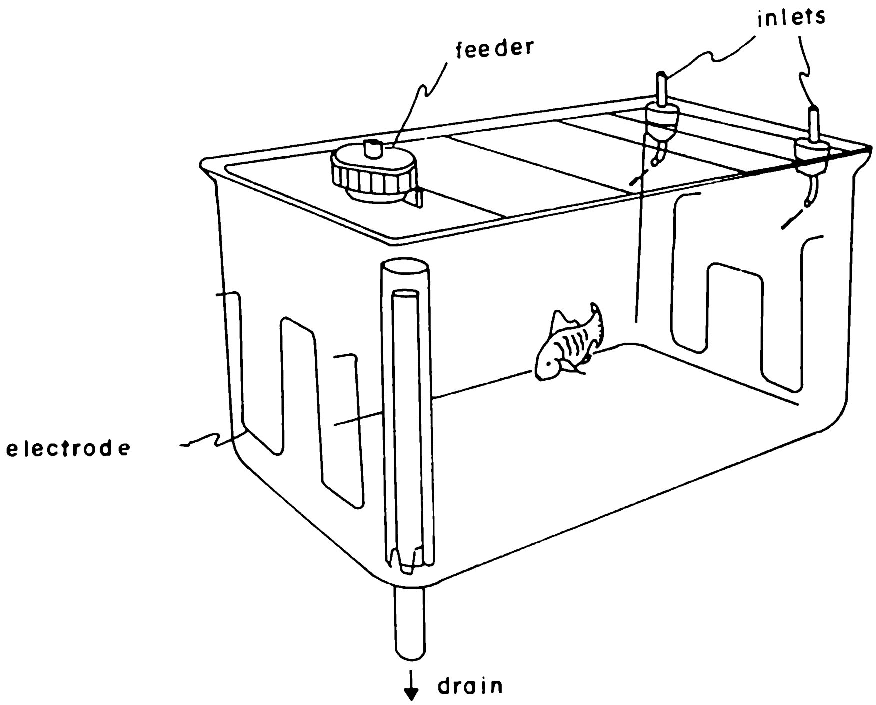

Figure 3. Biomonitor Tank

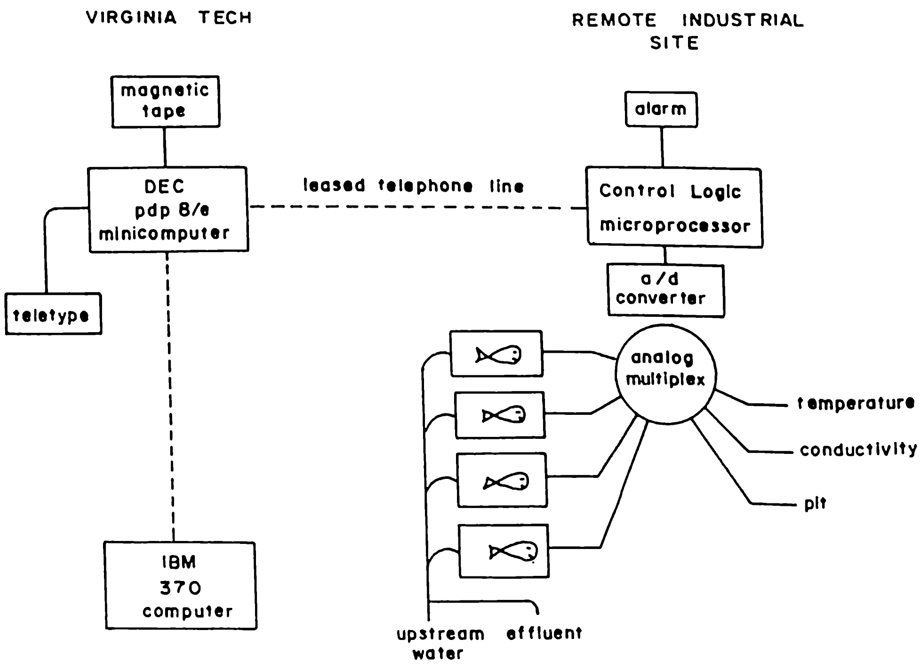

Figure 4. Schematic Diagram of Monitoring System

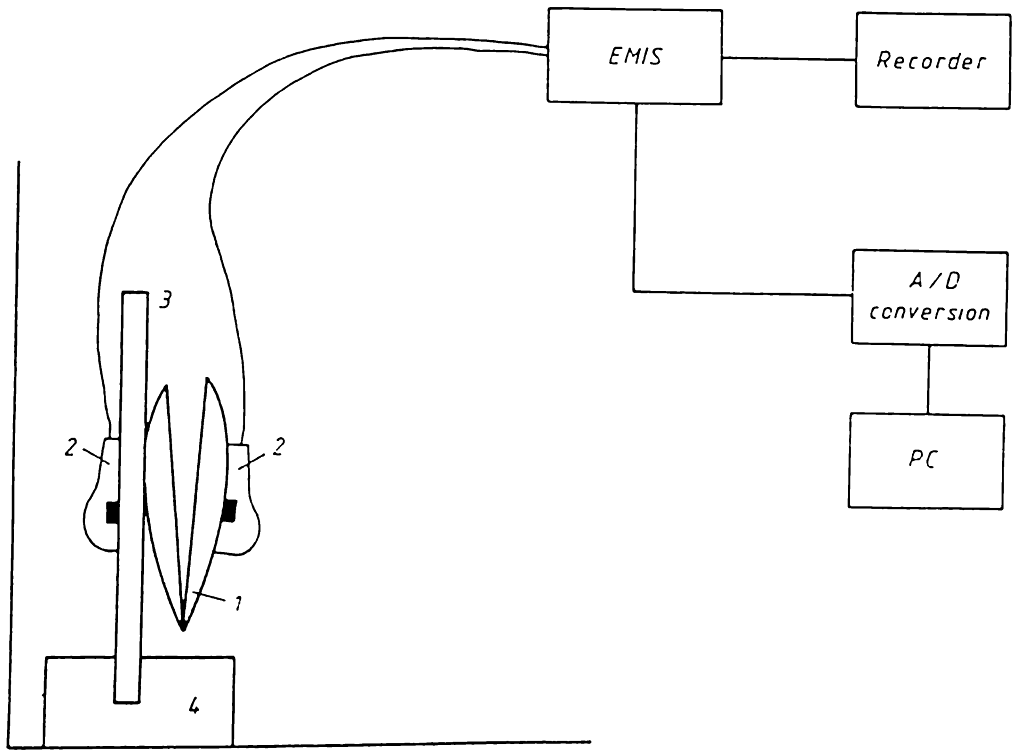

Figure 5. Schematic Presentation of the Electromagnetic Induction System (EMIS) based on Bivalve Movement Detection System
1: Mussel; 2: Coils; 3: Perflex Substrate; 4: Support.

close their shells for an extended period of time; the length of this period depends upon the level of pollution. Movement of the mussel through the tank may, however, cause interference between the different signals. The mussels are, thus, usually glued to perspex plates attached to the tank.

The other parts of the instrumentation would now be similar to all other state-of-the art systems, with a computer doing the data storage and evaluation. In real-time data collection a continuous recording is made on a chart recorder or on magnetic tape. Figure 6 is an example of a chart-recorder output.

The result. This valve movement detection method was used to study both natural changes in the environment and the effects of pollutants, e.g. the effects of temperature, light, tidal movements, salinity, food quantity and quality, and a series of toxicants like trace metals,

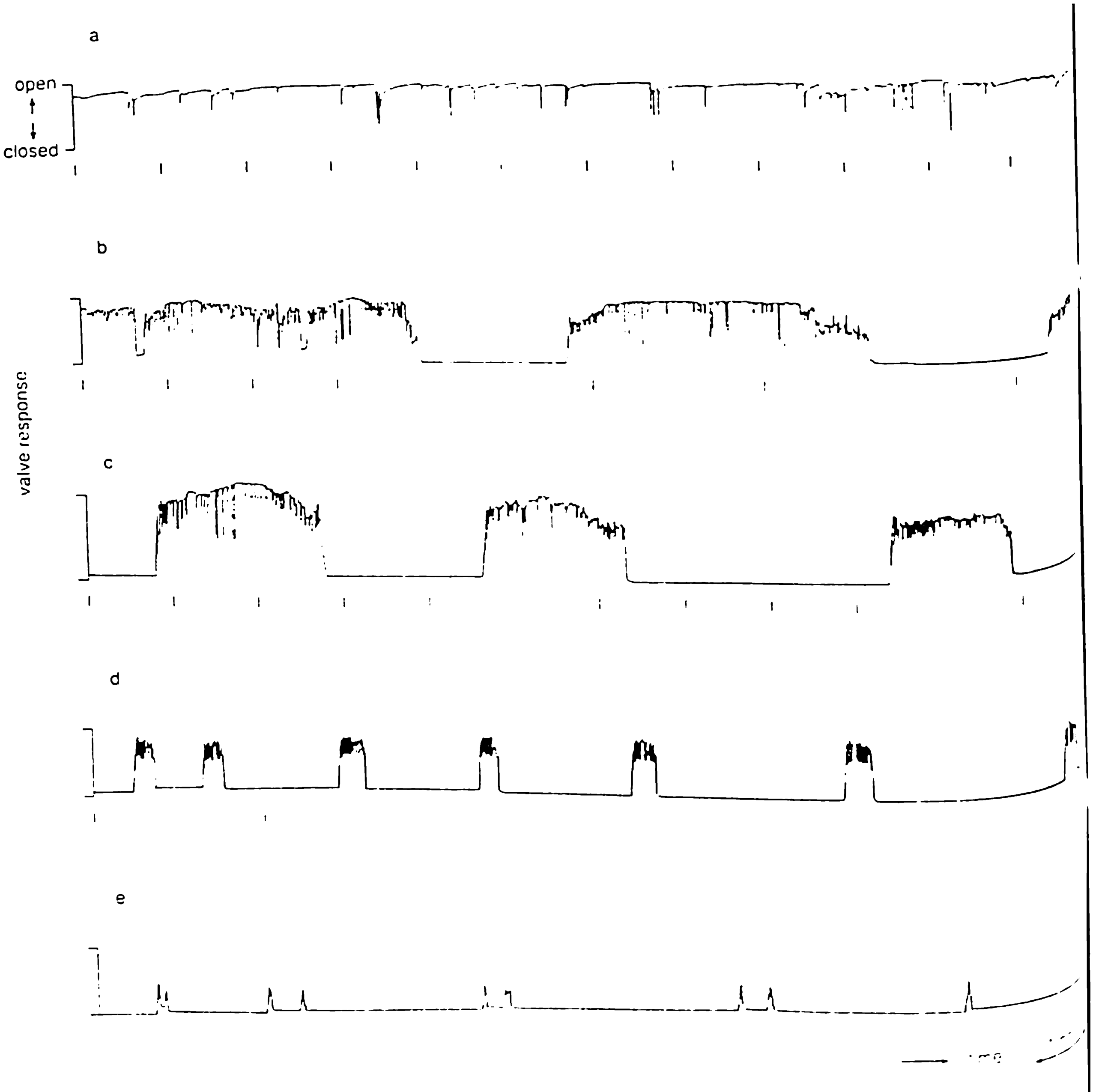

Figure 6. Real Time Recording of the Movement of Dreissena Polymorpha under a Continuous Stress of Chlorine.
Chlorine Additions (in ug/1): A: Blank; B:37; C:55; D:180; E:550.

pesticides, and other trace organics. Using the EMIS, specific detection limits have been established as shown in the table below:

Table 1. Estimated detection ranges or several toxicants as detected by the valve closure response of Mytilus edulis (M) and Dreissena polymorpha (D) using the EMIS.

Compound	Estimated Detection Limit (ug/l)	Organisms
Copper	<10	MD
Cadmium	<100	MD
Selenium	<100	D
Zinc	<500	MD
Lead	<500	MD
Chlorine	<10	MD
Dispersed crude oil	<6000	M

A number of applications for the use of the EMIS, or an equivalent version, can be developed, especially for environments where large variations in the toxicological conditions are to be expected. Other possible applications are the following:

- effluent monitoring (discharge pipes)
- general water quality monitoring (rivers, coastal environments)
- monitoring of water inlets (drinking water, aquaculture)
- early warning system (alarm function triggering a water sampler for chemical proof)
- toxicity testing
- physiological and behavioral studies

The WRC Mark III Fish Monitor (Diamond, M., Huntington, UK, 1984) [6]

The problem. "*The phenol-pollution on the River Dee, January 1984, revealed a serious gap in the monitoring systems on the River Dee intakes. In response, an improved river and intake monitoring system was developed, an integral part of which is a physico-chemical monitoring station on the Huntington Intake (Huntington Intake Protection System: HIPS).*" [6]

The system. The overall protection system incorporates both the physico-chemical system (in the manner of "Sherlock") and the biological system (in the manner of the mussel monitor). The physico-chemical part, designated as HIPS, includes sensors specific to phenol, total ammonia, temperature, pH, conductivity, turbidity, strippable pollutants and dissolved oxygen. The biological part, termed the WRC Mark III fish monitor, is a non-specific pollution sensor to complement HIPS; it measures the frequencies and powers of electric currents produced during the gill ventilations of eight rainbow trout bathed in water continuously abstracted from the River Dee. All these sensors are connected to a microcomputer which is programmed to monitor and record changes in water quality and to send alarm signals when determinands or parameters are outside threshold limits.

The role and effectivity of the Huntington or HIPS will not be presented here. Instead, focus is given to the WRC Mark III Fish Monitor.

Two alarms could be generated from the Mark III. When the current frequencies are different to those measured one to two hours previously, a frequency alarm signal is given; this may be due to pollution. When the power or ratios of total power to power of frequency are the ones of significant deviation a ratio alarm is generated; this could be due to poor fish condition.

The result. It was observed that too many fish frequency alarms were produced by the fish monitor. This means that there are either too many otherwise undetected pollution events (which is unlikely), or too many false alarms. This result limited the effectiveness and reliability of the fish monitor. Its capability, therefore, of acting as a non-specific gross pollution monitor during actual incidents is, as yet, doubtful. It was, however, concluded that if the number of frequency alarms could be reduced sufficiently, the fish monitor can play a useful role in the detection of trichlorophenol, paraquat and -HCH. But for reliable detection of other compounds of public health significance, its potential has yet to be tested.

The study [6] outlined three major components that are considered necessary in the assessment of the effectiveness of a biological monitor. They are:

- Operational reliability - the goal is to give maximum protection; ideally the monitor, therefore, has to be in operation all the time, be extremely reliable, and can be easily maintained

- Alarm signals - these signals should be unambiguous, i.e., they should clearly be caused by the pollutant so as to avoid false indications, and

- Sensitivity - ideally, for acute pollution events the monitor should react consistently to all potential pollutants harmful to human health at concentrations approaching the suggested-no-adverse-reaction-levels or SNARLS; (chronic pollution should be detected by routine monitoring).

CONCLUSIONS

The field of automated biological monitoring is a promising area. Depending on the degree of sophistication desired, the monitoring system can have all the elements characteristic of the computer age. However, if one has to develop his own "custom - built" system, many problems are expected to be encountered. Among them are those concerned with:

a. The availability of appropriate sensors,
b. Problems in the instrumentation itself (such as in signal processing, in integrating all the measured parameters,
c. Data analysis (including computer interfacing and programming problems) and
d. Cost.

For biological monitors there will be added problems with the biological sensing organism itself, like the inconvenience and inaccuracies due to constant replacement resulting from its death, or the effect of adaptation, seasonal variation, reproduction, etc. Future studies may take these considerations as guides in overcoming the shortcomings of past systems.

Whatever the case, automated biological monitoring systems are expected to play an increasing role in environmental protection and management in the near future.

Dr. Ross, Chief Biologist of Florida Department of Environmental Regulation provided a final insight into the reasonable applicability of biological monitors, as follows:

"...it would be difficult to use (the biological monitor) in a large number of domestic or industrial plants. This is due to the presence of acutely toxic substances in many of these effluents which would kill the test organisms, necessitating their constant replacement.

I would recommend the use of an automated biological monitoring system...only after a discharger has gotten its acute toxicity problem under control. The automated system would then be useful in detecting plant 'upsets'..." [7]

REFERENCES

1. Stover, E. L., M.L. Woldman, and P.J. Marks, 1977. *Biological monitoring in activated sludge treatment process*. ASTM STP 607: 147-156.

2. Kelly, M.G., G.M. Hornberger, and B.J. Cosby, 1977. *Automated measurement of river productivity for eutrophication prediction*. ASTM STP 607: 133-146.

3. Swinnerton, C.J., D.J. Palmer, and P.N. Williams, 1989. *"Sherlock" - an integrated approach to pollution monitoring*. A paper of the National Rivers Authority, Somerset, England: 7 pp.

4. Westlake, G.F. and W.H. van der Schalie, 1977. *Evaluation of an automated biological monitoring system at an industrial site*. ASTM STP 607: 30-37.

5. Kramer, K.J.M., H.A. Jenner, and D. de Zwart, 1989. *The valve movement response of mussels*. Hydrobiologia 188/189:433-443.

6. Diamond, M., 1987. *An assessment of the WRc Mark III Fish Monitor.* Report No. 1479R (unpublished): 20 pp.

7. Ross, Landon, Department of Environ-mental Regulations, Tallahassee, Florida (Personal communication to G. L. Peralta, December 29, 1988)