

**A Brief Review of Chemical and Biological Continuous Monitoring
of Rivers in Europe and Asia**

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1. Introduction

The continuous chemical and biological monitoring in Europe dates back to the sixties and seventies. After three decades of development there are a number of reliable chemical monitoring systems for river monitoring, but biological monitoring is still in the stages of infancy (Baldwin & Kramer, 1994; Kramer & Botterweg, 1994; Gunatilaka et al. 2000). However it is a fast developing field with the availability of powerful tools from biochemistry, molecular biology and genetics. At the molecular level the developments are only two decades old. Research and development has stimulated development of a series of novel on-line sensors which are quite promising and different to conventional sensors (see Cowell, 2000; Scully et al., 2000; Girotti et al., 1993, 1992; Roda, 1989). Increased reliability requirements has stimulated research into non-invasive sensor techniques using laser technology and into optical sensors. The non-invasive laser sensor has the advantage of not being prone to fouling, freedom from electromagnetic interference and of being less susceptible to corrosion (Meredith, 1997). Optical sensors are promising and it is a fast emerging branch in the monitoring technology (Scully et al., 2000; Zhang et al. 1996; Bruno et al. 1995).

The major reasons for improvements in river monitoring in Europe are: (a) establishment of an international monitoring net along the main rivers and tributaries (e.g. Rhine; there are nine International Monitoring Stations from Switzerland to North Sea), (b) improvements in the regulatory policies of regional and national governments and (c) strict regulations on industrial and municipal waste emissions. As a result by the end of eighties, off-line and on-line monitoring nets were established along almost all the major river systems in Europe. During the last two decades rivers have been investigated using sophisticated technologies, later extended from detailed chemical investigations of water (more than 300 parameters are routinely analyzed) to sediment, biota and to comprehensive biological surveys.

These developments were supported parallel by the impact of micro-electronic development in the last three decades. This led to the use of new instrumentation and their application in information gathering, data transmission, computation and process control through advancements in Information Technology (IT). Alarm and warning services became a cardinal aspect of river monitoring through the availability of real-time information (Gunatilaka & Dreher, 1996, Hendriks & Stouten (1994). The expansion of the automatic control systems through micro-electronic development has been a major contributor to the increased use of instruments and their applications in river monitoring.

2. Need for river monitoring

Since the well documented Sandoz incident in Basel, Switzerland on 1st November 1986 (LWA, 1986), where the river Rhine was polluted due to a fire in the industrial storage building, the development and installation of biological early warning systems has been seriously pushed forward in Europe especially in Germany, the Netherlands and the United Kingdom. During this accident, pesticides in large quantities (nearly 30 tons) were released into the Rhine which resulted in complete damage of a large portion of the river biotope. As a consequence fisheries suffered very badly; the eel population (specialized benthos feeder) was completely eradicated in the Upper Rhine. However, 500 km down stream, in North Rhine-Westphalia (NRW), the 'Dynamic Daphnia Tests' in operation registered an alarm situation.

This gave a signal to the Environmental Protection Organizations for the importance of biological monitoring systems as 'Biological Early Warning Systems (BEWS)'. The basic idea of the use of automated biological sensor systems for water quality management was first proposed in the early seventies by Juhnke & Besch (1971) and Cairns (1973a, 1973b) and similar systems were deployed in the Rhine in the late seventies (Poles, 1977; Knie, 1978).

Chemical monitoring was introduced in most of the large rivers of Europe during the last three decades, with varying amount of sophistication. Earliest monitoring was limited to easily measurable physico-chemical parameters such as temperature, pH, conductivity and oxygen. Today it has evolved into automated laboratories (Figure 1-4), that measure a large number of parameters including organics (Diehl et al., 1997; Gunatilaka & Dreher 1996), which need elaborate sample preparation procedures. This is achieved through development of efficient on-line methodologies for screening of a large number of organic micropollutants which include halogenated hydrocarbons, herbicides and pesticides, nitro aromatics, phosphoric esters and other priority substances (screening on-line techniques using GC, GC-MS and HPLC). The results are obtained after a few hours of laboratory analyses (see Frintop, 1984; Albert & Willemsen, 1989; Brusse & Willemsen, 1990) in time to inform the down stream water supplies. However, according to Hendriks et al. (1994), the above methods are still incapable of detecting all the organic micropollutants; about 1000 individual compounds could be identified with GC-MS analyses. In the Rhine, since early seventies the chemical monitoring is supplemented with continuous biomonitoring; the organisms used at the beginning were fish (Hendriks & Stouten, 1994). Later a number of biomonitors were deployed in continuous monitoring either in flow-through systems or in-situ (e.g. Daphnia, algae, mussels, fishes and photo bacteria; see Kramer & Botterweg, 1991). Biomonitoring is an alternative to chemical tests, and it is capable of rapidly detecting acutely toxic conditions in river water. Depending on this distinctive feature they are referred to as Biological Early Warning Systems (BEWS). The basic principle used is that of monitoring some function of physiology or behavior, in a test organism which is changed when exposed to a toxic substance at a sufficient concentration. BEWS are automated continuous monitors which employ biological organisms or material as primary sensing element and their use is discussed in several recent publications (LAWA, 1998; LAWA, 1996; Knie, 1994; Irmer, 1994). Puzicha (1994, 1995) has discussed the field testing of several biomonitors under the research project '*Wirkungstests Rhein*'. Baldwin & Kramer (1994) and Kramer & Botterweg (1991) provide two exhaustive reviews on commercially available biomonitors.

Of all the biomonitoring methods that have been deployed over the last two decades, many have remained at a laboratory stage. Only a few tested under field conditions, even fewer are really commercially available. After intensive field testing (Puzicha 1994, 1995), the 'Working Group of the Federal states on Water Problems', Germany (LAWA, 1998) recommended a few reliable continuous biological test systems for river monitoring and they are listed in Table 1.

3. Trans-boundary monitoring

Water quality monitoring of international rivers has always been a difficult task in Europe, but great strides have been achieved through international commissions such as International Commission for the Protection of the Rhine (ICPR) and the recently established International Commission for the Protection of the Danube River Protection Convention (ICPDR). On-line monitoring has been introduced in most of the large rivers in Europe and they served as

Table 1. Continuous Biotest Systems for river monitoring – a synopsis of the recommendations of LAWA (1996, 1998; Working Group of the Federal States on Water Problems, Germany), based on biotest systems tested in the research project ‘*Wirkungstests Rhein*’ and those implemented by the state authorities in Germany (modified and translated from German). Since the table was updated by the LAWA working committee “Biomonitoring” in 1996, several more biomonitors have been developed and tried to be established on the market. None of these younger biomonitors has been tested in such a systematical way as those mentioned in the table. Nevertheless some of the tentatively tested new systems seem to have a realistic chance to be established well in the next few years. The LAWA working committee attends the further development critically and discusses it continuously during its meetings several times

No.	Biotest system	Organisms	Principle of the measurement	Evaluation	Maintenance & annual operation costs (approx.)	Producer and Instrument cost	Dimensions (mm)
1	Dynamic Daphnia Test	<i>Daphnia magna</i>	swimming behavior by IR light sensors	dynamic alarm thresholds	4 hrs. per week 1.500 DM	Elektron, Krefeld 47.000 DM	H 1000 W 600 D 650
2	Koblenz Behavioural Fish Test	Golden ide (<i>Leuciscus idus melanotus</i>)	behavioural parameters as video images	dynamic alarm thresholds	2 hrs. per week 900 DM	metacom GmbH München 67.000 DM	H 1800 W 1500 D 800
3	Mossel-Monitor	Bivalves (<i>Dreissena polymorpha</i>)	opening/closing of valves, distance of valves	comparison of activity patterns, dynamic alarm thresholds	1 hr. per week 700 DM	Delta Consult b.v AC Kapelle Holland 36.000 DM	H 350 W 600 D 600
4	Dreissena-Monitor	Bivalves (<i>Dreissena polymorpha</i>)	opening/closing of valves	comparison of activity patterns, dynamic alarm thresholds	2-5 hrs. per week 200 DM	Envicontrol, Frechen 35.000 DM	H 700 W 1200 D 600
5	DF-Algae Test	algae (various species)	delayed fluorescence (DF),	comparison of fading curves, sample vs. control	5 hrs. per week 1.200 DM	V. Gerhardt & J. Putzger, Univ. Regensburg 50.000 DM	H 1000 W 900 D 900
6	FluOx-Algae Test*	algae (various species)	fluorescence and oxygen production	comparison of actual with former data	3 hrs. per week	Kolibri, Schwerte 110.000 DM	H 1600 W 500 D 600
7	Biosens Algae Toximeter*	Green algae (<i>Chlamydomonas reinhardtii</i>)	spontaneous, variable chlorophyll-a fluorescence	fluorescence parameter (ET-value) difference	3 hrs. per week 6.900 DM	Dr. Noack, Hildesheim 86.000 DM	H 2000 W 620 D 560
8	bbe-Algae Toximeter	algae (various species)	variable chlorophyll a fluorescence	comparison sample vs. control, adaptive Hinkley detector	1 hr. per week 600 DM	bbe Moldaenke Kiel, 57.000 DM	H 600 W 350 D 380
9	Regensburg Luminous Bacteria Test	<i>Photobacterium phosphoreum</i>	decline of luminescence	comparison sample vs. control	1 hr. per week 1.200 DM	V. Gerhardt & J. Putzger, Univ. Regensburg 45.000 DM	H 600 W 500 D 500
10	BioLum Luminous Bacteria Test*	<i>Photobacterium phosphoreum</i>	decline of luminescence	comparison sample vs. control	2 hrs. per week	Kolibri, Schwerte 70.000 DM	H 700 W 500 D 550 (2 pieces)

* For further information contact the producer

cornerstones in establishment of trans-boundary monitoring between cross border countries (e.g. Rhine, between Switzerland/Germany and Germany/Netherlands).

In the nineties with establishment of the New Independent States in the Europe (and together with East European countries) the number of international river boundaries increased rapidly. In 1992 in Helsinki, Water Framework Directive of the European Commission under the auspices of United Nations Economical Commission for Europe (UNECE), established the Convention on Protection and Use of Trans-boundary Watercourses and International Lakes. The convention was set up as a framework for management of nearly 115 major trans-boundary rivers and 20 international lakes. This came into effect in 1996 and under the UNECE Water Convention, the Task Force on Monitoring and Assessment has drafted 'Guideline for Water-Quality Monitoring and Assessment of Trans-boundary Rivers'. The implementation of the guidelines will be effected in a series of trans-boundary river basins in Central and Eastern Europe. On-line monitoring stations will be established on either sides of the boundaries for compliance and regulatory monitoring and as well as a control measure between the bordering countries with the aim of improving health and environmental impacts. As a result a large number of on-line monitoring stations will be established not only in the main rivers, but also along the tributaries of large river systems. For example the following Danube tributaries will be installed with on-line monitoring stations: Ipel/Ipoly (between Slovakia and Hungary); Mures/Maros (between Romania and Hungary); Latorytsya/Latorica and Uz/Uh (between Ukraine and Slovakia); Morava (between Czech Republic and Slovakia).

Trans-boundary water pollution is a widely recognized environmental problem in Central and Eastern Europe. A key objective of the EU environmental policy for the future is the protection of water resources (Hayward, 1999). The establishment of trans-boundary monitoring in Eastern Europe as well as New Independent States (NIS) will lead to improvement of the river systems through the control of 'trans-boundary impacts' in river systems. This will include pollution control through emission limitations, action programs for improvements in waste water treatment, water quality improvement and water management in the basin and sub basins. This will eventually result in improvements in water quality in large river systems.

Such improvements are already visible in the Rhine and the Danube, but monitoring efforts were initiated three decades back. Today an effective early warning system in both rivers can deal with short and sudden contamination, as in case of accidents spillage and malfunctioning of waste water treatment plants (Figure 5 & 6; Gunatilaka & Dreher, 1996; Rodda, 1994; Botterweg & Rodda, 1999; Pintér, 1999; IKR, 1987). In the Rhine, the pollution load from the nutrients, heavy metals and organic micropollutants have decreased nearly to one tenth and the organic load to half that of the seventies. The International Rhine Action Program adopted in 1987 stresses the further reduction of pollution load to improve the Rhine ecosystem and to protect the North sea (IRC, 1987). The effectiveness and successes of protection measures resulted from among others, a continuous water quality monitoring net built along the Rhine and its tributaries where trans-boundary monitoring, vigilance and peer-pressure has played an important role. Figure 7, (Panel A and B) show a comparison of water quality in the Rhine during 1969/1970 and 1994, in the State of North Rhine-Westphalia, the State which is adjoining The Netherlands (Trans-boundary stations: Lobith / Netherlands; Kleve-Bimmen / Germany). Here there is a drastic improvement in the water quality as well as in the river environment; the biological assessment shows the transformation of the Rhine and the tributaries from *alphamesosaprobic* (Class III, heavily

contaminated) to *betamesosaprobic* (Class II, moderately polluted) (see Figure 7 for the details of the classification). However, this transformation took nearly twenty five years.

In the early seventies due to high organic load in the Rhine through untreated sewage, the oxygen saturation was low. Gradually treatment plants were built for the treatment of industrial and municipal wastes in many cities and industrial complexes along the river. These measures resulted in improvements in oxygen levels in the river, and at present even under dry weather flow, oxygen concentrations are above 6 mg/l (Irmer 1996), which is also the critical limit for fish. As Rhine water was heavily polluted in the sixties and seventies, it caused acute deaths of *Daphnia* and trout embryos (Poles et al. 1980; Slooff, 1982, 1983; Sloof et al. 1983.) but in early nineties, the toxicity of Rhine water in terms of acute mortality of *Daphnia magna* has markedly improved (see Hendriks et al. 1994).

Macrozoobenthos are good indicators of river water quality. With the reduction of the pollution load, macrozoobenthos populations have reacted immediately, their numbers started increasing since the mid seventies. However, in the lower Rhine the species composition has changed; some sensitive species have disappeared and several new species (neozoa) have colonized the vacant niches. This is seen with Molluscs, Chironomids, Caddies flies, and flatworms; Crustaceans became dominant in the nineties. In general immigrant species have shown a steady increase in the Rhine and this is true for macrozoobenthos as well for fish populations (van den Brink et al., 1990). The Ecological Master Plan under the Rhine Action Plan (IRC, 1987) is directed towards restoring the river as a habitat for sensitive migratory fish species ('Salmon 2000'). This includes the protection, preservation and improvement of ecologically important stretches of the Rhine and its tributaries (Irmer 1996).

Both off-line as well as on-line monitoring programs executed in the upper Danube (from source in Germany to Austrian/Slovakian border; nearly 350 km stretch) in conjunction with stringent environmental regulations have resulted in improvement in the river water quality (Class II, *Betamesosaprobic*). Also structural improvements in the main river as well as tributaries have contributed to improved habitat structure for the fish fauna. The fish fauna of the Austrian Danube is characterized by its large number of species (Jungwirth 1984, Schiemer & Spindler 1984). Fifty seven species have been recorded during the recent surveys, 52 of which are autochthonous or long-term established elements (Schiemer & Waidbacher 1992). These include rare Salmonids like *Hucho hucho* which are very sensitive to poor water quality and oxygen concentrations; the other Salmonids found commonly in the Austrian Danube are *Salmo trutta forma fario*, *Salvelinus fontinalis* and *Oncorhynchus mykiss*. In general fish communities are good indicators for habitat structure as well as for the ecological integrity of large river systems.

4. Needs for standardization

With the expansion of on-line monitoring, the need for standardization of commercially available measuring systems are increasing. It is needed by the users, law enforcing authorities to compare the results of measurements from different sources carried out by using similar instruments but produced by different manufacturers. At present it is difficult to compare instruments from different vendors due to lack of proper documentation as well as test protocols of the instrumentation. More over most of the on-line instruments which are sold, are not field calibrated and tested. Rivers are dynamic systems and the instruments may be exposed to completely different matrices than the laboratory calibration medium or physical conditions (e.g. floods, high sediment loads). The users as well as authorities are

unable to test and compare different products before purchasing due to lack of the test protocols and some shortcomings described below.

During installation of on-line, water quality monitoring stations along the Danube for river water and ground water control (Gunatilaka & Dreher 1996), we had to find answers by ourselves for many questions in regard to the installed instrumentation. This included specific information such as rise and fall time, up time, dead (lag) time, drift, memory effects, trueness / bias and accuracy to mention a few. To our surprise some of the information supplied by the vendors on basic specifications such as linearity, lowest detectable change and limit of detection was either inaccurate or completely wrong. Common sensors used in monitoring like red-ox electrodes (oxidation reduction potential measurements) or analyzers used for dissolved organic carbon (DOC) or total organic carbon (TOC) were plagued with such problems. The red-ox sensors we installed had inherent problems such as platinum electrodes getting coated with reduced substances (common in ground water) which needed daily cleaning and calibration to obtain accurate results. Other than that, the instrument recorded a false redox value without subtracting the electrode potential of the reference electrode (see Zo Bell, 1949) and introduction of a correction was not possible. We tested five DOC analyzers from well-known instrument makers (2 from USA, 2 from Europe, 1 from Japan) before the final selection. The main criteria given for selecting an instrument was that they should stand a six months continuous field test with no break down and should have a capability of measuring low DOC concentrations (low as 1 mg l^{-1}). The measuring range given in the technical specifications for all instruments were $1 - 10 \text{ mg l}^{-1}$. However, almost all the instruments tested were either inaccurate or incapable in measuring low concentrations (in the stations we are monitoring, ground water DOC concentrations are usually below 2 mg l^{-1} and it is common to have values around 1.20 mg l^{-1}) and the precision and accuracy of the measurements were poor. Two instruments were withdrawn from the test during the first week; another two in the third week. With the one left, the test was continued up to the second month. As we needed an accurate measuring instrument for DOC for the monitoring stations, we personally collaborated with the technicians from the vendor in rectifying the faults in the instrument which in total took 18 months. The same company produced an on-line, TOC (total organic carbon) process analyzer which we installed for river water analyses. Again it took another two years for modifications and adjustments to produce reproducible accurate results. The above examples show the dilemma users have to face, and the problems mentioned are solvable only by trained experts. In most cases the users buy the instruments on the recommendation of a vendor without the consultation of a specialist.

On the other hand the same on-line sensors today are used in large quantities by the water industry, food and beverages industry, and waste water treatment plants. There is a large effort in Europe to upgrade the waste-water treatment plants (numbering more than 60,000) through process optimization using on-line monitoring and up to date information technology (IT). On-line measurements deliver 'real time' data and serve as a link to the real world. However, inaccurate on-line measurements coupled to high computational power will not bring the expected results. Redox potential and oxygen in waste water treatment plants (WWTP) are measured using electrodes (the classical sensors used in waste water treatment industry) and they are coupled to activation of blowers for aeration. When the redox potential in treatment ponds drops close to zero mV (at the nitrate break point; parallel the oxygen concentration drops), the blowers are activated for re-oxygenation. However, faulty redox measurements naturally could lead to high energy consumption in the WWTP. The same is true for on-line nutrient measurements (ammonia, nitrate and orthophosphate) which provide basic information on nitrification and denitrification processes as well as the biological and chemical processes removing phosphorous. Based on calculations for Denmark (5 million

population, 1.5 bill ECU investments, operational costs/year > 5%), with accurate on-line measurements, it is estimated that 15-25% could be saved on investments alone. If this is extrapolated to Europe (>250 million population) savings for investments and operations will be high as 15 billion ECU and 1 billion ECU/year respectively (Jakobsen, 1998). [1 ECU is approximately equivalent to 1 US \$ in 1999].

Based on this information, to remedy this deficiency a European project for evaluation of on-line sensors was established in 1998 referred to as ETACS (European Testing and Assessment of Comparability of on-line Sensors). The scope of the project is to present: (a) a standardized description of on-line in-situ sensors, (b) establishment of standards for on-line sensors and (c) development of an accurate test protocol useful for manufacturers as well as users (ETACS, 1999).

It is the intention that the findings of the ETACS project to be used as a basis for a European as well as a ISO-Standards for on-line in situ analyzers and sensors. The standards will ensure the uniformity of the on-line water quality measurement. This will bridge a serious gap in the monitoring and control technology and help to produce reliable data for real time process control as well as for river monitoring. Additionally it will be an advantage for environmental authorities for compliance monitoring as well as harmonization of databases.

5. Contemporary developments

The urgent need for drinking water, food and recreational areas on one hand, and dangers of increasing eutrophication and pollution (chemical and microbiological) on the other, are problems well known in the temperate zone. Although not yet serious as in many industrial, temperate countries, the latter problems may develop quickly and probably become much more serious in fast developing regions in the tropics, especially in South East Asia.

In the developing countries problems concerning water quality have become aggravated during the last decades (World Bank 1994). In industrialized countries, the problems of pollution through intensive agricultural practices, release of large amounts of industrial effluents and domestic wastes gradually developed during the last century but fast developing countries are experiencing the same effects in much shorter time (see WHO 1989). Wide spread anthropomorphic pressures on aquatic ecosystems have been caused by rapid urbanization (organic and inorganic load), industrial expansion, and excessive sedimentation from land clearance and deforestation. For the major river systems in most of the South East Asia today suffers from these anthropomorphic stresses to such an extent, that in the lower reaches of the rivers, the water quality was considered substandard [untreatable by conventional means; based on 80% samples taken; see Gunatilaka, 1999]. To avoid social chaos and environmental catastrophe, the management of existing water resources (as there are nearly no new resources to develop) should take priority; and hence the management of rivers and river basins is an important task. In time, it is hoped that the standardized, improved sensor techniques and automated control systems developed for river monitoring in Europe will become available for developing countries.

Similar to most of the developing countries in South East Asia, Indonesia has most of the contemporary water quality problems of the developed nations such as pollution, eutrophication, toxicity development, ecosystem dysfunction, acidification from air pollution now aggravated through long standing forest fires. Industrialized countries have faced most of these problems sequentially but Indonesia is facing them simultaneously. Due to severely degraded water quality several developing countries are facing water shortages (United

Nations, 1997) and it is true for East Java. Even more grotesque is that there are a few new sources of water available in East Java to be developed, which means that remediation of available sources will be a necessity in the near future. For example in Indonesia, a country with 204 million population, the demand for bottled drinking water has increased from 323,000 liters in 1987 to 4 million cubic meters in 1998 (an increase of nearly 12,000 times). Therefore development of river basin or sub-basin management programs should be given priority to avoid water scarcity in the next 25 years. The major problem the government has faced today is to improve the water quality of the river systems to meet the demand from different sectors and to improve the capacity of water supply for domestic, industry, agriculture, energy, tourism and other uses.

To achieve this goal the government of Indonesia emphasizes the importance of an integrated approach for water resources management based on river basins. The intention is to meet the conflicting demands through managing the available water resources using up-to-date, state-of-the-art technology and appropriate tools. A key to water resources management is availability of reliable data, which are lacking in most of the developing countries. The new water resources management activities introduced by the government will eliminate this deficiency. The proposed program is comprised of the following elements: a water resources data management system, a basin water allocation/operation system, a quality management system and a river management system. As a first step, an elaborate water quality and water quantity monitoring network comprising of both on-line and off-line monitoring stations is implemented in one of the largest rivers in East Java (Brantas), along with other river basin management operations. If this program is successful, similar monitoring systems will be established in other river systems in West and Central Java (Gunatilaka, 1999).

6. Conclusions

The above mentioned developments stress once more the importance, as well as the need for the availability of accurate monitoring sensors and analyzers. The expansion of the continuous monitoring with the interests in obtaining accurate real-time data for process management as well as river monitoring has become a global need which is pushed forward through development of sophisticated sensors as well as rapid development of the information technology (IT). These processes will be facilitated through development of standardization for all type on-line sensors and analyzers, and the economic impact of adopting such products has to be emphasized. As the sensors generate vast amounts of data, parallel development is necessary in data acquisition and telemetry, IT – concepts for data handling, database management and guidelines for efficient use of the generated information.

With respect to the development of new on-line sensors the following requirements must be addressed: sensitivity, precision, reliability, repeatability, reproducibility, stability, plausibility of data. Also self-cleaning, low maintenance requirements, auditable performance to a defined standard, availability (up-time) should be anticipated characteristics of on-line sensors. Analyses are carried out in remote locations, they require more rugged but reliable instrumentation than laboratory installations. Another proviso is that the instruments will be in operation round the clock (continuous, unsupervised operations), and hence, total automation of calibration of the instrumentation as well as simplicity in operation will be required.

With large numbers of new chemical substances entering river systems, continuous monitoring systems for their detection will become increasingly important with respect to environmental effects they produce, in addition to carcinogenic, endocrine or other toxic effects. Much effort has to be directed towards the on-line detection of such pollutants in

ivers. Thus the challenges to continuous chemical and biological monitoring will be immense. Finally the importance of integration of biological and chemical monitoring has to be emphasized. The on-going efforts for such integration by the International Commission for the Protection of the Rhine should serve as an example for other large river systems in Europe.

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Figures and Table Titles

Figure 1. Rhine Water Monitoring Station at Worms (river-km 443.3). The instruments for sampling, measuring and analyzing river water are located within the historic bridge tower and the laboratory (white) building. Samples are taken by means of diving motor pumps at four sampling sites across the river section of which two pumps are located at the opposite river banks, and the other two pumps are fixed to the central bridge piers. As the contamination plumes from the discharges are concentrated close to the river banks, the biomonitors (Dynamic Daphnia Test, DF-Algae Test) continuously monitor the left and right bank sampling sites. (Photo: Diehl)

Figure 2. The water from the four sampling sites (located across the river section) is led through 4 sets of on-line instruments where water temperature, pH, oxygen concentration, electrical conductivity, turbidity, spectral absorption coefficient (SAC, 254nm) and fluorescence are measured. Also four sets of automatic samplers (2 for each sampling site) are installed for continuous sampling for routine (major and minor ions, metals, nutrients and organic micropollutants etc.) analyses. In addition to the chemical/physical on-line measurements, biomonitoring (algae, Dynamic Daphnia Test) and routine analysis, a GC/MS screening for organic micropollutants is made daily. The photo shows the on-line instruments and the automatic samplers which are integrated into the restored vaults of the historic bridge tower. (Photo: Diehl).

Figure 3. On-line monitoring station at Lobith (Netherlands) on the Dutch – German border (River km 862,3, right river bank; at Kleve -Bimmen , River km 865,0 on the left bank is the corresponding German continuous monitoring station and both serve as International trans-boundary monitoring stations). The ship anchored at the shore houses a well equipped laboratory which analyses a wide variety pollutants in the river ranging from standard parameters, nutrients, trace elements to GC-MS and HPLC screening for micro organic pollutants and biomonitoring (algae and Dynamic Daphnia Test). (Photo: Gunatilaka)

Figure 4. Donaukraft – Groundwater on-line monitoring station along the Danube at Nussdorf (River km 1932,26;). The station controls the water quality of the river bank filtrate that is recharged into the ground water aquifer in the second and twentieth districts of Vienna. The station also continuously monitor river water; facilities installed includes both chemical and biomonitoring (Dynamic Daphnia Test). (Photo: Gunatilaka)

Figure 5. Alarm alerting through Danube Action Plan which is in operation in the Austrian stretch of the Danube (executed through Donaukraft). Hierarchical organization of the alarm plan couples the on-line as well as off-line information and stored in a central database which is used for decision making processes. In case of an alarm, groundwater recharging will be automatically stopped and remedial measures are undertaken.

Figure 6. Proposed alarm warning plan for the Rhine. At present the Rhine Warning and Alarm Service relies on on-line chemical measurements and information on emissions. In the future information from both chemical as well as biological monitoring will be coupled for conformation of alarms. (Monitoring concept of the Rhine, LAWA working committee, Diehl, in prep.).

Figure 7. A comparison of the water quality of the Rhine River in the State of Nordrhein-Westfalen, Germany during 1969/1970 and 1994. Water quality is both chemically and biologically assessed. The legend to the water quality assessment shown in the maps is as follows:

Quality class I: Unpolluted to very lightly polluted (*oligosaprobe*)

Quality class I-II: Lightly polluted (*oligosaprobe to betamesosaprobe*)

Quality class II: Moderately polluted (*betamesosaprobe*)

Quality class II-III: Critically polluted (*betamesosaprobe to alphamesosaprobe*)

Quality class III: Heavily contaminated (*alphamesosaprobe*)

Quality class III-IV: Very heavily contaminated (*alphamesosaprobe to polysaprobe*)

Quality class IV: Excessively contaminated (*polysaprobe*)

Note the water quality change in the Rhine from heavily contaminated (Class III/*alphamesosaprobe*) in 1969/1970 to moderately polluted (Class II/*betamesosaprobe*) in 1994. Under alphasaprobic conditions, the river was heavily polluted with organic matter which consume oxygen leading to low oxygen levels and periodic fish deaths were common. Under these conditions sewage micro flora was dominant and macro organisms were limited to sub-oxic species that have adaptations to live under low oxygen concentrations. Similar conditions prevailed in almost all the major tributaries. Due to strong national and international monitoring efforts, the water quality of the Rhine improved gradually and the 1994 inventory shows a change to betasaprobic conditions. This means that although the river is moderately polluted there is no oxygen depletion. Due to improved oxygen condition reduced pollution load the disappeared macro invertebrates and fish assemblages are returning back to the river but along with new migrant species. Also similar changes are observed in the tributaries.

(Maps: Through courtesy of Landesamt für Wasser und Abfall Nordrhein-Westfalen, 4000 Düsseldorf).

Table 1. Continuous Biotest Systems for river monitoring – a synopsis of the recommendations of LAWA (Working Group of the Federal States on Water Problems, Germany), based on biotest systems tested in the research project ‘*Wirkungstests Rhein*’ (Irmer 1994) and those implemented by the state authorities in Germany. (modified and translated from German).

Figure 5. Alarm alerting through Danube Action Plan which is in operation in the Austrian stretch of the Danube (executed through Donaukraft). Hierarchical organization of the alarm plan couples the on-line as well as off-line information and stored in a central database which is used for decision making processes. In case of an alarm, groundwater recharging will be automatically stopped and remedial measures are undertaken.

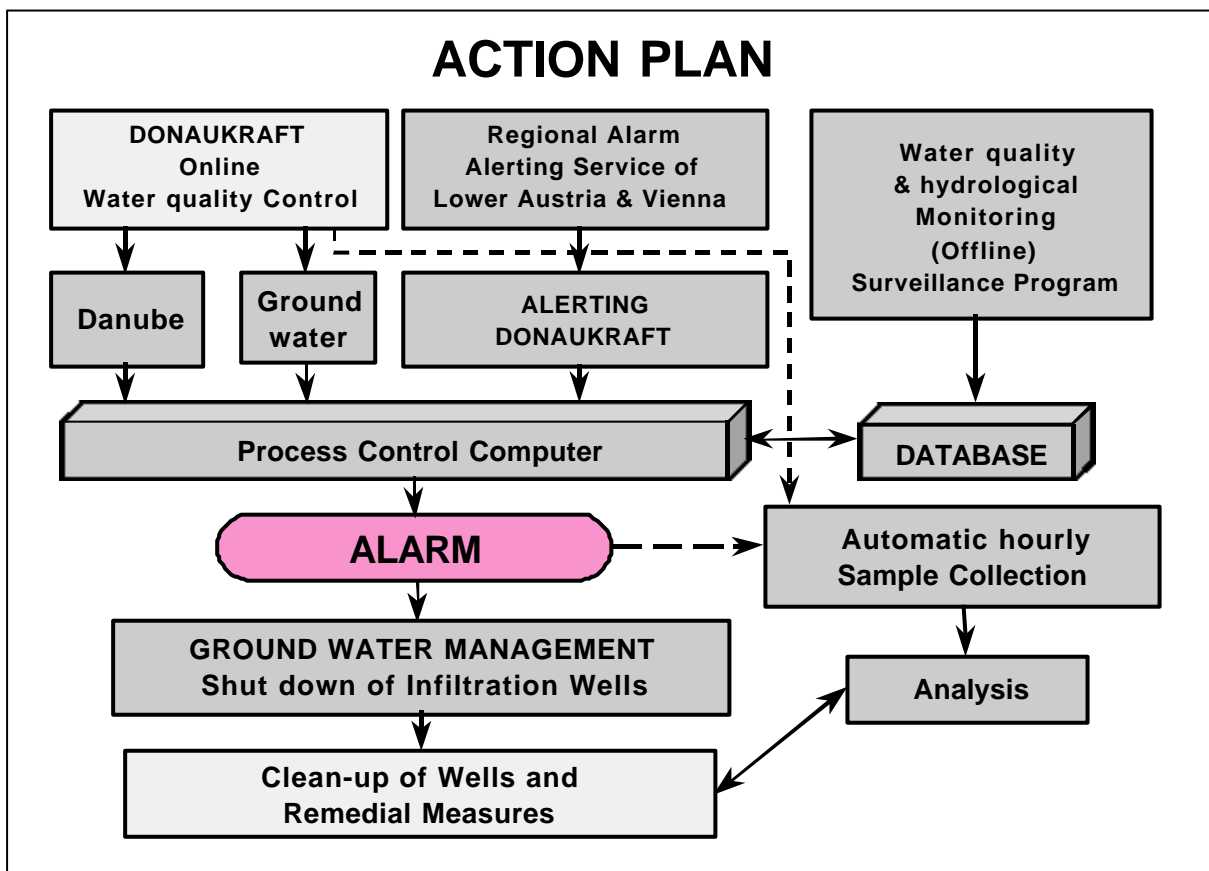


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