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AUTOMATIC WATER QUALITY MONITORING

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1989-90

PREFACE

The continuously rising demand for water for domestic and industrial purposes, and the increased use of rivers for fisheries, recreation, drainage, irrigation, power, and navigation, have resulted in an obvious need for careful river management and for the future development of the amenity afforded by canals, lakes, and multipurpose reservoirs. For these purposes accurate information on river flow, storage, water quality, and climatological conditions is required.

Measurement of water quality is of particular importance in relation to research, the protection of water taken for domestic and industrial supply, and the accumulation of the basic data required for planning for future needs. The use of manual sampling and analysis techniques for rapid changes in various water quality parameters such as dissolved oxygen etc. may not be adequate and hence the advantages of continuous measurement become apparent. In addition, there are some other shortcomings of manual techniques such as cost, accuracy, limitations on the fequency with which analyses can be made, and the time lag between collection of samples and receipt of analytical results.

As a first step in this direction, and realising the need for assembling the available information in this new area of "Automatic Water Quality Monitoring", the Institute took up the task of preparation of a technical note on this area. This report entitled "Automatic Water Quality Monitoring" is a part of resarch work of Environmental Hydrology Division of the Institute. The study has been carried out by Shri Aditya Tyagi, Scientist B. The manuscript has been typed by Shri S.S.Kanwar, Documentation Officer of the Institute.

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ABSTRACT

Increasing development of towns and industries has resulted in an increase in water consumption and waste water volume. Therefore, the danger of pollution has become greater for natural water sources and especially surface waters. One of the main problem of the public economy and health today, is the pollution of surface basins, as the water wasted by chemical and biological agents causes or favours serious diseases. In addition to its direct influence on public health, water pollution is unfavourably affecting the quality of water supplies, which adversely affect the water consumption and also the standard of comfort and sanitation of the people.

Chemical pollution by organic matter, even in low concentrations and impossible to detect by means of the routine manual methods, results in a modification of the organoliptic properties. The low concentrations do not cause acute symptoms that are felt immediately, but if the substance have cumulative and synergistic action, chronic diseases may result . It is still more complicated if the diseases are caused by substances with a strong toxic action, resulting in a modifications which can not be felt by the water consumers. The situation is much more severe with substances which have a synergistic or intensifying action. Under such conditions optimum treatment can only be achieved when the quality of the raw water is accurately known at all times.

Water quality is a complicated function of a number of parameters such as - temperature , conductivity, dissolved oxygen, turbidity, pH, chloride, phenols etc. which may very in an unpredictive manner. To study such a function (water quality) successfully, a large number of stations, capable of sampling and

their analysis for various required parameters, are necessary to set up over a given stretch of river to be studied. An increase in the number of stations, and an increase of manual sampling and water sample analysis frequency for monitoring over a station is directly associated with a significant increase of labour consumption and costs. This could be minimized by the installation of automatic water quality monitoring stations equipped with modern units for continuous measurement and recording of water quality parameters. Furthermore, the data so obtained will be more systematic and reliable which may be used for a more reliable study of water quality of a given stretch of river.

CHAPTER - 1

1.0 INTRODUCTION

The past decade has produced a new and accelerated interest in water pollution control activities. Early efforts were primarily concerned with the control of water borne disease; however it is becoming apparent that water pollution control must be considered as a part of an ecological system which must be continuously improved if we are to attain the environmental quality goals that we seek.

The obvious objective of water pollution control is the attainment of satisfactory water quality goals, which can only be achieved through adequate water quality management on a basinwide basis. In order to attain this objective, meaningful and economical water quality data collection systems are mandatory.

The ultimate success of water quality management efforts will depend on our ability to provide adequate water of appropriate quality for its intended beneficial use. It is obvious that the ability and capability of measuring water impurities and predicting their effect on the aquatic environment are requisite to an effective water quality management program.

The last twenty years or so have seen a large increase in the measurement and control of the quality of many types of natural and treated waters. In this period, many instruments and associated techniques have been developed and applied with varying degrees of success, a voluminous but rather scattered literature has evolved, and many problems have been encountered. The severity of some of these problems depends on the particular type of water, but in our view the general approach to, applicability of and types of problem likely to be met in automatic water quality analysis are almost entirely independent of the nature of the water of interest. In the literature with which we are familiar, greatest attention is paid to the automatic water quality monitoring of natural, surface waters, but it can be believed that they are generally relevant to other types of waters also.

Objectives of continuous water quality monitoring :-

Significant changes in water quality characteristics may occur rather suddenly, both from natural and man made causes. In the past, the manual collection of samples and their manual analysis after transport to a laboratory have been very widely used in the measurement of water quality. Hence it is obvious that the water quality characteristics will not be absolutely correct. On the other hand the natural change may be caused by intense storms, industrial spills, releases from impoundments and stratified flow. In addition, rapid changes in parameters such as dissolved oxygen and salinity may result from natural tidal fluctuations. This particular combination of sampling and analytical systems, however, has increasingly and especially during the last ten years or so been found to have a number of limitations that may prevent the required informations on water quality from being obtained. These limitations may be summarized as follows:-

i) The delay between sample collection and the reporting of the analytical result may be too long.

ii) Difficulties may arise when, as will often be necessary samples have to be collected and analysed outside normal working hours.

iii) The man power and laboratory facilities available to a laboratory may be insufficient to allow collection and analysis of all the required samples.

iv) The accuracy of analytical results can be markedly dependent on the skill of the analyst and the conscientiousness and accuracy with which specified analytical procedures are followed in routine, manual analysis.

v) It may be difficult to ensure adequately small instability of samples for certain determinants, particularly when samples must be collected at locations remote from the laboratory. In addition to these limitations, the use of manual sampling and analysis techniques may not be adequate and, the advantages of continuous measurement become apparent. In addition, klein et.al(Ref.1) stated that the three major shortcomings of manual sampling based on ORSANCO experience were cost, limitations on the frequency with which analyses can be made, and the time lag between collection of samples and receipt of analytical results for stream evaluation purposes.

The specific objectives of a continuous, automatic water quality monitoring system may include:

i) The detection of compliance and non-compliance with water quality standards.

ii) The establishment of water quality base lines and trends.

iii) The ascertainment of improvement in water quality resulting from abatement measures.

iv) The implementation of flow augmentation.

v) The detection of emergency water quality problems.

vi) The determination of the offender in cases of waste spills.

vii) The detection of natural causes of abrupt water quality changes.

viii) The establishment of water quality relationships that would allow prediction of downstream quality conditions.

ix) The early warning of down stream users that adverse water quality conditions are approaching their water intakes.

Automatic water quality monitoring' is also very important tool for water quality surveillance which can be used to:-

i) Detect violations of standards or other undesirable quality conditions so that remedial action can be taken quickly.

ii) Verify and provide bases for improvement of evaluations and predictive calculations of water quality survey teams, including computerized mathematical models to simulate quality characteristics of receiving water pollution facilities, and

iii) Show short range water quality trends for programme management and public information purposes.

Definition of Automatic Water Quality Monitoring:-

The 'Automatic Water Quality Monitoring' is very useful for the automatic acquisition of pertinent data for river management conservation and research purposes in the field of water pollution control. The automated water quality monitoring systems rely on the use of automatic, unattended measurement procedures operated on a continuous basis of intermittently at a determined frequency. The main advantages in using automated systems lies in the ability of maintaining a continuous, instantaneous record on water quality in rivers, lakes and estuaries, industrial effluents, etc.

The term 'Automatic Water Quality Monitoring' to denote these analytical systems in which either -

i) the sensor of an automatic analytical system is placed directly in the water of interest at the desired sampling point, or

ii) an automatic analytical system is automatically presented with a sample stream (continuous or discontinuous) from the sampling point in the water of interest.

With both (i) and (ii), a series (continuous or discontinuous) of analytical results is obtained automatically. Given this definition, note that automatic water quality monitoring systems generally require calibration, and that the calibration standards for this may be presented either manually or automatically. of-course, automatic Water Quality Monitoring systems avoids human involvement in sample collection and transport.

There are two main approaches for water quality management in automatic monitoring systems. The first approach is based on in situ measurement by means of electrochemical transducers without altering the physicochemical characteristics of the test water. The use of automated repetitive wet analytical procedures in which chemicals are added to the test water and measurements are made after suitable chemical reaction have taken place, e.g., the Technicen Auto analyzer.

1) **In Situ Measurement**;- Monitoring systems in which the measurement is done by transducer systems (with out the addition of reagents) are being widely used for monitoring water quality of rivers, streams, estuaries and industrial and domestic waste effluents. The systems are usually capable of measuring temperature, electrical conductivity, dissolved oxygen, turbidity, pH, sunlight intensity, chlorides, oxidation-reduction potential (ORP), and Alpha and Beta radioactivity. Certain parameters are measured for specific applications, e.g., the monitoring of flouride ions, residual chlorine, nitrates and hardness in drinking water supplies and monitoring of cyanides, sulfides, copper ions in certain waste effluents. This type of analysis has very valuable feature of eliminating the various problems that may arise through the use of sample collection devices.

2) **Automated Wet Analytical Techniques**;- The second main type of monitoring system is based on automating wet analytical

techniques, e.g., The Technicen autoanalyzer. Such systems are essentially capable of automatic sampling, filtering, diluting, reagent addition, mixing, heating, digesting, and after appropriate delay for color development, colorimetric measurement are done. All these steps, which are usually done by an analyst, are automated and performed on a stream of samples moved by a fixed speed peristaltic pump.

This technique finds its widest application in laboratory applications where large samples of waters are handled daily. There have been certain attempts however, to use this technique for water quality monitoring where the autoanalyzer is kept in a trailer autoanalyzers were used for monitoring silicates and nitrates in sea water and for monitoring nutrients concentrations in lakes.

One of the main advantages of applying the "autoanalyzer" for water quality monitoring purposes lies in its ability for measurement of a large number of parameters such as phosphate, chromium, copper, iron, ammonia, hardness, sulphate, phenol, cyanide, cod, chlorides, nitrate + nitrites, fluoride and silicate etc.

The application of the autoanalyzer for water quality monitoring purposes has been faced with a number of limitations;

a) the effect of turbidity in colorimetric measurements.

b) these systems need more frequent attendance for servicing, and

c) autoanalyser systems seem to have a higher capital cost and running expenses in comparison to the in-situ monitoring systems.

Type of Automatic Water-Quality Monitoring Analysers:-

The equipment involved in on-line analytical systems may be regarded as composed of a number of units, each with a particular function as shown in Table 1. Of course, the physical realisation of these functions, is achieved in a variety of ways, one physical unit may serve more than one function, and some equipment may not include all functions. In principle, therefore, most automatic analysers intended for the analysis of discrete samples in a laboratory may be applied to on line analysis by provision of suitable sampling lines and sample conditioning and presentation units. In practice, however, such adaptation is generally much simpler for continuous flow than for discrete sample or parallel analysers.

Table - 1

Equipment Components of an Automatic Water-Quality Monitoring System:

S.No.	Component	Function	Example
1	Sampling	To convey a portion of water of interest from the sampling point to the automatic analyzer	Automatic samplers
2	Sampling conditioning unit	To ensure that the properties of the sample entering unit 3 donot cause deteriorating in the performance of units 3 to 6	Heat-exchangers to control temperature, filters to remove undissolved materials
3	Sample presentation unit	To select appropriate volumes of sample or to ensure a suitable flow rate of sample to be presented to the following units	Automatic pipettes, peristaltic pumps
4	Sample transport unit	To convey the sample from unit 3 through units 5 and 6 and thence to waste	Peristaltic pump and connecting conduits
5	Sample treatment unit	To effect any chemical and physical process required before assurement in unit b	Reagent addition, heating the sample,gas stripping
6	Analytical sensor unit	To provide a response whose magnitude is governed by the concentation of the determined in the sample	Automatic spectrophotometer, automatic electrodes
7	Local calculation and read-out unit	To provide a print out of analytical results and some other indication of the concentration of the determined installed at the sample position as unit 3 to b.	Chart recorder, galvanometer, automatic printer
8	Remote calculation and read-out unit	To provide an indication of the concentration of the determined and a print out of analytical results installed at a position remote from unit 3.	Computer/printer, chart-recorder

Studies necessary for the establishment of proper location of AWQMS-

Installation in cross-section particularly important for water economy, and where continuous measurement and recording of water pollution parameters is indispensable, should be prime factor in the location of AWQMS.

Development of the network of Automatic Water Quality Monitoring Stations:-

Tremendous development of instrumental automated analysis in water quality has been recently observed in the USA and in other European countries. In 1968 in the United States some 205 automatic water quality monitors were operating and in 1975 the system was expanded up to 1200 AWQMS(Ref. 2). Each monitoring station was equipped in Europe, first in multifunctional analytical monitors for measurement of the following parameters: pH, ORP, Chlorides, dissolved oxygen, water and air temperature and solar radiation.

Water quality monitoring stations were installed in GER in 1950. In 1967 the rivers of German federal Republic were controlled by 14 stations. In these stations, equipments were installed for measurement of: conductivity, reaction(pH), temperature, turbidity and dissolved oxygen(DO). In Australia, in the period of 1960 to 1964 one monitoring station was constructed at Aschach on Danube(Ref. 3).

Actual and planned location of automatic water quality monitoring stations in various countries are presented in table-2, taken from the report of UNO Economic Commission for Europe, Geneve, January 6, 1969.

Table 2: Actual and Planned location of automatic water quality monitoring in various countries

NO	Country	Number of stations	
		Existing	planned
1	USA	205	1200
2	SWEDAN	12	30
3	POLAND	7	53
4	GER	6	75
5	GREAT BRITAIN	4	240
6	AUSTRALIA	1	-
7	SPAIN	-	10
8	HUNGARY	1	40-50
9	HOLLAND	-	2

Study on General location of Automatic Water Quality Monitoring Stations:-

General location of AWQMS should be established on the basis of actual characteristics of state of pollution of rivers, characteristics of main source of pollution, methods of water utilization in a given recipient and location of existing and planned waste treatment plants and hydro technical facilities.

Actual characteristics of pollution of state of the rivers should be performed by means of hydrochemical profiles i.e., curves of changes of indicative concentrations of pollution parameters along the river course. This characteristics should be elaborated on the basis of actual results of studies conducted in fixed monitoring cross-sections. The course of changes of individual pollution parameters along the river course should be determined on the basis of previously established values of indicative concentrations: BOD 5, suspended solids. Indicatives values of various parameters should be found from the relationship between concentration of a given parameter and the rate of flow with reference to the indicative mean flow.

Studies on detailed location of Automatic Water Quality Control Stations:-

The purpose of these studies is to establish technological principles for detailed location of water intakes for measurement of state of pollution in the rivers by means of automatic monitoring equipment installed in the proposed AWQMS.

The scope of studies included hydrometric studies and studies on the heterogeneity of water composition in various cross-sections taken in to account when establishing water sampling points for automatic water quality monitoring stations.

Hydrometric studies included leveling and river bottom depth sounding in predetermined cross-sections. Hydrometric studies have also included measurement of local point velocities of flow in order to establish mid stream and velocity distribution pattern in the cross-section.

Physico-chemical studies are aimed at establishing heterogeneity of water composition in cross-sections of proposed water in takes for AWQMS.

Determination of water composition heterogeneity is based on the following parameters: dissolved oxygen (DO), permanganate value from clarified and non clarified samples, chlorides and dissolved solids.

The studies are based on simultaneous sampling from various water depths in predetermined verticals. On the basis of data for discussed pollution parameters, isolines of the same concentrations should be drawn assuming a suitable differentiation (say, for DO every 0.5 mg/l O_2, for permanganate value, every 2 mg/l O_2, for chlorides, every 10 mg/l cl and dissolved solids, 100 mg/l. The degree of heterogeneity of water composition in respect to the pollution parameters is one of the decisive factors when accounting for representativeness of a given cross-section.

Final location of AWQMS is also considered from the view point of: field conditions, easy access by car, power connection, land implements, and the possibility of providing constant supervision of the stations.

CHAPTER - 4

Sensor Development for AWQMS

The equipments described subsequently were developed at the water pollution research laboratory and elsewhere, for the continuous measurement of those parameters which are of most significance in water pollution research. Particular attention however has been paid to instruments which are of value in sewage works operation or in the water quality monitoring stations at present being installed by river authorities and the various pollution control boards.

i) Measurement of Dissolved Oxygen

Paramount importance in the work of the Laboratory, in pollution control, and in the efficient operation of the activated sludge process, is the determination of dissolved oxygen. As a result, many form of continuous monitor have been produced. The first of these was a semi-continuous automatic titrator employing the Winkler reactions. This approach resulted in equipment which, although accurate, was bulking and required a great deal of maintenance. It was therefore soon superseded by a whole range of instruments based on the wide bore dropping mercury electrode, this system still remains the most satisfactory where rapid response is required, for example in measurement of respiration rates or in static system such as BOD bottles. However, in systems for the continuous monitoring of water quality or for control of aeration at sewage works, this has now been replaced by electrodes of the membrane-covered type, those in most general use being based on a temperature-compensated modification of the patented design of Mackereth.

This electrode consists of a perforated of cylindrical silver cathode surrounding, and insulated form, a porous lead anode, the electrodes being bathed in an electrolyte prepared by mixing equal volumes of saturated solutions of potassium carbonate and potassium bicarbonate. A 0.063 mm thick polythene membrane, permeable to oxygen, retains the electrolyte and prevents most harmful substances from entering the cell. It is essential for reliable performance to maintain a resistance of atleast 10 megohms between either electrode and the external solution. This is achieved by filling the 'O'-ring retaining grooves with a cold setting silastomer prior to assembly and subsequently sealing the filler cap in the same manner. The lead electrode, which must be of adequate surface area to prevent polarizations is prepared by soft soldering a sheet of perforated lead foil to a central supporting pillar, covering it with woven nylon insulating material, and rolling it up to form a cylinder. It is essential to make an electrolyte proof seal around solder joints between the electrodes and connecting wires, otherwise spurious voltages will be generated. The reactions taking place are-

$$O_2 + 2H_2O + 4\bar{e} \text{-------} 4O\bar{H}$$

$$2Pb + 4O\bar{H} - 4e^- \text{-------} 2Pb(OH)_2$$

The steady state current I, obtained with this cell is given by the equation

$$I_T = Ae^{-J/T}$$

where

I_T - is the current at temperature T^oK

T - Temperature in ^oK

A and J - Constants, for polythene membranes

$J = 4500^oK$

Compensation for this high temperature coefficient (about 6 percent per deg c) must be achieved in some way if the electrode is to be used for continuous monitoring.

It is of interest that those instruments employing membrane electrodes which are calibrated in terms of dissolved oxygen concentration (mg/liter) achieve this by shunting the meter or recover with a second resistance or thermistor combination to compensate for the effect of temperature on oxygen solubility (an additional temperature coefficient of about 2 percent per deg c). The readings given by these instruments must, however, be corrected for the salinity of the sample.

2. Measurement of Suspended-Solids Content

The instrument available at present for measuring concentration of suspended solids depend on the optical properties of the suspension and, in particular, on the measurement of the proportion of the incident light reflected by or scattered by the suspended particles. These methods may be divided into two main classes-those which depend on measurement of the attenuation of the light beam (turbidimetric methods) and those in which the amount of light scattered or reflected by particles in the incident light beam is measured (nephelometric method).

Measurement of Light Attenuation

According to the theory developed by Rose, the intensity, I, of a light beam, originally of intensity I_o, after passing through length 1 of a sample containing suspended particles, is given by

$$l_n\left(\frac{I_o}{I}\right) = \frac{1C}{4} \sum_{o}^{h} k_z n d_z^2$$

where

e - concentration of suspended matter,

k_2 - ratio of the light absorbed by a particles of size dz. (varies 1 to 3) n - number of particles of size dz per gm of suspended matter

Sludge Level Detector -

In the simplest type of instrument a beam of light passes from a small bulb through a fixed thickness of liquid and is received by a photo electric cell. The essential components are contained in a water proof head mounted on a pole or cable, which is marked at appropriate intervals by means of colored rings. The instrument is adjusted to read full-scale, when the head is immersed in clear water or, when appropriate in the supernatant liquor. The meter reading is then a measure of the suspended solids content at a particular depth.

Suspended Solid Monitor

For continuous operation and recording, manual standardization must be eliminated and compensation must be provided for variations in the intensity of the light source and for other source of error. These requirements are partially met by the suspended solid monitor which was developed to record the changes in the suspended solid content of effluents from extended aeration plants, but has since found many other applications.

The instrument should have reasonable compensation for variations in lamp intensity and the instrument as a whole should be stable within ± 2 percent for periods of atleast a week. Depending upon the path length chosen, full scale reading may be obtained with samples containing as little as 20 mg/l or as such as 10,000 mg/l of suspended matter.

Instrument of this type are portable, relatively in expensive, and can be made independent of mains power. They are thus particularly suitable for short period survey work on rivers and at waste water treatment plants.

Measurement of Organic Matter

Mains and/or battery-powered equipment, suitable for monitoring organic matter in river waters and effluents and based on the absorption of ultraviolet light, is at present being developed. Since ultra-violet light is also attenuated by suspended matter present in a sample, a pair of photo cells sensitive to visible light is included in the optical assembly and used to provide a compensating signal. In order to obtain adequate sensitivity and stability it has been found necessary to develop special photo cells sensitive only to ultra-violet light. These comprise an interference filter in front of a silicon photo voltage cell which has been coated with a red phosphor. By using a third pair of photocells incorporating an interference filter with a pass band centered around 225 mm and recording the difference in the outputs of the two ultra violet light sensitive cells, it is also possible to measure oxidized nitrogen in the sample.

Measurement of Ammonia

The methods of measurement of ammonia developed so far have been basically of a wet chemical nature. Brydges and Briggs developed a method in which alkaline hypobromite solution was added to a de-gassed acidified samples, thus liberating a quantity of nitrogen proportional to the ammonia originally present. Nitrogen was then removed in a second stripping device using helium or hydrogen, and after drying the nitrogen in the carrier gas, was determined using a four element diffusion katharometer. Full scale deflections were obtained with 10 mg/l ammonia as N and the precision was ± 0.1 mg/l. Diggen has developed a coulometric batch titration method in which potassium bromide, buffered to pH 8.4, is added to a sample of the water. Bromide is generated electrolytically using platinum electrodes and the first inflection on the resultant potentiometric titration curve is detected using a gold cathode and a calomel reference electrode. Sensitivities of the order of 2 mg/l ammonia as N for full scale deflection have been achieved provided ammonia free reagents were used.

Measurement of pH Value

In general this parameter seems to have presented fewer problems than was anticipated and a precision of $\pm$ 0.1 pH units is commonly obtained. The preferred glass electrode is a low impendance variety marketed by Backman Instrument Co. Ltd. and the preferred reference electrode is a mercury/mercurous sulphate electrode marketed by Radiometer Inc. This combination is said to give rise to far less drift than is obtained from other systems.

Measurement of Chloride Ion Concentration

Specific ion electrodes are in common use and are in general satisfactory. However, it is generally agreed that the most stable system is the silver-billet/silver/silver-chloride system.

Measurement of Conductivity

The system which is in common use appears to have the advantage, compared with other systems, of being drift free for periods upto one year. A strain less steel flow cell which acts as a shield contains four stainless-steel electrodes. The two other electrodes are connected to a constant current, a.c. source so that fouling of these electrodes does not alter the potential developed between the inner two electrodes. This potential, a measure of the conductivity of the sample, is measured using a high impedance operational amplifier with the result that fouling of these electrodes also does not give rise to errors since fouling would only increase the input circuit resistance by an amount that was negligible compared with the amplifier input impedance. In some variants this magnitude of the energizing current which is then recorded.

CHAPTER - 5

STORAGE AND RETRIEVAL OF DATA

The need for water quality Data:-

Water quality data are required for management of water courses, and this involves a knowledge of the present state and future trends in the quality of the water. The ability to warn users of sudden changes in water quality is also of paramount importance. The data are of value in water conservation work, such as mixing of waters, storage of water, and the use of river regulating reservoirs, and in the control of the quality of the under ground water.

Immediate information is normally required in respect of accidental discharges of pollutants. Short term information may be required for remedial measures to be taken in the case of existing pollution, and for possible water uses. Finally, long-term data are needed for prediction purposes.

The Data needed and Methods of Collection:-

In general, the data may be divided into two main classes.
a) Values of parameters that need to be monitored continuously or semi-continuously; this may be because they vary rapidly either in the river itself or in a sample bottle or because they form the basis of an automatic alarm system.

b) Concentrations of stable substances, such as soluble inorganic solids, when a knowledge of long term trends alone is required; these data can be obtained by manual or automatic sampling followed by laboratory analysis.

Because any organization concerned with pollution control is likely to be collecting both classes of data, there is a clear need for a system of collection, storage, and retrieval which is capable of accepting information obtained either from automatic monitors or from discrete samples.

A suggested order of priorities for water quality parameters is given in table 3. It was further suggested that following parameters should be measured at all water quality monitoring stations on a continuous or semi-continuous basis: temperature, dissolved oxygen, ammonical nitrogen, organic matter, suspended matter, conductivity, chloride ion, and althoough not a water quality parameter river flow. Other parameters whilch might need to be measured, but not necessarily at all stations, are: nitrate ion, hardness, p^H value, sun light intensity, dissolved carbon dioxide, cyanide, phenol,copper, Zinc nickel, cadmium, chromium, pesticide and herbicide residues, color COD, toxicity and substances responsible for taste and odor.

A continuous measurement of toxicity might be made by recording the movement of fish in a tank at the water quality station. Provision should also be made to retain a water sample when any particular parameter reaches a dangerous level.

The Accuracy of the Recorded Data:-

Table 3 shows the units in which data obtained from automatic monitors might be expressed and the limits of accuracy required.

The value of river water parameters will often vary as the

Table 3. Required units and limits of accuracy for data from automatic water-quality monitors

Data	Unit	Range	Accuracy
Temperature	^oC	-10 to 40	± 0.5^{o}C (linear scale)
Dissolved oxygen	% of air saturation value	0-100 0-200	± 1% of saturation ± 2% of saturation (linear scale)
Ammoniacal nitrogen	mg N/1	0-5 0-10 0-50	± 5% of reading (log scale)
Organic matter	mg C/1	0-10 0-100	± 5% of reading (log scale)
Suspended matter	mg/1 based on formazin standard	5-500 50-5000	± 5% of reading (log scale)
Conductivity	micromhos/cm^2	5-5000 50-50000	± 5% of reading (log scale)
Chloride	mg Cl/1	0.5-500 25-25000	± 5% of reading (log scale)
Hardness	mg/1 as $CaCO_3$	10-1000	± 5% of reading (log scale)
pH value	units	2-11	± 0.1 (linear)
Sunlight intensity	cal/cm^2 h	0-120	± 1.2 (linear)
Dissolved carbon dioxide	mg/1 as CO_2	0-100	± 5% of reading (log scale)

flow in that river changes, and because of a complex interdependence between these variables, the value of the results for quality measurements is at times limited by the relatively low accuracy of flow measurement. In assessing mass balances for nutrients in a water, it is very essential to be able to measure flows to a higher degree of accuracy. When possible an accuracy of 1 percent of reading for both flows and concentration of nutrients would be desirable. One point which can not be over stressed is the need to record the results of standardizations (preferably automatic) in any file of water quality data so that the precision of data recorded for future use is known and so that better accuracy can be achieved by corrective processes carried out by the computer. The frequency of standardization depends on both the nature of the sample and the type of sensor. However, if automatic cleaning is carried out daily, most physical, optical, and electrochemical sensors could be expected to operate sufficiently reliably to allow standardization at weekly and perhaps for nightly intervals.

Manual analysis (i.e., determinations carried out away from the monitoring station) might include BOD, COD, nitrite metals, phenols, cyanide, pesticide, herbicide, detergent, phosphate, sulphate, boron, permanganate value, total organic carbon, and toxic in table 3. Even using modern instrumentaltechniques, few of these parameters can be measured with an accuracy better than 2 percent at a reasonable cost, but in the case of nutrient balances, an accuracy of +1 percent is required.

Sampling Frequency:-

Data collection at a water quality monitoring station should be in general be at hourly intervals, although in certain circumstances it may be necessary to increase the sampling frequency to once every 15 minutes. A recording of an integrated hourly reading, particularly in the case of rapidly fluctuating parameters would in many cases be desirable. With respect to discontinuous sampling, it is impossible to generalize. When sampling of chemically stable and non-biodegradable substances considered, an ideal solution would be a 24-h composite sample, bulked according to flow and taken at intervals of eight days so that, over a comparatively short period of time, samples are taken on all days of the weeks. When parameters are being measured for alarm purposes then the relationship of the sampling point to the intake being protected largely dictates the sampling frequency.

Sampling Position:-

Unless continuous sampling at a large number of stations is envisaged, the sampling point should be at a sufficient distance down stream of a confluence or source of pollution to ensure that adequate mixing has taken place, and preferably in a place where the river cross-sectional area is small and rectangular; this ensures a rapid flow and a fairly simple means of assessing flows by measurement of stage height. Where possible, monitors should be sited in a municipal treatment plant or in a power generating plant located on a river bank. This has a number of advantages; since large volumes of water are pumped, it is possible to tap the intake lines and thus obtain a representative sample, damage by vandals is largely avoided, and local personal may be employed to clean and maintain sensors and cells.

Data storage and Evaluation:

Paper tape appears to be the most common method of compiling raw data for long time of storage. The cheapest method for retrieval of this data for processing is through the magnetic disk which combines the low cost paper tape storage method with the processing speed that can be obtained for the disk. However, paper tape units are subject to occasional mal-functions which produce a punch in the wrong place or do not give a punch when called for. Thus purity checking of the tape is necessary before processing in the computer.

The introduction of a digital computer into an automatic monitoring systems provides the user with an excellent instrument capable of calibration and testing of the system it is controlling and checking of the data which it receives. Thus malfunctions in the sensor such as low flow conditions or loss of power may be indicated by a test signal imposed up on the regular data transmission. To be assured that a legitimate signal is being received, the signal span can be checked to determine if a live zero has been reached or if 100 of the scale has been exceeded. Furthermore, checks can be made on the time sequence of the data to be sure that the appropriate day and latest data reading is being retained for processing. The magnitude of the data can then be verified by making sure that reasonable values are obtained for the season of the year, for example: that the values are within reasonable limits for the variable being monitored, and that the rate of change of the values with time do not exceed a normal velocity. The value for the comparison in this part of the program as well as the frequency of sampling need to be determined from prior manual monitoring as well as from continued use of the automatic system with up dating of the information.

The advent of time shared computers means that the computer is capable of more than one job at a time. While the computer is monitoring and controlling the data gathering network, it is normally doing a process programming operation which is the gathering of the raw data and the printing of a standard report on hourly values. Furthermore, doing this process it is possible to have the computer continually checking readings made or averaged over shorter time periods against the environmental quality goals previously set in to the computer. When the goals are exceeded on the short time basis, the computer can signal by having the print out change color. The system then can be further extended in to a warning system for control.

METHOD FOR PROCESSING OF DATA FROM A NETWORK OF AWQMS

The control of water quality is based on information obtained from the system of automatic water quality monitoring stations(AWQMS) located in fixed points of the catchment area under control.

The first is to ascertain whether the concentration of any parameter exceeds the permissible levels. In this event, the data processing system relays necessary information to assist in decisions for preventive measures.

The second purpose is to gather summary number characteristics concerning certain periods of time (e.g. one day) for long range studies on the degree of water pollution in a given catchment area. These characteristics are stored by the processing system and may be utilized for economical and research purposes in any desired configuration.

Recording of data from AWQMWS):

AWQMS system consists of monitoring control stations having numbers 1,2,.........,m. The stations in the system record every time 't', i.e. in moments t, 2t, ...,rt. and transmits information on the concentration of individual pollution parameters to the central stations.

Information transmitted in a moment 1t, where 1=1,2,.......,r. by the station of number i, i=1,2,.....m, consists of a series of numbers $xi1^{(1)}$,......, $xin^{(1)}$. These are the values of pollution indexes recorded by this station.

Thus, 1-matrix transmitted by the whole system of AWQMS will be the matrix of form:

$$(1.1)\ x(1) = \begin{bmatrix} x11(1), & x12(1), \ldots\ldots\ldots\ldots x1n(1) \\ x21(1), & x22(1), \ldots\ldots\ldots\ldots x2n(1) \\ - - - & - - - - - - - \\ - - - & - - - - - - - \\ - - - & - - - - - - - \\ xm1(1), & xm2(1), \ldots\ldots\ldots\ldots xmn(1) \end{bmatrix}$$

Where element xij(1) is the j^{th} value of the parameter recorded by i^{th} station in the moment 1t. In questionable cases, we will simply write xij instead of xij(1).

Matrix (1.1) is the initial information for the whole conversion process. In case of incomplete information(e.g. as a result of monitoring equipment's failure), for corresponding matrix elements (1.1) one should substitute agreed values denoting this fact.

Stored Information:

The storage of all data derived from the entire network of AWQMS system is necessary. Rather, a number of parameters which define the state of pollution should be chosen and the time unit then selected for stored parameters.

Assuming one day to be a basic unit for j-parameter of the i- monitoring station, the following daily values are proposed for recording:

Xmax-daily maximum

Xave-daily average

Xmin-daily minimum

$\sum X^2 ij$ (1)-Sum of squares

$\sum X^3 ij$ (1)-Sum of third powers

r- number of observation.

The first three provide average value and daily process variations. Sum of squares and third powers and number of observation are necessary for statistical computations.

Basic Processing:

Each matrix X(1), where for one day 1 assumes values 1,2,......r, is currently processed for management purposes in real period of time (e.g. signaling values exceeding permissible) and for daily data preparation.

If number of stations is equal to m, and number of recorded parameters n, then for each 1, this program would be realized m.n times. As a result of processing matrix X(1) for 1=1,2,.....,r, i.e. for the period for one day, the following matrix Y(i) is obtained for the i-station and for leach parameter Sj:-

No. of station:-i

Parameter Daily values	S_1	S_2	......	S_n
X_{max}	Y_{11}	Y_{22}	......	Y_{2n}
X_{ave}	$Y_2 11$	Y_{22}	......	Y_{2n}

X_{min}	:	:	....	:
$\Sigma X^2_{ij}(1)$	:	:	....	:
$\Sigma X^3_{ij}(1)$	:	:	....	:
r	Y_{61}	Y_{62}	......	Y_{6n}

This information is sent in predetermined order to the external memory, where it is stored in the block subjected to the number of the monitoring station, year and day. The program of basic processing may be realized invariants depending up on the equipment and utilization.

Fig.-1 shows a block diagram of the program for daily processing in which the course of matrixes X(1), X(2),....,X(r),allows for obtainment of the series of the matrixes Y(1), Y(2),....Y(m), where m is the number of the stations in the AWQMS system.

The course of daily processing is as follows: The program begins its operation after receiving a signal of transmission completion of matrix X(1), 1, 2, 3,......,r, from the network of AWQMS to the operational memory (store).

The first matrix for the day, i.e X(1) is processed by block 3, which prepared elements of the matrix Y(i) for i=1,2,.....m.

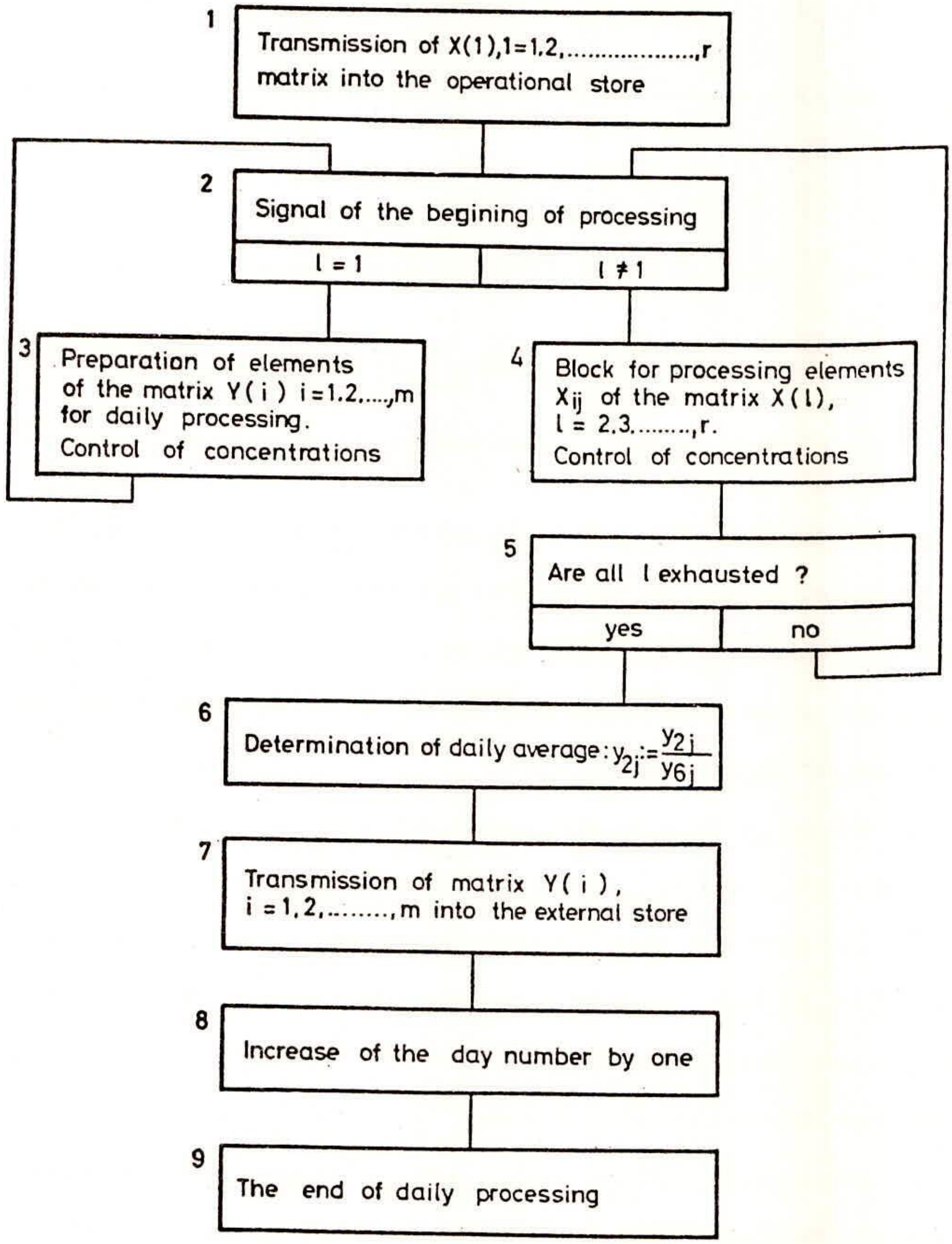

Fig. 1 Block diagram of daily processing program

This block relays the following numbers to the elements of j-column of the matrix Y(i).

$y_{ij}=x_{ij}$ $\qquad$ $y_{4j}=x^2_{ij}$

$y_{2j}=x_{ij}$ $\qquad$ $y_{5j}=x^3_{ij}$

$y_{3j}=x_{ij}$ $\qquad$ $y_{6j}=1.$

When the observation X_{ij} is lacking, then elements $y_{kj}(k=1,2,...,m)$ are equal to zero.

Moreover, this block ascertains that none of the indexes x_{ij} has exceeded permissible values. In this scope, the elements x_{ij} are compared with elements c_{ij} of the permissible concentration c matrix for i=1,2,.....,n. The fact of exceeding permissible concentration results in printing appropriate information.

For next matrixes X(1), i.e. for 1=2,3,...r. the program is realized by block 4, which converts the elements X_{ij} according to the layout in fig.2. The block accumulates appropriate values of y_{kj} for k=1,2,.....6 and prints alarm information and in case of lack of observation X_{ij} it is omitted for given i and j.

After the transformation of the last matrix X(r) for a given day, average daily parameter values (block (6)) are computed for each column j=1,2,......,n of each of y(i) matrix, i=1,2,......,n, forming ratios

$$y_{2j} = \frac{y_{2j}}{y_{6j}}$$

Thus obtained Y(i) matrixes are sent to the external store where they are stored in blocks subjected to the given station, year and_day.

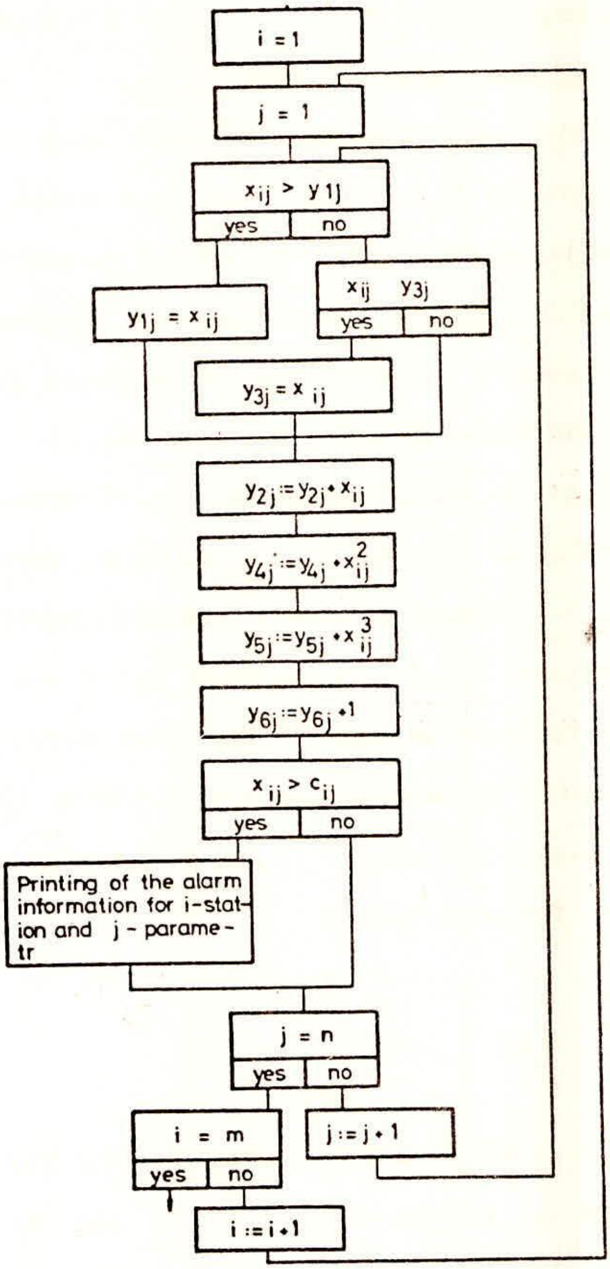

Fig. 2 Layout of processing elements x_{ij} of the X(l) matrix for l = 2,3,..........,r.

Arrangement of Information in the Blocks of External Store:

Information stored in the external store must be arranged for the most expedient retrieval of sets most frequently utilized. The units of external store is subdivided in to blocks and sub blocks of varying degrees so that the characteristics concerning definite parameters of a given station are grouped close together. This division is as follows. The unit of external store is divided into blocks subjected to the monitoring control stations, having sequential numbers 1,2,.......,m.

The block subjected to a given station is divided in to annual blocks, whose quantity depends on the storage capacity of the unit of the external memory.

The annual blocks is divided into blocks of parameters recorded by the network of AWQMS.

The parameter's block is divided into blocks subjected to the days of the year.

Finally, one day's blocks contains daily values of a given parameters-X_{max}, X_{are}, X_{min}, $\Sigma X^2{}_{ij}$, $\Sigma X^3{}_{ij}$ and r.

Due to unexpected failure of some of the elements of the AWQMS network, or the data conversion equipment or other trouble, gaps may appear in the information to be stored. The blocks corresponding to these informations must then be filled with pre-defined acceptable symbols of the lack of data. Any movement of the blocks is not permissible.

Program Library of the System:

It is very necessary to work out a proper collection of programs and subprograms accomplishing the widest choice of tasks concerning water economy.

The collection may be divided in to two parts. The first part includes programs of permanent use being utilized continuously for particular purposes. The second part deals with programs used only once, or those which are being modified.

Programs classified in the first part include:

- -Programs of periodical reports.(patterns are shown in fig.2 to 3).
- -Programs of estimation of polluters concentrations curves.
- -Programs of calculation of polluters load.
- -Programs of estimation of flow discharges shown by water gauges.
- -Programs for calculation of statistical characteristics of water quality.
- -Programs of typical statistical calculations for research purposes, etc.

The above mentioned programs should be worked out carefully to insure the minimum period of their run.

Program of the second group are being worked out to meet the economical and scientific demands. According to recent experiments, some of these programs are marked by a complicated structure. Never the less, they often contain typical elements occurring in various problems. For instance, those programs utilize as input data certain sub-sets of the whole information set stored in the system, that is, concentration of pollutions and flow discharges for the days of the considered year or any other period. In those programs, typical statistical calculations often occur, for instance, estimation of variance, correlation coefficient, regression lines etc.

Daily report

AWQMS		River			Km ....
Year..........		Month			Day ....
No	Parameters	Units	Observed values		
			maximum	mean values	minimum
1	Chlorides	mg/l Cl^-			
2	Conductivity	μScm^{-1}			
3	Turbidity	°J			
4	ORP	mV			
5	Dissolved Oxygen	mg/l O_2			
6	pH	pH			
7	Insolation	cal cm³/min			
8	Water temperature	°C			
9	Water revel	cm			

Fig.3: Example of daily report

Monthly report

Parameter			
AWQMS .... Year.............	River .... Month	Km............	
Date	Observed values		
	maximum	mean values	minimum
1			
2			
3			
4			
⋮			
31			
maximum			
mean values			
minimum			

Fig.4: Example of monthly report

Annual report

Parameter			
AWQMS........................ River............. Km .... Year..........			
Month	Monthly characteristic values		
	maximum	mean values	minimum
I			
II			
III			
IV			
V			
⋮			
XII			
maximum			
mean value			
minimum			

Fig. 5 Example of annual report

Loads of pollutants			
AWQMS .... River .... Km .... Year			
Months	Characteristic loads of .... in kg/sec		
	maximum	mean values	minimum
I			
II			
III			
IV			
V			
⋮			
XII			
maximum			
mean values			
minimum			

Fig. 6 Example of compilation of loads

Working out programs containing the above mentioned elements simplifies and speeds up the utilization of the proper subprograms which are transformed in to the desired unit by the main program and supplemented by fragments which are not contained in the subprograms.

The programs and subprograms library should be continuously developed and improved and every program recently worked out should be described in detail and listed.

Optimization of Automatic Water Quality Monitoring

The optimization of Automatic water quality monitoring is an important question, and a difficult one. The primary difficulty rests with the problem of defining "optimum". According to Webster to "Optimize" means to make as perfect, effective or functional as possible. In one instance, it might be a network of monitoring stations which maximizes the information on water quality for a given budget, or one which minimizes the cost of data collection for a required accuracy of information. In any event, one can not begin to design an optimal monitoring program unless a clear objective has been specified.

Thus the first step in the design of a monitoring program is the establishment a clear and unambiguous objective in quantitative terms. For instance, a treatment plant monitoring program may be designed which determines the BOD of the effluent to $\pm$ 5 mg/l, or a regional river basin survey should be conducted such that the total pollution load is determined to within 10 percent. These are clear and quantitive statements of an objective, and it makes sense to label a monitoring program, which will achieve these objectives at minimum costs, as optimal in an economic sense.

If one attempts to classify different water quality monitoring programs, a separation in to national, regional and local programs appears to be feasible. At the highest, or national level, information is necessary for broad planning purposes, such as to determine an overall level of water pollution, to determine the total investment necessary for pollution abatment, to determine national policies and to project the problems into the future. At the second highest level, the regional level, all of the above information is necessary, plus the particular information needs for this region. The third, local level, consists usually of checking the operation of waste water treatment plants to insure compliance with regulations and statutes. Thus, due to the different requirements and objectives, a monitoring program which may be optimal at one level, is usually far from optimal at some other level. Unless a clear objective has been set, there is no guarantee that all critical bits and bytes of information are collected, and that the gathering of useless data is minimized.

Monitoring a Single Point

Monitoring the water quality at a single point may be required for a variety of objectives. These include

a) to determine the suitability of the water as a source of water supply for swimming or boating or recreation purposes,

b) the day-to-day monitoring of the effluent of a treatment plant, an out fall or water intake, to determine compliance with regulations, and

c) to detect accidents and spills

Monitoring a single input can be optimized. The sampling frequency is based on the variability of the data. To get an estimate of the variability, a first, almost continuous recording of the data is necessary. Based on this information, the necessary frequency of samples can be determined for various confidence levels and a decision can be made on grab sample versus continuous recording conventional statistical methods can be employed to resolve the questions of an optimal strategy and of statistical significance. With automatic data collection, the data can be digitized at a time interval larger than the recording interval without lossing essential information. If this is the case, then data collection program can be designed accordingly with a saving in the cost of collection, storage and analysis.

In general, the sampling frequency depends on the variability of the data. The larger the variability, the more samples must be taken. Assuming the data are normally distributed, the number of samples to be taken may be determined by

$$n = \frac{\sigma_x^2 . z^2}{h^2}$$

where

n = number of samples to be taken

σ_x^2 = population variance

z = Standard normal deviate

h = half width of the confidence internal

Suppose one consists a 10 percent deviation from the means, the equation may then be written as

$$n = \frac{\sigma_x^2 . z^2}{(0.1)^2 . m^2}$$

where,

m = mean

Introducing the coefficient of variation the equation may be written as-

$$n = \frac{z^2}{(0.1)^2} . (CV)^2$$

(6.1)

where

$$CV = \frac{\text{Standard deviation}}{\text{mean}}$$

Thus it may be seen that the number of samples to be taken is directly proportional to the square of the coefficient of variation.

Determination of Sampling Intervals.

The most powerful tool for determining sampling intervals is spectral analysis. Wastler (Ref.3) has prepared an excellent description of the utility of spectral analysis.

To carryout the spectral analysis a fairly long record is necessary and there must be no missing data. As guidelines a record with more than 100 sequential measurement is necessary. The necessary steps in a power spectrum analysis are as the following:

1) Calculate mean and square of the mean of the record.
2) Calculate the auto correlation function.
3) Use a Fourier cosine transform to smooth out the fluctuations.
4) Use another weighting operation to compensate for small sample size.

The necessary formulas for such an analysis are summarized below-

$$Cr = \frac{1}{n-r} \sum_{1}^{n-r} x_t \, x_{t+r} - [\frac{1}{n} \sum_{1}^{n} x_t]^2$$

where

r = auto correlation at lag r,

x_t = record value at t,

t = 0, 1, 2,...n = sequential index of values,

r = 0, 1, 2,...m = lag number,

m = total number of lags

$$y_r = \frac{k}{m} [C_o + C_m \text{Cos } r\pi + 2 \sum_{q-1}^{m-1} C_q \text{Cos } \frac{qr\pi}{m}]$$

where

V_r = Fourier Cosine transform of the auto correlation at lag r,

q = lag number, having values between 1 and (m-1).

k = a constant, k = 1 for r = 1.2... m01,

k = 1/2 for r = 0, r = m

$$U_o = 0.54 [V_o + V_1],$$

$$U_r = 0.23 V_{r-1} + 0.54 V_r + 0.23 V_{r+1},$$

for r= 1, 2, 3, ... (m-1)

$$U_m = 0.54 V_{m-1} + 0.54 V_m$$

Gunnerson (Ref.4) used spectral analysis to study the sampling internal frequency for the Potomac river in Washington.

Monitoring a Region

The monitoring of a region is usually done for several reasons:

a) to establish the pattern of the pollution loads,

b) to determine compliance with existing water quality standards, and

c) to estimate the parameters of a mathematical model of the system useful for predicting water quality for other flows and loads.

In contrast to the monitoring of a single point over a long period, these studies are concentrated over shorter times but are more intensive. Problems which arise here are the number and location of sampling stations and a sampling frequency. There are no general rules for such a study, except that the data collected should be analyzed immediately, used in the mathematical model, and the outputs or predicted values from the model should be compared to the data collected. This in turn will dictate new data collection, and thus there exists a closed loop between data collection and model building. This relation is shown in fig. 7 Since these models usually serve as the basis for optimizing investment programs for pollution abatment, the sensitivity of the parameters should be tested. The number of monitoring stations and the length of their record should be based on the values of monitoring stations and the length of their record should be based on the values of the information they provide. Under budgetary constraints, those stations should be deleted which contribute the least information.

The basic concept is that the flows in streams are correlated as a result of meteorologic phenomena, that to an extent, affect all streams in a region. In water quality monitoring, this would only hold true if a number of monitoring stations are located below a major industrial area, and no additional pollution load occur between these stations.

Correlation implies that information about some property of a sequence of parameter values may be transfered from one station to another. This implies that the monitoring at some stations may be discontinued, since the parameter values may be inferred from the properties of adjacent stations. The notion of information content is the basis of the scheme. Information content is defined as the inverse of the variance. Maximizing information content is equivalent to minimizing the variances. The approach is therefore to identify those stations that are to be discontinued, such that the sum of the variances of the

Relationship between data collection and model building

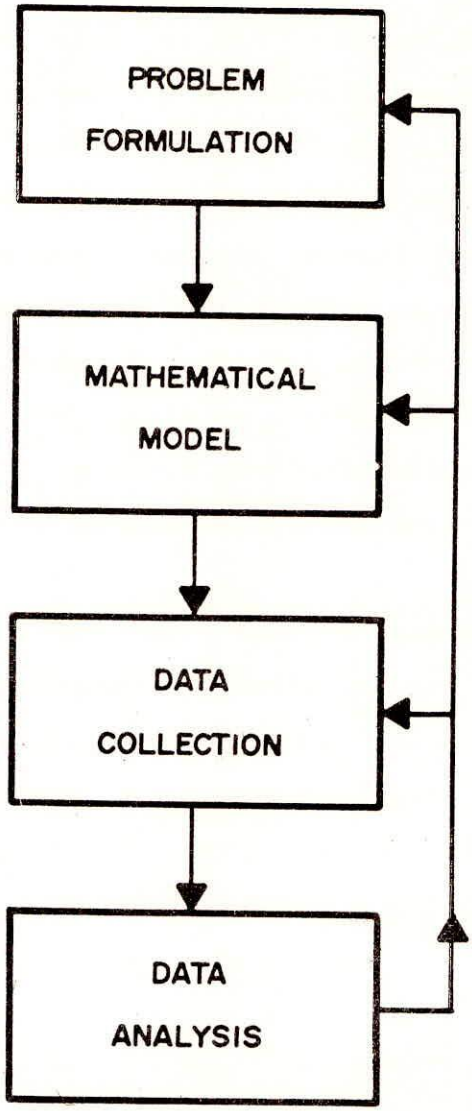

FIG. 7

estimates at all stations are at a minimum, subject to the budgetary constraint. Minimizing variances is equivalent to maximizing information content. Suppose for q monitoring stations, there are $(n_1 + n_2)$ observations, and for (p-q) stations there are n_1 observations. Means may be calculated and the means of the (p-q) stations may be estimated via regression analysis. This is shown below-

Total number of monitors = p		
Number of monitors	q	p-q
Observation period	(n_1+n_2)	n_1
Means	$x_{1,i}$ $x_{2,i}$	$x_{1,j}$

Estimated Means $$x_j = x_{1j} + \frac{n_2}{n_1} \Sigma\, b_{1j}(x_{2,i} - x_{1,i})$$

Similarly, the variances and the relative information content may be calculated -

Variances

$$V(\bar{x}_{i,j}) = \frac{\sigma_j^2}{n}, \quad V(\bar{x}_j) = \frac{\sigma_j^2}{n_1} \left[1 - \frac{n_2 \left\{q-(n_1-2)R_j^2\right\}-q}{n_1 \left\{q-(n_1-2)\right\}}\right]$$

The variance of the mean of monitor j for the period n is given by:

$$V_j = \delta_j \; o_j^2 / n + (1- \delta_j)\; V[\bar{x}]$$

where δ_j = 1, if monitor j is continued

δ_j = 0, if monitor j is discontinued

The objective then is:

$$\text{Minimize} \quad \sum_{j=1}^{p} V_j$$

$$\text{subject to : } \sum_{j=1}^{p} \delta_j \, u_j \leq B$$

where

u_j = cost of maintaining monitor at station j

B = annual budget allocation

This problem so called intiger programming problem and poses difficulties for solution. For a few stations, it is possible to use a complete enumeration approach.

For this optimizing scheme to be meaningful, the total annual allocation for monitoring must be less than one presently available. Whether or not such a number can be set in a meaningful way is an open question.

Maximum Spacing of Monitors

Ideally speaking, automatic monitors should be spaced very closely if it is desired to follow the variation in the water quality along a river. However budgetary constraints usually prohibit an unlimited number of monitors. The basic question therefore is how far apart monitors may be such that the quality of water in between two stations can not vary significantly from the values recorded at the two monitoring stations.

Consider, for example, that it is desired to monitor only the dissolved oxygen concentration of the river. Assume further more that the classical streeter Phelps equation describes adequately the deoxygenation and re-oxygenation in the river. The familiar form of the oxygen sag equation is

$$D = \frac{kL_o}{r-k} \left(e^{-kt} - e^{-rt}\right) + Do \cdot e^{-rt}$$

where D = oxygen deficit at time 't'

D_o = oxygen deficit at time zero

L_o = BOD at time zero

t = time in days

k = de oxygenation coefficient

r = re oxygenation coefficient

Consider now that a certain dissolved oxygen concentration must be maintained in the river. If this oxygen standard is maintained at two monitoring stations, the worst case which may happen is that the so-called critical point with maximum deficit occurs between the two monitors and that the oxygen standard is being violated. This situation is shown in fig.8 where the oxygen curve passes exactly through the two monitor points, but dips below the standard in between. The maximum deviation from the standard is clearly a function of the distance (time) between monitors. The shorter the distance, the lesses will be the deviation.

Let 't' be the flow between the two monitoring stations, and let D_s be the oxygen deficit at both monitoring stations. Then we may write -

$$D_s = \frac{kL_o}{r-k} [e^{-k\Delta t} - e^{-r\Delta t}] + D_s \cdot e^{-r\Delta t}$$

This equation may be rearranged and solved for L_o to yield-

$$L_o = \frac{D_s(1-e^{-r\Delta t})\ (r-k)}{k(e^{-kt} - e^{-rt})}$$

The equation for the critical oxygen deficit is-

D

$$D_c = \frac{k}{r} L_o [\frac{r}{k} (1- (\frac{r-k}{r}) \frac{o}{L}]^{-k/(r-k)}$$

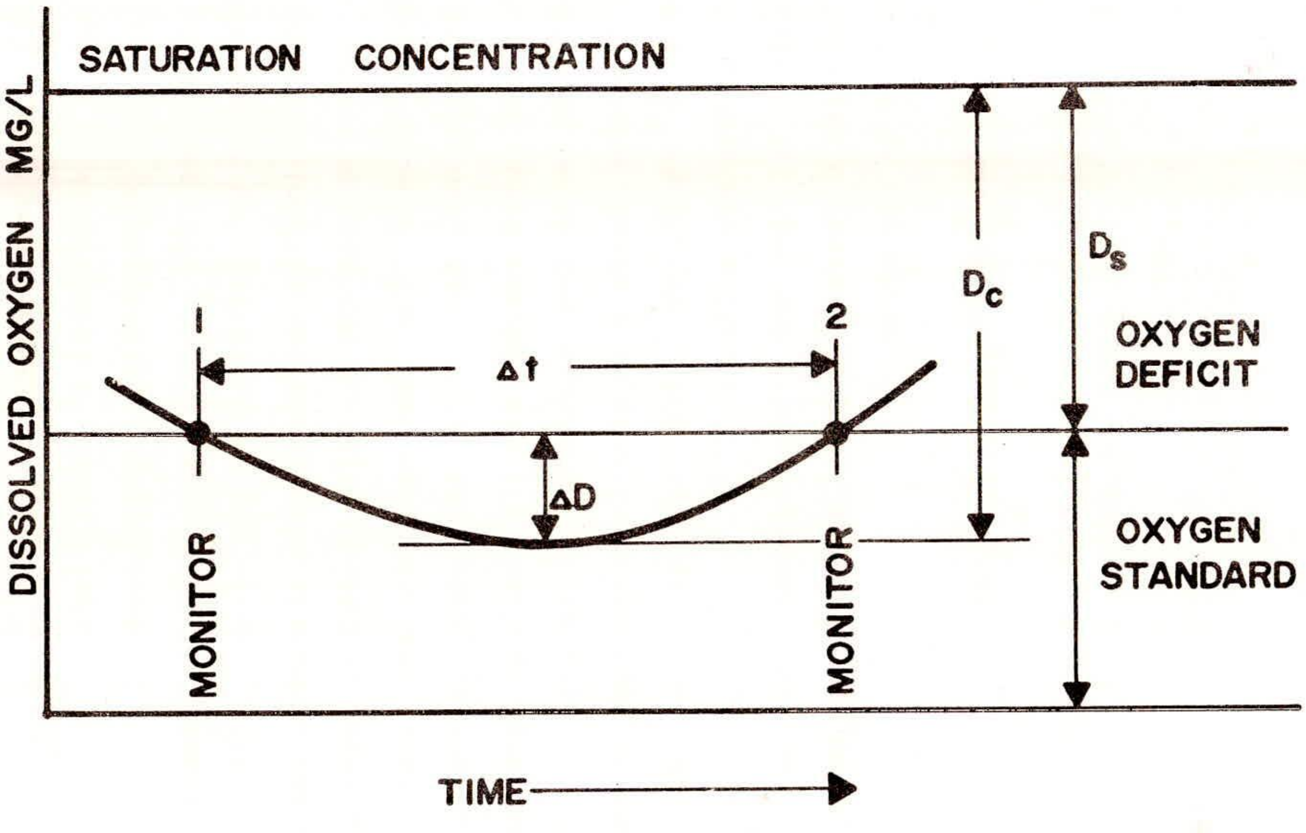

FIG. 8 OPTIMUM SPACING OF MONITORS

But since D_o in this case is equal to D_s and C_o is given by the previous equation, one may substitute the values and obtain

$$D_c = D_s \left(\frac{r-k}{r}\right) \left(\frac{1 - e^{-r\Delta t}}{e^{-k\Delta t} - e^{-r\Delta t}}\right) \left[\frac{r}{k} \left(\frac{1 - e^{-k\Delta t}}{1 - e^{-r\Delta t}}\right)\right]^{-k/(r-k)}$$

The maximum deviation, D, is the difference between D_c and D_s. Thus for a given reach of the river the maximum D is a function of the time of travel between monitors Δt.

CHAPTER - 8

Indian Status of Automatic Water Quality Monitoring

India is a vast country with a total geographical area of about 3.29 million sq. km.. India is also fortunate to have numerous rivers. The linear length of its 113 rivers, although difficult to estimate, should add up to 45,000 km. and 80 percent of this total length is contributed by 14 major rivers (Ref. 5).

As a result of rapid urbanization and industrialization in several parts of the country, there has been several fold increase in generation of waste water - For most of the cities and towns, municipal sewage is being discharged either directly or without proper treatment in the rivers. And hence country's major water resources which were relatively free from pollution up to some year back, started of showing marked deterioration in water quality in a number of locations. Even the Ganga Water which is serving considerable part of the country , once considered the purest of all, and regarded as sacred, is getting polluted by discharge of untreated sewerage and industrial wastes.

Central Pollution Board has adopted a three tier grid system of monitoring water quality of the Indian rivers. Global level under Global Environmental Monitoring Systems (GEMS), National level under Monitoring Indian National Aquatic Resources (MINARS), and state level under minimum action plan. In the first phase under GEMS 24 surface water locations were identified. The monitoring at some of these selected locations started on a trial basis from the year 1979 and the network consisting of 23 surface water stations expected to be operative by the beginning of 1981 (Ref.. 6)

To facilitate the interpretation of water quality data at various monitoring locations on the rivers, where comprehensive basin wide studies have not been conducted so far, collection of information about the activities in the immediate neighborhood with in a radius of 25 km,had been taken under the consideration. The Central Pollution Control Board has been monitoring the water quality for the river Ganga since January 1980 at 39 monitoring locations on the main stream for 19 parameters. A close scrutiny of five years data (Jan. 1980 - Dec. 1984), in the light of the basin, sub-basin inventory of the Ganga (Basin Report - Part II recommendations and the water quality trend.), revealed that as many as 20 of the 39 monitoring locations may be discontinued and 8 additional new monitoring stations have to be introduced to lay emphasis on the contribution of major tributaries towards pollution of the Ganga . Accordingly, Ganga is being monitored at 27 monitoring locations since June 1986 (Ref 6)

The data discussed so far has been taken manually and with a large interval of time, furthermore, the distance between the two consecutive stations were very large of about 50 km or so. This type of data can serve the following purposes:

i. To determine the suitability of the water as a source of water supply for swimming or boating or recreation purposes at a given location of the river.
ii. To detect violations over prescribed water quality standards.
iii. To detect accidents and spills.

But the above data not sufficient to fulfill the need of following studies:

i. To estimate the parameters of a mathematical model of the system useful for predicting water quality for other flows and loads.
ii. To establish the pattern of the pollution loads.
iii. To identify the polluted stretches for planning the pollution control programmes.
iv. For better understanding of long term changes in the aquatic environment etc.

For the above mentioned studies it is very necessary that their should be a monitoring network system over a region/stretch of the river to be studied.

Further more, it is very essential that the monitoring stations should be closely spaced and the monitoring interval should also be less.

To meet all above requirements it is proper to say that we should install Automatic Water Quality Monitoring Stations over our pollution receiving rivers.

After reviewing of the water quality data, central Pollution Board is planning to install automatic water quality monitoring stations at sites on Ganga viz Kannauj (1), Kanpur (2), Allahabd (3), Varanasi (1), Patna (1), and Palta (1), since the river is considerably polluted in these stretches (Ref. 6).

The automatic monitoring station would involve installation of the situ problem systems on a floating platform to measure and record water quality parameters like Dissolved oxygen, temperature, pH, conductivity and turbidity. The equipment shall be self-sufficient in recording for periods of at least one week (7 days), even if mains power is not available . The data produced will be captured in solid state data loggers and provisions would be there to download data into a specific micro computer.

Two automatic monitoring stations are also proposed to be set up in Yamuna at Delhi under Indo Dutch bilateral assistance programme.The two instruments are proposed to be installed, one each at Wazirabad (u/s of Delhi_ and Okhla (D/s of Delhi) in Delhi. The instruments have facility to measure pH, conductivity, DO, Turbidity , temperature, Ammonia phosphate and nitrate. These monitoring stations are proposed to be installed on fixed concrete platforms. Training for operation and maintenance and data handling is proposed to be given by M/s Dubas, Madras and Data Interpretation by Netherland agency (Ref..7..).

CONCLUSION

A proper water quality management can only be achieved when the quality of the raw water is accurately known in the desired interval of time and at the appropriate locations of the water body. Furthermore the quality of raw water depend upon the technique employed for sampling and analysis of the required water quality parameters.

Manual techniques, if evolved, the following demerits may appear which in turn, may affect the proper utilization of our available water resources.

a. **Accuracy of measurement:**

The higher accuracy cannot be achieved due to following reasons.

i. The lag time between sample collection and the reporting of the analytical result will affect the true value (value at the site) of the parameter due to intrection of the environment.

ii. The accuracy of all analytical results can be markedly dependent on the skill of the analyst and the conscientiousness and accuracy with which specified analytical procedures are followed in manual analysis. Skillness and consciousness of the analyst is an important factor. However the most important one of the techniques which is being followed for reporting analytical results.

b. Difficulties may arise when, samples have to be collected and analyzed outside normal working hours due to natural calamities.

c. The manpower and laboratory facilities available to a laboratory may be insufficient to allow the collection and analysis of all the required samples.

d. Cost involvement for manual technique is a considerable aspect but seldom do we realize and take into consideration.

With the use of automatic technique of water quality monitoring, a modern tool of water quality management, not only the above stated demerits are removed but also the following studies can be made successfully.

a. To estimate the parameters of a mathematical model of the system useful for predicting water quality for other flows and pollution loads.

b. To determine long term trends and variations in water quality.

c. To provide a rapid intelligence system for the preservation of the waters and the protection of the water users, including assurance of compliance with water quality standards.

d. To detect violations of standards or other undesirable quality conditions so that remedial action can be taken quickly.

e. To show short range water quality trends for programme management and public information purposes.

Tremendous development has been made in the field of 'Automatic Water Quality Monitoring' in the USA and in other European countries . Hence it is apparent that India should also use automatic water quality monitoring systems to make better exploitation of its water resources potential.

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