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AVAILABILITY OF AUTOMATIC WATER QUALITY MONITORING FOR FINNISH WATERCOURSES

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The purpose of this work was to investigate the availability of automatic water quality monitoring for watercourse monitoring in Finland. The National Board of Waters has used during the years 1974—1983 eleven automatic water quality monitoring stations, of which five made up the River Kymijoki and Kokemäenjoki system and the others were easily transportable stations. The variables measured were temperature, pH, conductivity, dissolved oxygen and turbidity, as well as chloride at five stations. The major causes of disturbances were difficulties in sample water pumping and malfunctions of the station microprocessors and the system main computer. The operational efficiencies of both the stations and the measured variables were satisfactory and improved markedly when maintenance procedures were modified from troubleshooting calls to preventive maintenance. Automatic monitoring disclosed at many locations previously undetected fluctuations in water quality, while at other points confirming the stability of the quality level. Continuous monitoring revealed illicit discharges by the pulp and paper industry and displayed the effects of unusual operations on water quality. The effects of treated municipal waste waters on stream quality could also be clearly observed, especially during the summer season. Stream regulation and dredging altered noticeably and rapidly the quality of the water. The character of fluctuations in water quality, the statistical parameters of the data and the optimal monitoring frequencies calculated from these values can be applied to the development of manual monitoring. There are only a few watercourses in Finland requiring permanent automatic water quality monitoring stations. Mobile automatic stations are suitable for the water quality monitoring of small streams over a relatively short time. The automatic monitoring of the water quality of watercourses should be used as a part of a wider jointly supervision of the environment.

Index words: Automatic monitoring, river water quality, sampling frequency, Finnish watercourses.

1. INTRODUCTION

The increasing pollution loads applied to watercourses have led to an intensification in water research. This in turn has made it necessary to develop also newer and more reliable measuring methods to provide rapid and sufficient data on abnormal loads and their effects on the quality of the recipient watercourse.

The monitoring of waste water discharges and their effects on watercourses relies on periodical manual samples analysed either in a laboratory or in the field. However, this traditional monitoring method cannot be intensified very much at reasonable cost without problems in working time and personnel. The main advantage of automatic monitoring lies in the possibility to yield data much more frequently than by manual methods, if required even continuously. Water quality can vary very rapidly, particularly in heavily loaded rivers. In such a situation automatic monitoring presents indisputable advantages as a supplement to manual monitoring. Continuous supervision of water quality is particularly important when water resources are limited, the water is in danger of being polluted, and it is used also for other purposes than receiving waste waters.

Finnish inland waters are mainly watercourses consisting lakes joined together by streams. The variations in water quality in lakes are usually fairly slow, and for that reason a frequent monitoring is not necessary either from a utilization or a conservation point of view.

Three main objectives may be assigned to automatic water quality monitoring:

- the monitoring of loads, such as the supervision of discharge permits, the control of accidental spills and the monitoring of raw material wastages,
- the monitoring of water quality in watercourses for controlling the effects of waste disharges and the suitability of the water for certain purposes and
- the monitoring of the condition of watercourse for detection of trends.

The beginnig of automatic water quality monitoring can be traced to the late 1940's, when industrial control systems and instrumentation began to improve rapidly. The world's first automatic measuring stations began operation in the Federal Republic of Germany at the beginning of the 1950's (Liepolt 1963, Malz 1963, Eckoldt 1967). The first stations were separate instruments located at bridges and dams, measuring continuously temperature, pH and conductivity. Ten years later the stations on the River Emscher and Lippe monitored also turbidity, sedimentation and water toxicity using fish tests.

Automatic measuring instruments were used in the United States first under field conditions during the mid-fifties. Only one or two variables were measured at the time, water temperature and conductivity, and the results were plotted on to recorder. Recording the data on punched paper tape in 1965 enabled direct processing by computer. Stations located on the Delaware Estuary measured towards the end of the 1950's also pH, dissolved oxygen and turbidity. A fundamental improvement in instrument design took place in 1963, when the first monitor, where sensors were all contained in one cabinet, was developed. This unit measured also air temperature and solar radiation (Ward 1973). The world's first automated water quality monitoring system was built in 1960 in the Ohio Valley (Cleary 1962). The ORSANCO system included fourteen river stations under computer controlled operation and data transfer.

The establishment of new automatic monitoring systems and the construction of new stations advanced fairly slowly at the beginning of the 1960's. However, progress was made at such a pace that by 1968 there were about 250 monitoring stations in the world, more than 200 of these being located in the United States (Florczyk 1971).

The proceedings of the conference held in 1971 in Poland in conjunction with a project supported by the WHO provides an excellent overview of the situation of automatic water quality monitoring systems and installations in various countries at the beginning of the 1970's (Krenkel 1971). Five years later Muhonen (1976) published a literature review of the situation then prevailing. The introduction to this study will therefore limit itself to information missing from these publications and concentrate on the developments of the last ten years.

The water quality of the River Mosel in the Federal Republic of Germany has been monitored since 1977 at five stations, which a year later were connected by a data transfer network (Kalweit 1981). Eleven in-situ stations have been operating on both the stream and the tidal sections of the Unterweser for ten years. This system, featuring data transfer by radio, may be expanded by a further eleven stations (Kunz 1981). In 1981 a system consisting of 20 stations became operative in Lower Saxony and the stations measure meteorological variables in addition to the traditional ones. It is planned to expand the water quality monitoring system by 16 stations during the current year (Plate 1981). A river monitoring station described by Klöppel (1981) has proved capable of measuring the same variables in treated waste waters, too.

The automatic stations introduced in Scotland at the beginning of the 1970's suffered from such extensive operating difficulties arising from various external factors that most stations had to be taken out of operation by the end of the decade.

In 1974 there were 33 monitoring stations in England and Wales. The number increased to 80 by 1982. About half of these stations were used to protect a water supply intake. Routine measurements included also NH_4 and NO_3 nitrogen determinations through ion-selective electrodes. Automatic mobile stations capable of measuring water quality and its potential toxicity to fish are in routine use (Sharpe 1979, Best 1983, Evans and Johnson 1983). A measurement of organic load presently under development uses ultraviolet radiation while suspended solids determination is based on laser technology (Cope 1981). Three stations located on the Thames Estuary have monitored since 1981 the impact of the discharges flowing from the upper reaches on oxygen conditions at the tidal sections of the river where fresh and sea water is mixing (Cockburn and Furley 1981).

In Japan automatic monitoring of water quality began in 1969. Progress has been very rapid, since in 1977 there were already 295 stations in operation. In addition to the traditional variables, the stations measure NH_4 nitrogen as well as cyanide, sulphide, chrome, total mercury, oil, phenol and TOC through the use of separate analysers. In the Osaka region, the COD load has successfully been automatically measured for the last seven years at ten river stations, three water treatment plants and six factories. Both river and sea monitoring stations are joined through a telecommunication network to a central computer. A need is felt for commercially available nitrogen and phosphorus analysers (Irie 1978, Nanbo and Kunogi 1981).

France began automatic monitoring of water quality in the 1970's. The stations measure pH, conductivity, turbidity, ammonium or total nitrogen and TOD. The measurements have been found adequate, even though investments and operation expenses have been high. In 1975 two mobile stations were taken into operation in the Artois-Picardie region. This soon brought out the need for continuous monitoring of waste water quality. The first four waste water stations were built in 1978 and 1979 (Journet 1981).

According Solov'yev et al. (1976) already at the beginning of 1970's on the River Volga and the Moscow Canal in the Soviet Union was made investigations about systems with continuous sample delivery to the research vessel's laboratory for automatic monitoring of temperature, pH, conductivity, dissolved oxygen and transparency. During the early part of the 1970's two Soviet made and some imported automatic stations were put into use for scientific and experimental purposes. According Stradomskiy (1976) the first Soviet automatic stations were designed to measure temperature, pH, conductivity, dissolved oxygen, suspended solids, redox potential, copper, hydrogen sulphide, and water level. Development of first local experimental monitoring systems have been planned for a 100 kilometer reach of the River Moskva with seven to nine stations. Another system of two stations was to be installed on the Mozhaysk Reservoir. The first stage of the systems was to be completed at the end of 1975. The initial factor in the development of a mathematical base for automatic monitoring systems was analysis of water quality data obtained through an experimental model of an automatic station operating since the end of 1972 on the River Aksay in the city of Novocherkask.

In the middle of 1970's Stradomskiy et al. (1976) investigated the electrode systems of automatic stations, the effect of pollutants on them, and methods of protecting them from pollutants. They also developed new sensors and monitors for measuring several additional surface water variables, such as chloride, sodium, fluoride, sulphide and total content of organic substances. Stradomskiy (1976) also treated the necessity of transportable and portable monitoring instruments, as well as in-situ measuring technique. These subjects have been handled in the last years in the Soviet Union very intensively in Estonia (Kohonen and Viies 1985).

In Rumania, continuous water quality monitoring was initiated in 1971. About ten years later eight stations were operative. Two of these were mobile stations on the Donau. Measurement variables worthy of note are water toxicity using fish tests, cyanide, sulphide and ammonium (Antoniu et al. 1983).

In Italy the regional and governmental authorities have planned an air, water and meteorological monitoring system which was to have comprised 30 stations in 1978. At first there were three monitoring stations on the River Reno similar to those installed on the River Kymijoki. Both radio links and telephone lines are used for data transfer (Gatt and Lee-Frampton 1976).

In Norway the national research institute, NIVA, has used four automatic monitoring stations measuring three to five common variables. Satellite telecommunications have been successfully used for data transfer. There is a need for continuous measurement of new variables, such as aluminium, orthophosphate and alkalinity. Probes for biological variables are also required both for field and laboratory work (Källqvist and Arnesen 1983).

Bulgaria uses both domestic and Czechoslovakian and Hungarian built stations. In addition to variables commonly monitored automatically, instruments to measure chloride, cyanide and nitrate nitrogen are being developed for the Bulgarian station. The remaining two types of stations allow the measurement of organic substances (United Nations 1984).

The station made and used in Czechoslovakia measures also organic contents through an ultraviolet technique, chloride, air temperature and total solar radiation (Bayer and Radouch 1975).

A general trend of the last few years has been an obvious increase in the applications of new content measuring electrodes and analysers to the automatic quality monitoring of watercourses and waste water discharges. Instrumentation based on biological monitoring and suitable to water supply supervision has been developed to monitor toxicity. More efficient maintenance, greater reliability through automatic cleaning and calibration, and use of double or even triple piping and electrode systems have resulted in improved operation efficiency and reliability of the monitoring stations.

The aim of this study was to investigate the availability of the automatic water quality monitoring for Finnish watercourses subject to various types of loadings, on the basis of results and experiences from the stations and systems used by the National Board of Waters during the years 1974–1983.

2. MATERIALS AND METHODS

The possible applications of automatic water quality monitoring in Finland were investigated on the basis of the experience and results obtained from the stations available to the National Board of Waters during the years 1974–1983. This study also includes some unpublished data, which was felt to be essential to the study.

The monitoring system of the River Kokemäenjoki, released for research work in February 1976, included in its original configuration a computer controlling the system, a remote terminal located at the local water authority, three watercourse stations and nine measurement sites at pulp and paper mill. Four of the latter were situated at effluent drains and five within the mill on the waste water piping to the treatment plant. The river stations measured temperature, pH, conductivity, dissolved oxygen and turbidity. Two of the stations also measured flow. The electrodes were installed in an open measurement chamber through which the sample water circulated. The electrodes could be automatically cleaned and calibrated under computer control. The river stations were also equipped with an alarm sampler holding 24 bottles (Kohonen 1979).

Fouling and plugging problems at the stations led to efforts to improve the deficiencies noticed in the design of the river and mill monitoring stations in order to raise their operation. At the beginning of 1978 lack of funds, however, made it mandatory to focus development work on two river stations only. The completion of the task became more difficult since the technology of the stations did not come up to expectations in the polluted Nokianvirta stream and no financing could be obtained for the multiplicity of structural alterations required. A satisfactory level of measurements would have necessitated several daily maintenance calls, automation was therefore not found to be worth the costs involved at the time. The wide variations in water quality and flow due to upstream regulation and downstream discharges at a hydroelectric plant impaired the application of the data obtained to the detection of loading alterations. For these reasons the initial goals of the research project could not be attained and the project was stopped in 1979 (Kohonen 1982).

The monitoring system of the River Kymijoki completed in 1977 included a PDP 11/35 computer and peripherals as main processing unit. Data transfer from the microprocessors controlling operations at the river stations to the computer was initiated twice daily by the computer through the national telephone network. The computer output consisted of a daily report listing alarm limits and deficiencies for each monitoring station, the average and extreme values of the measurements, and half-hourly averages as a routine operation. The Kymi Water District Office could also request computer reports at its own terminal (Kohonen and Lee-Frampton 1979, Kohonen et al. 1980, Kohonen 1982).

The above mentioned stations measured temperature, pH, conductivity, dissolved oxygen and turbidity. Three stations also measured chloride. The electrodes were subjected automatically to an ultrasonic cleaning every hour. The pH, conductivity, oxygen and chloride electrodes were automatically calibrated once a day. Every station included a 24 bottle alarm sampler. Submerged pumps provided the water flow through the measurement chambers for monitoring and sampling purposes. The measurement values could be output to recorders or a printer whenever required, such as during maintenance calls.

In 1979 a new contract was signed to succeed the 1974 development agreement on automatic monitoring system of the River Kokemäenjoki. It comprised the planning and building of a new station taking its measurements directly within the stream. Two of the five monitoring stations originally located on the River Kymijoki were moved to the River Kokemäenjoki. This made it possible to report measured data also to the terminal of the Tampere Water District Office.

In 1974 the first and in 1976 the second trailer-build mobile automatic monitoring station was taken into operation. Both stations measured temperature, pH, conductivity, dissolved oxygen, turbidity, chloride and whenever necessary redox potential. A pump located in the stream or on the shore supplied sample water to a flow-through measurement chamber. Except the turbidity, all electrodes were subjected to an automatic ultrasonic cleaning every hour, and the pH, conductivity, oxygen, chloride and redox electrodes were calibrated daily. The mobile stations also had alarm samplers.

Both stations wrote out water quality data on recorders. A data logger in the first station calculated half-hourly and daily averages and recorded them on a printer and on punched tape. The averages calculated by the microprocessor in the second station were recorded on punched tape and a C-size magnetic tape cassette (Kohonen 1979, 1982).

The automatic and easily transportable monitoring station called for by the River Kokemäenjoki agreement of 1979 was taken into operation at the end of 1980. Probes submerged into the stream report temperature, pH, conductivity, dissolved oxygen and turbidity measurements to a microprocessor located on the shore, which outputs the values to a printer and punched tape (Kohonen and Princz 1983). This newest station also carries out repeatability and reproducibility tests on the measured variables (Kohonen 1982, Kohonen and Princz 1983).

The data provided by the first two mobile monitoring stations was processed at the Government Computing Center. Following completion of the automatic monitoring system, of the River Kymijoki, the data produced by both mobile and landbased monitoring stations was gradually modified for processing by the computer of the National Board of Waters.

Operational efficiencies of the stations were calculated as the percentage value of time in operation with respect to the total time on duty. Efficiencies of variables were calculated as the percentage value of the active time of each variable with respect to the time during which the variable could have been measured. The station locations and the operational efficiencies of each station and each variable as well as the sources of the disturbances were described for the three mobile stations over the years 1975—1982, depending upon the date each was taken into operation. Efficiency values of the River Kymijoki monitoring stations was calculated yearly (1977—1981) for each station as the average of the efficiency value of each variable (Kohonen 1982).

The study of the measuring values produced by the automatic monitoring stations was based on the half-hourly averages output by the processors. These were calculated from one minute measurements made by the instruments. A maximum of 46 half-hourly averages was used to calculate the daily averages for the two mobile stations and the monitoring system stations, since no measurements were carried out during the hour long calibration process of the electrodes. The electrodes of the newest mobile station were calibrated manually during maintenance calls, and thus a maximum of 48 measurement values was available to provide a daily average. Erroneous measurements arising from instrument defects or maintenance were removed from the data prior to statistical processing (Kohonen 1984).

The applicability of automatic monitoring to detect the variations in river water quality caused by pulp and paper mills waste discharges, municipal waste discharges, stream regulation and contruction works was estimated on the basis of the results provided by the mobile monitoring stations (Kohonen 1984). The suitability of the monitoring system to detect abrupt variations in water quality was judged on the basis of data measured on the River Kymijoki in May 1977 and June 1981. Data gathered from the River Kokemäenjoki from August to October 1980 was also used for the same purpose (Kohonen 1982).

An estimate of new, previously unperceived data produced by the mobile automatic monitoring stations was arrived at through a comparison of the characteristic parameters of both automatic and manual monitoring (Kohonen 1984). The data retrieved from the water quality register had been acquired either through normal observation programs or in some cases as reference measurements carried out simultaneously with automatic measurements. Only data of the samples analysed in laboratories and originating from identical time periods and locations as the automatic monitoring data was taken into account for these estimates (Kohonen 1984).

The observation and sampling frequencies were based on the international standard method (ISO 5667/1 1980), which Kohonen (1981, 1982, 1983, 1984) has adapted to data produced by continuous monitoring. The method defines an observation frequency whereby the average value of each variable will fall at a required confidence level within a given confidence of the actual average value. The large quantity of observations produced by automatic monitoring will satisfy the requirements of statistical theory that the characteristics of the entire population be known. This is a requirement which normal monitoring cannot usually fulfill. Since in Finland there are no confidence requirements assigned to averages of water quality variable, the values suggested by Ellis (1980) and Walker (1982) were used to define an optimal monitoring frequency.

3. RESULTS

3.1 Operational efficiencies

The operation of the original monitoring system of the River Kokemäenjoki would have required frequent maintenance which neither the polluter nor the authorities were able to organize. Furthermore, the wide variations in water quality and flow resulting from upstream regulation complicated the application of any data obtained to the monitoring of loading alterations (Kohonen 1982).

The equipment supplier of the River Kymijoki monitoring system guaranteed 90 percent operational efficiency for the monitoring stations during the hand-over trial period, which efficiency was achieved. The operational efficiencies of the stations and of each variable measured and the accuracies obtained during the first three months following commissioning of the system have been described in a special project report of the National Board of Waters (1978).

The yearly efficiency values for each variable at the Kymijoki system and later also at the Kokemäenjoki varied during the years 1977–1981 from 32 to 100 percent. The most frequent disturbances arised from the station microprocessors damaged by lightnings and from pump damage particularly in winter and during the spring thaw. Operational difficulties in the central computer also caused high data losses (Kohonen 1982). During longer interruptions in data transfer, chart recorders or printers were taken to the more important monitoring stations, Keltti on the River Kymijoki and Melo on the River Kokemäenjoki, to rescue the measurement data.

Initially, maintenance visits to the monitoring stations were spaced as widely as possible, sometimes as much as three to four weeks, in order to maximise the advantages of automation. These visits then were mainly troubleshooting calls. Restoring a station into operation and the consequent loss in measurement data might last from one day to a week (Kohonen 1982). These high data losses led to the initiation of regular preventive maintenance visits. Training given to the personel of the Kymi and Tampere Water District Offices has enabled them to carry out routine weekly maintenance and smaller repairs at the stations during the last few years. The actual repair maintenance has been carried out by the Water Research Office of the National Board of Waters in collaboration with the equipment suppliers. Although there has been a sufficient number of maintenance visits during the year, these have proved to be fairly irregular especially on the River Kymijoki, where only troubleshooting calls have been possible.

Operating experience from the years 1982–1983 shows that the shift from troubleshooting to preventive maintenance calls on automatic monitoring system has boosted the variable specific operational efficiency values over the 90 percent level for all variables when compared to the values listed by Kohonen (1982) for the years 1977–1981.

	1977–81	1982–83	1977–83
temperature	97 %	100 %	99 %
pH	80 %	98 %	90 %
conductivity	81 %	92 %	85 %
dissolved oxygen	64 %	95 %	78 %
turbidity	95 %	97 %	96 %
chloride	62 %	94 %	70 %

During the 1977–1983 period the most reliable measurements were temperature and turbidity, while oxygen and chloride measurements were distinctly inferior to all others.

The average variable specific efficiency values of the two stations transferred in 1979 from the River Kymijoki system to the River Kokemäenjoki improved by 2 to 21 percent units during the years 1980–1983 when compared to the previous values on the River Kymijoki. The increases must be attributed to the regularity and carefulness of the maintenance program and are listed below:

	River Kymijoki	River Kokemäenjoki
temperature	97 %	99 %
pH	88 %	96 %
conductivity	82 %	94 %
dissolved oxygen	71 %	92 %
turbidity	94 %	98 %
chloride	65 %	not measured

Since the mobile monitoring stations were located far from Helsinki, the local Water Districts personel were made responsible after proper training for regular maintenance while troubleshooting calls remained the responsibility of the National Board of Waters.

The operational efficiencies of the mobile monitoring stations varied between 29 and 100 percent according to the measurement location. The average values for each station were quite satisfactory and varied within a range of 79 to 93 percent. The newest station achieved an efficiency value of 99.8 percent during the one month commissioning period for each variable against a required value of 90 percent.

The best variable specific efficiencies for the entire study period were obtained at the first station with pH and dissolved oxygen (98 and 97 %) while conductivity proved to be the worst (78 %). At the second station temperature showed the highest value (99 %) and chloride the lowest (82 %). The corresponging maximum and minimum values for the newest station were 100 percent for temperature, pH and conductivity, and 94 percent for dissolved oxygen (Kohonen 1982).

To summarize, the mobile stations, which required pumping in the sample water operated satisfactorily and newest station which measured directly from the stream operated well. Seasonal factors and location affected most the operation of the stations. Supplying sample water to the stations caused such difficulties in winter that the two oldest monitoring stations had to be put out of operation during the winter seasons starting in 1979. In summer, the pumps, piping and measurement chambers tended to foul and clog within a short time period when monitoring strongly loaded watercourses. Also problems with temporary power lines disturbed the operation of the stations.

Difficulties were much rarer at the newest station, which took its measurements directly from the stream. Thus the station could be used to monitor also waste water. When monitoring the treated waste waters from chemical industry, the required maintenance need was one to two visits per week. Disturbances occurred in the microprocessor and electrical supply.

3.2. Operating experience

The experience obtained from automatic water quality monitoring is restricted mainly to watercourse monitoring, since the stations used had not been designed for waste water monitoring.

The purpose of automatic water quality monitoring in Finland has been the development of measurement techniques and operational reliability of instruments under various measuring conditions. It also provided an opportunity to observe the effects of waste water and non-point pollution as well as those of stream regulation and construction works on stream water quality. In the coastal sea area the variations in water quality caused by the flow of river water and currents has also been possible to monitor (Kohonen and Viies 1985).

Automatic monitoring provided data on water quality and the magnitude, speed and periodicity of its changes. The extreme values and the calculated half-hourly and daily measurement averages displayed the average level of the water quality, its long term alterations and any abrupt changes. The alarm samples taken by the stations enabled a later analysis of the discharges causing the sudden variations in water quality. Statistical methods could be applied to the data obtained to establish the required sampling or measurement frequencies (Kohonen 1982, 1984).

The effects of the waste water discharges of the pulp and paper industry on water quality were studied through a continuous monitoring of the River Kokemäenjoki, the River Kymijoki, the River Tervajoki and the River Tourujoki. These watercourses and their loads have been described in separate publications (Kohonen et al. 1978, Kohonen 1979, 1982, 1984).

Fish deaths were observed in July 1980 in the Nokianvirta of the River Kokemäenjoki. At that time the water was completely devoid of oxygen and the pH had decreased at least to 5, which was the lower limit of range. This situation was caused by a high temperature of the water and an exceptionally high by pass at the downstream Melo hydroelectric plant together with an effluent load upstream. Even towards the end of September the daily averages of dissolved oxygen still varied widely. Heavy rains at the beginning of October made it necessary to increase the river flow. This improved the oxygen situation markedly. Approximately a fifth of the improvement could be attributed to the high oxygen content of the rain water (Kohonen 1982).

Automatic monitoring stations produced large amounts of data from 1977 onwards on the River Kymijoki water quality and its variations. However, little use was made of this data and it was limited to the detection after exceptional industrial discharges from computer printouts. This situation improved following the accidental spill from Kymi Kymmene Oy pulp and paper factory in June 1981 which led to large fish deaths.

The first marked water quality alteration detected on the River Kymijoki through continuous monitoring took place as early as May 1977, when the Kymi Kymmene Oy sulphite pulp mill was shut down at Kuusankoski. The measurements taken at the two stations downstream, Keltti and Salonsaari, correlated well when taking into account the time delay required for the flow to proceed from the first station to the second one. The highest half-hourly pH averages detected by automatic monitoring exceeded three times within eleven days the previous highest values measured by manual monitoring during the years 1974–1976, at its maximum 1.4 units. The corresponding difference in conductivity was 1.8 mS/m (Kohonen 1982).

The June 1981 discharge which led to large fish deaths had been detected by the then operating Keltti and Hirvivuolle monitoring stations through a notable alteration in pH, conductivity and turbidity (Kohonen 1982). It was only as a consequence of this event that an effort was made to utilize the data produced by the automatic monitoring system in the researches and investigations relating to the River Kymijoki (Rautiainen 1983, Rautiainen and Virtanen 1984).

Automatic monitoring of the River Tervajoki, which receives discharges from the Tervakoski Oy pulp and paper mill, showed that the river water quality was noticeably worse and the quality variations were much more frequent and wider than had been suspected from manual monitoring. The condifidence level of the measurement averages selected to define a monitoring frequency resulted in a frequency requirement higher than daily. This may mean in practice automatic monitoring (Kohonen 1982, 1984).

Automatic and manual monitoring of the River Tourujoki, into which the Kangas paper mill discharges its waste waters, produced concordant results. The detection of extreme values and short term variations would require either frequent manual monitoring or automatic monitoring (Kohonen 1984).

The automatic monitoring of the River Porvoonjoki, loaded by the treated municipal discharges of the city of Lahti, showed that all variables varied more widely than manual monitoring had indicated. Automatic monitoring also revealed large daily variations which, as also the weekly cycle, were traced to maintenance operations at the waste water treatment plant. The variations in the water quality could still be detected twenty kilometers downstream from the point of discharge. The oxygen saturation average values differed markedly for identical periods when measured by various methods. The results of normal monitoring carried out over several years concorred well with the results of automatic monitoring. A reliable observation of the oxygen situation, especially during the summer season, requires daily sampling which in summer could also be carried out through automatic monitoring. A seasonal influence could be clearly detected in the calculated sampling frequencies and in the water quality (Kohonen 1982, 1984).

The importance of daily regulation on the variations in water quality of a stream heavily loaded by municipal and industrial waste waters became apparent in the results of the automatic monitoring of the River Loimijoki. The daily, weekly and monthly cycles observed in the measured variables would make either automatic monitoring or frequent manual monitoring mandatory in order to obtain reliable results. In the case of manual monitoring, the selection of the sampling time and the optimization of the resources available demand a complete investigation of the factors leading to and affecting daily regulation (Kohonen and Princz 1983, Kohonen 1984).

The trials made on the River Loimijoki in 1983 of continuously operating NH_4 and TOC monitors, carried out during the automatic monitoring period, were positive. The variations in NH_4 nitrogen detected, produced useful data with respect to the future development of the River Loimijoki monitoring (Kohonen and Princz 1983).

The effect of the Uljua reservoir regulation on the quality of the River Siikajoki could be detected eight kilometers downstream as noticeable daily variations. Automatic monitoring showed that with regard to pH and dissolved oxygen the average water quality was worse and the variations larger than had been suspected through manual monitoring. These variations could be detected by means of properly timed manual monitoring (Kohonen 1984).

A reliable monitoring of the River Kalajoki, where dredging increased turbidity and oxygen saturation varied during the winter on workdays and weekly cycles, would demand such frequent monitoring that the only practical method would be automatic monitoring. The effects of construction works on water quality could be observed in each specific case through temporary automatic monitoring. The results would then be used to define a suitable timing for manual monitoring (Kohonen 1984).

Whenever the loading to the river did not lead to noticeable quality variations, continuous monitoring brought out a daily variation in pH and dissolved oxygen arising from the primary production. This phenomenon was occasionally clearly noticeable on the River Loimijoki and Siikajoki (Kohonen 1984).

4. DISCUSSION

4.1. Utilization of automatic monitoring

According our experience the application of automatic monitoring equipment suffered from a decrease in motivation which followed the first enthusiasm. This may be attributed to:

- the difficulty of exploiting the large amounts of data produced by the stations,
- the extra work caused by alarm situations and the lack of means to prevent waste water discharges or their damages,
- the lack of a clear internal division of responsibility and method of operation up until 1982 within the Kymi and Tampere Water District Officies and
- the operating difficulties of the main computer.

The variables measured through automatic water quality monitoring at various locations occasionally displayed quite large fluctuations which previously had gone undetected by manual monitoring. The frequent data collected by the automatic stations uncovered short term variations and provided more reliable averages than the more widely spaced samples of manual monitoring. From a water research and control point of view it proved just as important that at some locations assurance could be gained of the lack of meaningful variations.

In cases where manual monitoring data was abundantly available for a given period of the year or more sparsely over several years, the statistical parameters calculated from both manual and automatic monitoring data were almost identical. Thus if it proves impossible to collect data over several years using sparse sampling, automatic monitoring will produce within a short period water quality data which will enable the determination of reliable average values, extreme values and short term variations. A dense water quality data will present, according to Belle (1983), fewer unexplainable variations than for instance material based on one or two samples per month taken over a long period, which, however, will be sufficient to indicate a trend. This has been clearly corroborated by the water quality data collected through the Finnish national water quality monitoring network (Laaksonen and Wartiovaara 1973, Laaksonen 1975, Laaksonen and Malin 1980).

In spite of the scarcity of variables measured through automatic monitoring, at least one always reacted to an alteration in river water quality resulting from discharges of the pulp and paper industry. In Norway, Källqvist and Arnesen (1983) observed also a correlation between discharges and pH fluctuations.

Continuous monitoring also detected the effects of loading variations on the quality of small watercourses caused by municipal waste waters and their treatment processes. The dense water quality data collected on the River Porvoonjoki clearly displayed seasonal variations, which has a large importance when defining sampling frequencies.

The information provided by continuous monitoring on the effects of daily regulation and dredging can be used in the selection of sampling times and frequencies in research programs. Kalweit (1981) has shown that automatic dissolved oxygen measurements can help in obtaining maximal aeration of the downstream watercourse by overspilling water at the weir steps, while at the same time striving to minimize the losses of water energy. Continuous suspended solids and flow data have been used according to Best (1983) to calculate the sediment load when drawing up a new dredging programme.

The rapidity of information availability offered by automatic on-line monitoring system on fluctuations in water quality and the continuous control of the situation proved to be essential particularly during the poisonous discharges in the River Kymijoki, which serves also a source of water supply.

The samples taken by the alarm samplers of the automatic stations were available to the local water authorities for further laboratory analysis. Because of the lack of data transmission the alarm samples taken by the mobile stations were detectable only during maintenance visits. In such cases they often proved too aged for laboratory analysis.

The false alarms initiated at the River Kymijoki as well as those at the River Severn (Cope 1981), a river also used for water supplies, created a state of frustration among the local water authorities. However, the possibility of discharge detection through automatic monitoring has increased the willingness towards voluntary information on the part of the polluters. This phenomenon observed at the River Kymijoki has also been reported by Moore et al. (1980) on the River Ohio. The results provided and the wide quality fluctuations detected by the River Kymijoki system have encouraged the local water authority to utilize the frequent water quality data in control, research and planning activities (Rautiainen 1983, Rautiainen and Virtanen 1984).

The frequent water quality data produced by automatic monitoring has enabled the application of statistical methods to the definition of optimal sampling frequencies. The results so far suggest that also other Finnish water quality data should be analysed with a view towards increasing sampling frequency and at the same time perhaps reducing the number of sampling locations.

A simultaneous fluctuation in pH and dissolved oxygen observed during the summer season have also been found in many watercourses subjected to frequent manual or automatic monitoring (Kim et al. 1977, Simonsen and Harremöes 1978, Källqvist and Arnesen 1983). Kalweit (1981) emphasizes the importance of continuous measurement of total solar radiation when following the fluctuations of pH and dissolved oxygen in watercourses. These natural variations must be taken into account when defining the sampling times.

The operation of automatic monitoring stations and thus the use of their results were impaired by pumping difficulties and breaks in electric current at occasional measurement points. Similar difficulties have been reported in foreign monitoring systems (Ballinger 1968, Best 1974, 1975, 1983, Toms et al. 1973, Ward 1973, Irie 1978). The monitoring system at the River Kymijoki and Kokemäenjoki turned out to be particularly sensitive to microprocessor and data transfer (modems, telephones) equipment malfunctions, which in most cases arose from lightning strikes. Similar difficulties apart from lightning protection have been described by Horváth et al. (1978), Kalweit (1981) and Källqvist and Arnesen (1983).

The collection and reporting of the monitoring data was hindered by repeated disturbances in the main computer, which caused large losses of data, particularly on week-ends. Repair and maintenance delays on the equipment, as well as the use of the computer by other departments of the National Board of Waters hampered the processing of the data and reduced the opportunities of the Kymi and Tampere Water District Officies to optimally benefit from the monitoring system. The release in 1984 of the data processing system, acquired in 1977 as central processor of the River Kymijoki monitoring system, from other usage has proved a step in improving the operational efficiency of the system.

Processing of the data was hindered most by the diversity in the collecting and recording equipment. As a consequence of equipment malfunctions, data had to be manually recorded from chart recorder outputs, which proved to be an extremely cumbersome and laborious process. Similar experiences have been reported by

Ballinger (1968) and Cope (1981).

The optimal operation of an automatic water quality monitoring station demands sufficient and expert maintenance and reliable equipment. Cornish (1977) has reported from tested equipment that up to 75 percent may originally be deficient in one way or another.

The variable specific operational efficiencies of the River Kymijoki monitoring system improved with operation experience almost in the same fashion as with the five station system on the River Lee taken into operation at the beginning of the 1970's (Best 1974, Hinge 1980). The variable specific efficiencies published by Irie (1978) were somewhat lower in Japan than those obtained in Finland excluding dissolved oxygen and chloride, which operated better in Japan.

A rearrangement of maintenance procedures made it possible to move from troubleshooting calls to an efficient preventive maintenance program, which improved the operational efficiencies of the stations and the measured variables. Ballinger (1968) and Nanbo and Kunogi (1981) have emphasized the importance of a sufficiently frequent and skilled maintenance and of a rapid supply of spares. The weekly maintenance cycle practiced in the last few years in Finland has been successfully applied for instance to the River Lee (Toms et al. 1973, Best 1983) and the Teltow Canal (Leschber and Schumann 1974). A biweekly maintenance cycle has proved satisfactory in Lower Saxony (Plate 1981) and on the River Clyde (Best 1983). A monthly cycle sufficed on the River Mosel (Kalweit 1981). Ward (1973) has reported that reliable operation of the five stations located in New York harbour has required a technically well trained maintenance team of three men. Thus if there exists a pressing need for water quality data produced by automatic monitoring, also reliable operation of the equipment must be ensured through efficient maintenance.

Operating experiences on the newest, in-situ type mobile monitoring station have been very positive, even though Ballinger (1968) predicted many problems for that kind of measuring method. The flexibility of the station makes it suitable for both watercourse and waste water monitoring.

Automatic water quality monitoring in Finland has provided opportunities over ten years to observe progress in the field elsewhere in the world, to adapt and develop our own procedures and equipment, and to participate in international research, development and publication work (Kohonen and Lee-Frampton 1979, Kohonen et al. 1980, Kohonen and Princz 1983, Kohonen and Viies 1985).

4.2 Future prospects

The future development of automatic water quality monitoring in Finland will be decisively affected by the need of water authorities and polluters for data as well as by the possibilities and desire to produce new information. The production of information is always tied to costs. New automatic monitoring stations, which make use of the latest and still developing technology, incur high costs. Also the increase in the amount of information will cause higher costs and more work to the authorities and will impose more obligations on the polluters. It becomes therefore the task of the water authority responsible for water pollution control to decide:

- whether he needs the data produced by automatic water quality monitoring stations,
- that if he needs it, then which data and in what form,
- whether he requires data transfer, alarm data and samples and
- whether this will provide cost-effective advantages over normal manual monitoring.

In Finland overall quality of surface waters is good on an international scale. Unlike continental Europe, we have few watercourses, used as water supply sources, which require continuous monitoring. The River Kymijoki monitoring system would better serve fresh water supply if the measuring stations were linked to the water treatment plant, or the latter at least had a connection to the main computer. The intensification of research on groundwaters and its interest in water quality may lead here in Finland as in England to a greater need for automatic measuring equipment (Hanson 1981).

A wider use of automatic water quality monitoring has been limited in Finland as elsewhere in the world by the lack of variables measurable under field conditions. However some countries have routinely measured more variables than the monitoring stations referred to in this study. As examples of these supplementary variables can be mentioned NH_4, NO_3 and total nitrogen, TOC, COD, fluoride, sulphide, cyanide, chrome and other heavy metals, total mercury, suspended solids, radioactivity, toxicity, oil and phenol (Davies 1972, Bayer and Radouch 1975, Irie

1978, Hinge 1980, Moore et al. 1980, Cope 1981, Günneberg 1981, Journet 1981, Nanbo and Kunogi 1981, Best 1983, Briggs 1984).

If, as our results seem to show, a need exists to continuously monitor the effects of waste water discharges on the quality of certain watercourses, new or improved electrodes and monitors developed abroad would provide better opportunities than have been available until now. Such equipment includes NH_4 electrodes and monitors (Princz and Literáthy 1977, Brinkhoff 1978a, Kohonen and Princz 1983), NO_3 electrodes (Brinkhoff 1978b), oil monitor (Szeredai and Szabó 1980) and TOC monitor (Small 1980, Tiemon and Wagner 1981, Kohonen and Princz 1983, Briggs 1984). The equipment being developed in Finland (Immonen 1983, Kaartinen et al. 1985), with a new sample filtration method and pretreatment using microelectro-termofluidistic (metf) technique currently allows the measurement of seven variables at intervals of fifteen minutes. The capability of the equipment to measure certain ion concentrations, such as nitrate, orthophosphate, iron and aluminium suggests that in some locations continuous monitoring could at least partly substitute for obligatory monitoring. This apparatus, which satisfies the requirements set by Ballinger (1968) for a wet chemical analyser, can also be applied to research of watercourse acidification through the measurement of pH and aluminium.

As monitoring proceeds towards contents measurements of water quality, each polluter should be investigated with a view towards substituting at least to some extent automatic monitoring for obligatory monitoring. Whenever economically feasible, the best solution would reside in the simultaneous automatization of both watercourse and discharge monitoring. To prevent occasional discharges an optimum solution can be found in an effective instrumentation and control of both industrial processes and waste water treatment. To ensure a safe operation of the treatment plant, the waste water supply to the plant should be continuously monitored as early as possible prior to arrival to the plant. This would permit for instance the detection of discharges poisonous to a biological treatment process at a sufficiently early stage to allow its diversion into a storage pool for any necessary supplementary treatment.

Most waste water quality fluctuations arising from process disturbances can be detected by the traditional variables and thus also by automatic monitoring. The measuring equipment should be directly linked to the waste water treatment plant to regulate the flows.

There are few watercourses in Finland requiring permanent automatic monitoring of water quality. Stationary monitoring stations should be built only if some usage of the watercourse demands continuous monitoring. Otherwise, as also Ward (1973), Journet (1981), Best (1983) and Källqvist and Arnesen (1983) have shown, the optimum solution may be found in mobile monitoring stations incorporating a large selection of measureable variables. The data produced by such a station may then be used to decide whether a stationary station needs to be built, which variables should be measured, as well as be applied to the development of manual monitoring. Källqvist and Arnesen (1983) have also shown that the usefulness and operational efficiency of a mobile station can be enhanced through the data transmission from the station to a control center. For instance a radiotelephone can be used to transmit information about malfunctions as well as alarm conditions and samples which may require a visit to the station. Portable equipment capable of measuring two to five of the most common variables would be eminently suitable to fairly simple investigations such as water mixing or distribution of waste waters. To reduce costs, the variable selection available at stationary stations may be kept small, consisting the most essential variables at each location, for example pH, turbidity, ammonium, orthophosphate and organic carbon. Data recording and output devices are essential at each station, even though data transfer equipment are installed due to the use of the watercourse downstream.

Plans for the automation of hydrological and meteorological observation networks should take into account the possibility of interconnections with water quality monitoring stations. Flow data could then be added to the content data produced by the stations, which would enable the calculation of material loads (Puranen 1982). Thompson (1980) and Hanson (1981) have reported posivitive experiences of combined automatized systems and equipment monitoring water quality and quantity as well as the weather in the drainage basin of the Thames. Günneberg (1981) relates similar experiences from the Federal Republic of Germany. Källqvist and Arnesen (1983) could only by automatic monitoring relate acid rains to sudden fish deaths. These authors also emphasized the importance of obtaining quality and quantity data from the same stations.

Automatic stations designed for watercourse monitoring were also tested in controlling treated industrial waste waters. According our experience a prevalence of automatic waste water monitoring will be attained only through the development of equipment capable of operating under adverse conditions, the availability of more measurable variables, and the organisation of frequent maintenance. Currently available equipment already operates reliably if efficiently maintained. Maintenance should be made the responsibility of waste water treatment plant personnel. Recording of the measurement data should take into account their further processing and their disturbance-free transmission from the monitoring station. A sensor measuring directly from the waste water canal has proved operational on normal quality variables. The metf-analyser presently under development in Finland may allow the continuous measurement of content variables requiring sample pretreatment.

5. CONCLUSIONS

The following conclusions can be drawn from the operational experience accumulated in Finland during the years 1974–1983 on automatic water quality monitoring systems and eleven monitoring stations:

- automatic monitoring brought out previously undetected fluctuations in the water quality of many rivers, while in other cases assurance was gained that the water quality remained constant,
- at least one of the variables measured by automatic monitoring stations always reacted to sudden discharges from the pulp and paper industry. The monitoring system on the River Kymijoki made it possible to observe the course and dilution of waste waters in the river,
- the deviations from the terms of the discharge permit could be detected by automatic monitoring and have been used in inspection,
- continuous monitoring detected the effects of daily regulation on water quality of rivers heavily polluted by municipal and industrial waste waters and by non-point pollution,
- the effects of dredging made in connection with hydraulic engineering works were best observed as alterations in turbidity and dissolved oxygen and
- the automatic stations and the present monitoring system operated on an international level, the problems encountered being similar, apart from winter conditions, to those of other countries.

As the future prospects of automatic water quality monitoring in Finland the following recommendations can be presented:

- an effective use, optimum operational efficiency and measurement reliability of expensive automatic monitoring equipment will require also in the future sufficient resources for investment in trained maintenance personnel,
- there are only a few watercourses in Finland which require stationary automatic monitoring stations. Mobile automatic monitoring stations are suitable for periodic quality monitoring of smaller rivers,
- the lack of measurable variables currently hindering the wider use of automatic monitoring will not present in the near future an obstacle to automation, even in obligatory monitoring,
- the character of the fluctuations in water quality, the statistical parameters of the data and the optimal monitoring frequencies calculated from these, all of which made possible by continuous monitoring, will prove useful also when developing manual water quality monitoring,
- a need has arisen in Finland for frequent monitoring of shortterm fluctuations of water quality. The most efficient use of automatic measurement technology will be achieved by acquiring a few mobile stations capable of measuring a high number of variables to replace stations being retired from duty, and by supplementing them with portable equipment suitable for two to four quality variables and
- due to the plurality of factors affecting environmental conditions, also in Finland there should be readiness for an optimal jointly use of various monitoring systems when adopting automatic measurement technology.

LOPPUTIIVISTELMÄ

Suomessa vuosina 1974–1983 vesihallituksen käytössä olleista automaattisista veden laadun tarkkailujärjestelmistä ja yhdestätoista tarkkailuasemasta saatujen käyttökokemusten perusteella voidaan todeta seuraavaa:

- automaattisella tarkkailulla todettiin monissa jokivesistöissä ennen havaitsematonta veden laadun vaihtelua, kun taas joissakin kohteissa saatiin varmuus veden laadun tasaisuudesta,
- automaattiasemien mittaamista muuttujista reagoi aina jokin metsäteollisuuden poikkeuksellisiin päästöihin ja tarkkailujärjestelmän asemien avulla oli Kymijoella mahdollista seurata jätevesien etenemistä ja laimentumista joessa,
- automaattisen tarkkailun osoittamia poikkeamisia lupaehtojen määräyksistä voitiin käyttää hyväksi jätevesikatselmuksessa,
- jatkuvalla tarkkailulla todettiin vuorokausisäännöstelyn vaikutus sekä voimakkaasti asumis- ja teollisuusjätevesien että haja-asutuksen kuormittamien jokien veden laatuun,
- vesistörakentamisen yhteydessä tehtävän ruoppauksen vaikutukset näkyivät parhaiten sameuden ja liuenneen hapen muutoksina ja
- automaattiasemat ja nykyinen tarkkailujärjestelmä toimivat kansainvälisesti saavutetulla tasolla tarkkailun ongelmien ollessa, talvioloja lukuunottamatta, samoja kuin muissakin maissa.

Automaattisen veden laadun tarkkailun tulevan käytön kannalta voidaan Suomen osalta todeta seuraavaa:

- kalliiden automaattisten tarkkailulaitteiden tehokas käyttö ja mahdollisimman hyvä toimivuus ja tulosten luotettavuus edellyttävät vastaisuudessakin riittäviä resursseja koulutettujen huoltohenkilöiden palkkaamiseen,
- Suomessa on vain harvoja vesistöjä, joissa tarvitaan pysyvästi automaattisia mittausasemia. Siirrettävät automaattiasemat ovat käyttökelpoisia pienehköjen jokivesistöjen veden laadun määräaikaiseen tarkkailuun,
- automaattisen tarkkailun laajempaa käyttöä rajoittanut mitattavien muuttujien vähäisyys ei ole enää lähitulevaisuudessa esteenä automaation soveltumiselle myös velvoitetarkkailuun,
- jatkuvalla tarkkailulla todetut veden laadun vaihtelun luonne ja määrä samoin kuin aineistojen tunnusluvut ja niistä lasketut optimaaliset tarkkailutiheydet ovat hyödynnettävissä myös tavanomaista vesistötarkkailua kehitettäessä,
- Suomessa on osoittautunut olevan tarvetta vesistöjen veden laadun lyhytaikaisvaihteluiden tiheään tarkkailuun. Parhaiten automaattista mittaustekniikkaa voidaan hyödyntää hankkimalla vanhojen asemien poistuttua käytöstä tilalle muutamia, mahdollisimman monia muuttujia mittaavia siirrettäviä asemia sekä 2–4 muuttujaa mittaavia kannettavia laitteistoja ja
- ympäristön tilaan vaikuttavien tekijöiden moninaisuuden vuoksi tulisi Suomessakin varautua eri tarkkailujärjestelmien mahdollisimman tehokkaaseen yhteiskäyttöön myös automaattista tarkkailutekniikkaa sovellettaessa.

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