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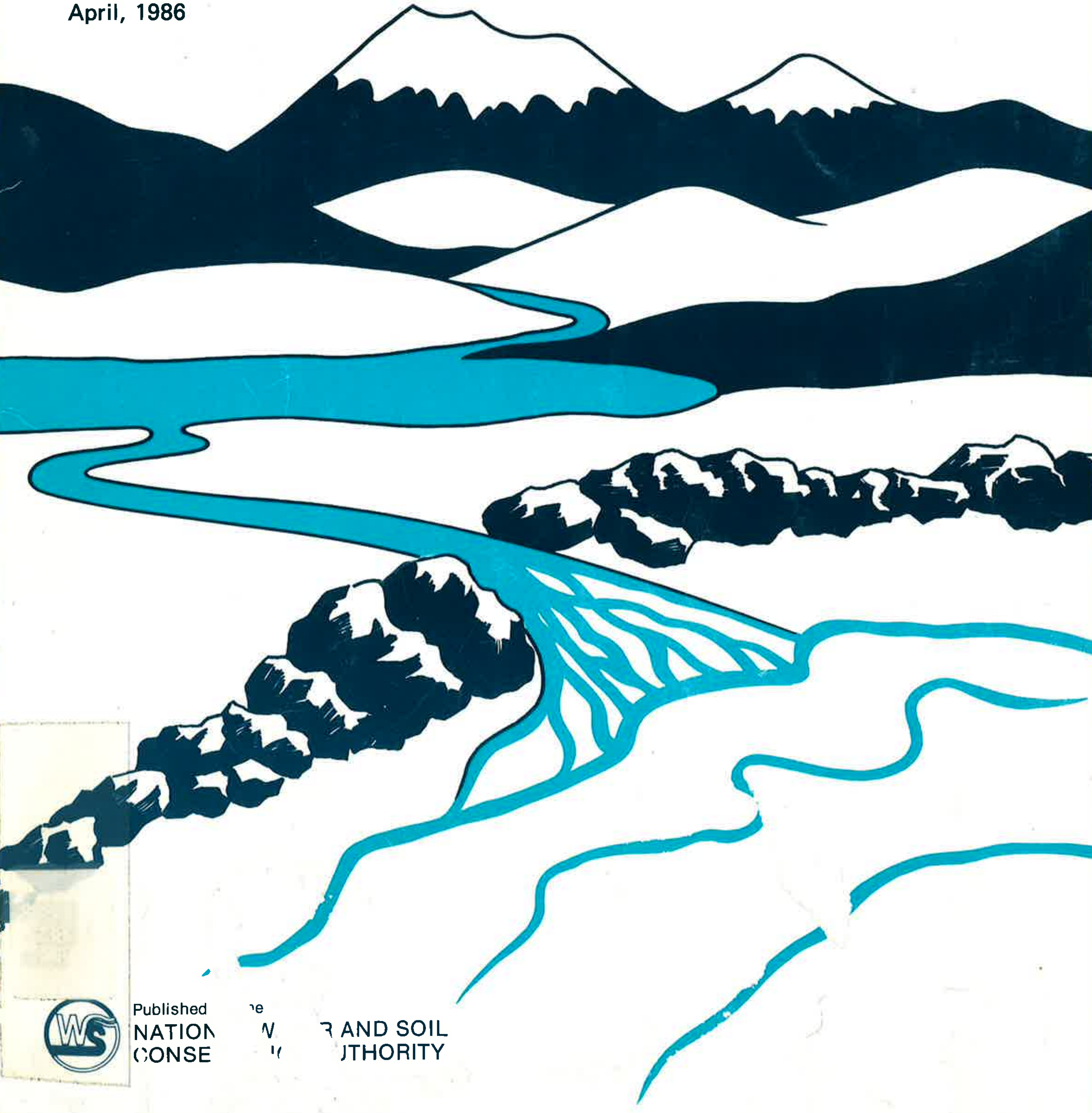
DESIGN OF WATER QUALITY MONITORING SYSTEMS IN NEW ZEALAND

by ***Robert C. Ward and Graham B. McBride***

Water Quality Monitoring Group   Water Quality Centre
Ministry of Works and Development Hamilton

April, 1986



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*R.C. Ward was on Sabbatical Leave from Colorado State University during preparation of this report

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PREFACE

Water quality monitoring, like the water management it supports, is evolving. I have been involved in this evolution for the past 14 years. During the first ten years or so, work on the design of water quality monitoring systems went rather smoothly. This work focused almost entirely on the "where, what and when" of sampling with considerable effort being devoted to defending the logic behind the design criteria employed. In the late seventies and early eighties, it became obvious to me that the wrong people were arguing over design criteria for water quality monitoring systems. Those designing the systems were making decisions regarding "proper" design criteria which should have been made by the users of the information.

The National Academy of Sciences (1977), perhaps, best summarised the situation [the comments address the situation existing with the US Environmental Protection Agency (EPA), but the insight has much wider application].

> "In recent years, there has been a number of research reports ... to describe various methods for designing ambient water quality monitoring systems. They [the reports] fail to demonstrate that <u>users</u> and <u>operators</u> of networks agree on criteria that are relevant to their needs. Because EPA did not supply the initial <u>criteria for design</u>, many of these reports differ in their techniques and fault the assumptions and criteria developed in the other reports" (emphasis added).

Several of my reports were presented in the references which followed the above quote.

The question I then had to ask myself was: am I defending my design criteria because the management agency, as the formulator of water quality management strategies, did not provide any? Should they be expected to? If I asked for monitoring system design criteria, would the managers know what I was talking about? Are there criteria that "users and operators" have agreed upon?

Finding no ready answers to the above questions, I concluded that there was a need to quantify the information required to manage water quality, and analyse and express them as criteria for the design of a water quality monitoring system to support such management. In this way, the criteria for design come from the information users and not from the monitoring system designer.

But how is a designer to go about acquiring design criteria? Information users, generally, will not be able to quantify their needs without some assistance. There appeared to be a need to greatly expand the traditional definition of monitoring system design to include phases where the designer, working iteratively with the users, develops mutually agreed upon design criteria.

This report is the result of a year's sabbatical where I have, in concert with Graham McBride, attempted to formulate monitoring system design procedures which incorporate the need to define criteria for design. The report, while focussing on specifying design criteria, also provides more detailed insight into the use of statistics in design (as opposed to data analysis). Both the criteria and statistics are cast in an overall framework for monitoring system design. Many aspects of this design framework are only now feasible due to the current evolutionary position of water quality management (especially, the existence of water quality data). The report is <u>not</u> intended to be an instruction manual for specific system design; rather, it is intended as a review of the general principles of monitoring system design.

Addressing the qualitative and subjective aspects of design criteria specification has been difficult. The result, this report, must be viewed as a first effort and one which will be modified as more experience is gained. It would not be surprising if the way water quality is managed has to be changed to reflect our ability to supply information on water quality itself. This would have monitoring influencing the way we manage water quality rather than vice versa, as now. Would not extensive efforts to apply the procedures outlined in this report ultimately lead to such a reversal?

As a visitor to the Water Quality Centre during the 11 month period from September 1983, I am very grateful to the Centre's staff for providing a most stimulating professional environment. Graham McBride, coauthor of this report, was in particular, instrumental in arranging for the visit and in formulating many of the insights between water quality management and monitoring, particularly as they relate to specifics of the New Zealand situation. I would also like to express my appreciation to Noel Burns (Scientist in Charge of the Centre) and Mike Taylor (Research Director) for their efforts in creating an excellent water quality research environment within which I received considerable support for my work.

In trying to quantify the subjective information needs of water quality managers, I spent considerable amounts of time discussing monitoring with staff at all levels of water quality management in New Zealand. I am particularly grateful for their patience, understanding and insight into the problems I was addressing.

Robert C. Ward
Hamilton, New Zealand
July 1984

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SUMMARY

Water quality monitoring is an effort to obtain an understanding of the physical, chemical and biological characteristics of water via statistical sampling. An accurate understanding of water quality over time and space is required to manage, or control, the water's quality within limits defined by society's needs. The design of monitoring systems to provide this understanding is the focus of this report. In particular, the report defines a framework within which monitoring system design can be accomplished. Unique features of the framework are that a quantitative assessment of the information the monitoring system is expected to produce and an organised approach to the use of statistics must be identified in the initial design phases.

Key to the monitoring system design framework is viewing water quality monitoring as an information system to be utilised in support of water quality management. The system consists of a number of interrelated operations through which the information is developed. Samples are taken, analysed in the laboratory, data are assembled and analysed, a report is written and the understanding of water quality is obtained by those who read the report (or hear it presented). But before a sample can be taken, the location of the sampling site must be identified, what to measure needs to be decided, and how frequently a sample is to be taken must be computed. Determining the "where, what and when" of sampling is very much a function of what information is sought and the statistical nature of the water quality characteristics to be measured. The need to redress the lack of any organised approach to these aspects of monitoring system design has been a major impetus behind this report.

Thus, the design of a water quality monitoring system involves much more than the operational aspects of sampling, laboratory analysis and data storage and retrieval. The information sought needs to be identified; the statistical nature of the water quality needs to be quantified; based on the above, the where, what and when must be determined; the operations must be planned and organised; and the reports to be written and distributed have to be defined because they serve as the ultimate output (i.e., "information product") of the entire system.

The concepts embodied in the design process outlined above require careful definition of information goals and the statistics to be used to develop the information from the raw data. These aspects of water quality monitoring have

not been thoroughly or quantitatively dealt with in the past; therefore, several appendices were developed to elaborate on these concepts, particularly as they might apply to New Zealand's efforts to design a water quality monitoring system(s). Appendix A deals with the information expectations placed on water quality monitoring by New Zealand's approach to water quality management, as an illustration of defining information goals for monitoring. Appendix B describes the use of statistics in the design of water quality monitoring systems, both in characterising water quality, and in selecting data analysis procedures. Appendix C, in elaborating on the final "product" of the monitoring system (i.e., reports) also discusses who the "consumers" of the "product" are and the form of the reports needed to convey the information to them. Thus the Appendices, in providing additional insight into aspects of the design process, will assist monitoring system designers in visualising how the entire design process functions.

The framework and procedures for designing a water quality monitoring system appear to require an excessive amount of work; and, compared to past practice, they do. However, when it is realised that water quality monitoring by a single agency, over a period of say 20 years, may consume $2,000,000 ($100,000/yr), the question becomes, what percent of $2,000,000 is spent initially to design the system properly? No building or bridge is built without careful design (seven to twelve percent of construction cost is an average design cost estimate often used). Seven percent represents a cost of $140,000 for initial design of the total system. It is the authors' contention that, while not saying seven percent is correct, logic, concerning initial design cost considerations similar to that above, has been sorely missing from most water quality monitoring undertakings.

The monitoring system design process, as an organised and systematic approach to establishing monitoring systems for water quality management provides designers with a framework within which they can define design criteria, utilise statistics and establish operating plans and procedures. Spelling out such a framework represents a new approach to water quality monitoring system design; one which the authors hope will lead to better monitoring in the future.

INTRODUCTION

Water quality monitoring is an effort, most often by statutory bodies, to obtain an understanding of the physical, chemical and biological characteristics of water via statistical sampling. It calls for repetitive measurements of such characteristics through time. The complex variations of those characteristics in the natural, and more especially the modified environment makes it difficult to obtain accurate understandings, especially with the limited resources available for monitoring. Thus, a water quality management agency, in acquiring an understanding of water quality conditions, must be extra careful to ensure that the monitoring systems it employs are designed to supply the information it needs at the required accuracy and precision.

In the early phases of water quality management (1960's for most countries), water quality monitoring was undertaken to define the problems. From this, and from a need to implement rational and fair means of allocation of water resources among competing uses, management techniques (water rights, classifications, enforcement procedures, plans, grants and research) were established. In many countries it seems that as management evolved from a "problem definition" phase into an "ongoing management" phase, monitoring systems often did not correspondingly evolve. The data generated by these early monitoring efforts, however, now become extremely valuable to the design of more appropriate systems.

In the United States, the inadequacy of monitoring systems for water quality management purposes was described by three major studies. The National Academy of Sciences (1977) noted the need to recognise monitoring as a statistical sampling process and design accordingly. The Council on Environmental Quality (1980) was an attempt to better coordinate monitoring to avoid duplication of effort while still providing the needed information. The General Accounting Office (1981) addressed the need to have monitoring results more closely tied to management decision making. The general consensus of all three studies is that a more scientific and systematic approach to water quality monitoring is required if it is to efficiently meet the information needs of water quality management.

In New Zealand, no such reviews of water quality monitoring systems performance have been undertaken - principally because the data are not generally available. [This should soon change, with the commitment to develop and use a computerised water quality data archive/retrieval system (called AQUAL)]. There is, however, a substantial effort (of the order of NZ$5 million per annum) in water quality monitoring, principally by the twenty Regional Water Boards. The National Water and Soil Conservation Authority (NWASCA) at its meeting of 3 July 1984, resolved to ask the Director of Water and Soil Conservation "... to develop, in cooperation with the Regional Water Boards a national monitoring and recording programme for water quality in New Zealand's natural waters". It is appropriate, therefore, to examine how such water quality monitoring systems should best be designed and implemented, in the light of the present state-of-the-art.

This report first defines the nature of monitoring within a water quality management agency and presents a framework for designing appropriate and complete monitoring systems. Those aspects of the design procedures for which there has been little previous work are then illustrated via additional elaboration in several Appendices using the New Zealand water quality management situation as an example. Emphasis in the Appendices is on identifying information objectives and developing an understanding of the statistical behaviour of the water quality random variables. The remaining, more traditional aspects of monitoring system design are dealt with in a summary fashion in the main body of the report. While the report and Appendices are built around the New Zealand situation, the findings are applicable to a wide range of water quality management strategies.

MANAGEMENT/MONITORING INTERFACE

The design of appropriate and effective water quality monitoring systems for management purposes is highly dependent upon a clear definition of "management" and thorough understanding of the relationship between management and monitoring. The interface between management and monitoring has not been addressed to the point where clearly stated monitoring systems design criteria can be formulated. The National Academy of Sciences (1977) describes this as a major problem in the design of monitoring systems for regulatory water quality management agencies. For this reason this study, in an attempt to identify correct design criteria, first addresses the nature of the management/monitoring interface.

The terms water quality "management" and water quality "monitoring" have different meanings within each of the different professions involved in water quality. For example, water quality "management" to a sanitary engineer can often mean the design, construction, operation and maintenance of a wastewater treatment plant. Water quality "management" to a planner can often mean a series of plans : (1) basin planning; (2) regional planning; (3) planning for a specific treatment plant; and (4) planning for the programs that control the quality of water. Likewise, water quality "monitoring" to a biologist, means some form of biological measurement while to a lawyer it would refer to measurements related to the water quality variables in the classifications. To a statistician water quality "monitoring" is viewed in statistical terms while to a hydrologist it is viewed in terms of flow related processes.

The following sections therefore seek to clarify the meaning of these terms. First, however, it is necessary to address a fundamental, but often overlooked, question. That is, what is meant by "water quality"? This must be clearly understood, since it is that which we seek to manage and to monitor.

The Meaning of "Water Quality"

Use of the phrases "water quality management" and "water quality monitoring" carries an implication to many that "water quality" is a definable, objective quantity. For example, in Mr Justice Cooke's definitive decision on water classification provisions he states (decision dated 3 July 1975, p. 33) "... existing water quality ...investigation will have to be made to find it out" (emphasis added). But can "it" be defined objectively? We believe that the answer is no. Pirsig (1976) presents compelling arguments to the effect that while in some philosophical sense a universal "quality" may exist, it certainly defies objective definition. It can mean different things to different people, and even one person's perceptions of quality may change through time.

It seems that the human mind perceives water quality as being good if desirable water uses inure, and not good if they don't. This means that a particular concentration of some chemical dissolved in water may reflect either good or bad quality water. For example, a concentration of 2 parts per million boron in a river may not affect any present uses of the river, and the river water might be considered to be of good quality. However, if the water is subsequently required for regular irrigation of certain horticultural crops the boron concentration will be too high and the water may then be considered to be of poor quality (that will certainly be the irrigator's view). Furthermore, suppose a definition of water quality had been made before the horticultural development appeared, and that boron was not included in the definition (it is seldom monitored routinely). According to such a definition the quality of the river water may be good, yet unsuitable for a desirable use!

In water resources literature there is now, somewhat belatedly, a recognition of the difficulties that this lack of definition imposes (e.g., General Accounting Office, 1981; Schroevers, 1983; van Belle and Hughes, 1983). There is an increasing consensus that "water quality" should be taken to mean the physical/chemical/biological characteristics of water necessary to sustain desired water uses. This is the view promoted by James (1979) and Lee and Jones (1983); water quality means the suitability of water for the use(s) for which the water is required. Such a definition can also be inferred from, though was not explicitly stated in, the now-defunct Waters Pollution Regulations 1963 (these were promulgated under the Waters Pollution Act 1953, and first introduced a system of water classification in New Zealand. They were repealed in 1971). This definition is used in this report. It is still not objective, because measurements that need to be made to assess the suitability of water for one use are not the same as those required for another use. In any event we have only incomplete knowledge of all the measurements necessary to assess suitability for a particular use, and of the significance of the results of those measurements. We do the best we can, in the light of present knowledge and available expertise.

Thus, it is important that the uses, and criteria required to protect the uses, be defined as part of the objectives of management. Furthermore, the definitions of water quality upon which the monitoring system is to be designed must be documented as part of the design report. Only via such documentations can future data users fully appreciate the logic for the monitoring system's design.

Water Quality Management

Water quality management, in the sense used herein, refers to all efforts by society to control the quality of water in order to meet the public's best interests. From the above definition of water quality it follows that the goal of water quality management is to promote and protect desirable water uses. This goal may also be inferred from New Zealand's major water quality management statute - the Water and Soil Conservation Act, 1967 (see Appendix A). Water quality management under such a goal involves five major components. These are:

1 Water in the environment;
2 Society's use of water;
3 Laws which regulate uses of water;
4 Public bodies which develop, and guide implementation of, law; and
5 Administrative and professional staff who implement the "tools" defined in the law which are to be used to manage water quality.

This broad view of water quality management places the role of the law, the public bodies established to guide implementation of the law, the administrative organisations established to actually implement the law, and the "tools" used to manage the quality in proper perspective. It is very important that the overall view described above not be lost in the details of a specific program established to implement a "tool" of management.

The latter three components of water quality management (i.e., law, public bodies and administrative staff) only exist because of the need to optimise the relationship between the first two aspects (the water and society's use of it). The efforts and activities, the money spent, and the effects achieved by the latter three components need to always be cast in terms of the relationship between the first two aspects. To do otherwise is to not acknowledge why the entire management program was created and continues to exist. And the only way accurate information can be obtained on the condition of the water is via water quality monitoring. Thus, monitoring becomes the common communication link between all five components. It ties them together in a way that permits management to focus clearly on the reason for its existence - maintaining desirable water uses. Monitoring results must be presented to the public and their elected representatives (who create the laws) in a manner that shows tax money is resulting in optimum control of water quality for the benefit of the public. This becomes a major information goal of any water quality management/ monitoring effort.

Getting more specific, water quality control laws generally identify the specific "tools" to be used in regulating or managing water quality in the public's best interest. In general there are seven categories of tools. These are listed in Table 1 along with references to New Zealand legal provisions. Monitoring, the focus of this report, can also be considered a management tool or a supporting activity to implement the other tools; the latter view holds here.

While a law may provide for most of these tools, the funding made available will influence the degree to which each tool, and its programme, is actually used for management purposes. The degree to which water rights are effective depends upon the administrative and financial support provided. The amount and type of planning and its usefulness often depends upon the support provided. The decision of which tool's program receives what level of emphasis and/or funding is a matter of policy, administrative will or, in the case of classifications in New Zealand, a legal decision (i.e., decision of Cooke J.). Thus, the policy or strategy of water quality management is the result of the legal tools provided, the total level of financial resources and the allocation of available resources among the various tools.

Under different hydrological and geological settings, population densities, industrial development and political attitudes, different management strategies are appropriate. In a country such as New Zealand, with varied situations as noted above, one could not expect water quality management strategies to be uniform across the Regional Water Boards. On the other hand, it is reasonable to ask each board and NWASCA to measure and report on the effectiveness of its management strategy [ss. 21(5) and 36 of the Water and Soil Conservation Act 1967 - see Appendix A, p. 42]. This calls for a water quality monitoring programme.

Table 1 : Water quality management tools

	CATEGORY OF MANAGEMENT TOOL	NEW ZEALAND REFERENCE*
1	Standards Designated use of water Criteria required for use to be met Non degradation statement Exemptions Implementations	Classifications (Sections 26A-26KA)
2	Discharge and abstraction permits Establishing effluent discharge limits - wasteload allocations	Water Rights (Sections 21-26 and 26L-26V)
3	Planning Programme - management tool implementation strategies Basinwide - water management plan Regional - coodination of control measures Facilities - wastewater treatment plants	Town and Country Planning Act
4	Grants Watewater treatment plants (structural) Non-point control measures (nonstructural)	Health Act 1956
5	Technical Assistance Design, operation and maintenance assistance Treatment plant operator certification Laboratory certification	(Section 14)
6	Enforcement Notice of violation Hearings Orders Fines Compliance schedules Court	(Sections 24G, 26N and 34)
7	Research Appropriate water quality criteria Wasteload allocation procedures Standing setting guidelines Planning methodologies Design manuals and handbooks Monitoring system design	(Section 14)

*Sections quoted refer to Water and Soil Conservation Act 1967

Water Quality Monitoring

There are two basic forms of monitoring water quality: (1) routine, fixed-station surveys (which actually better fits the traditional meaning of the term "monitoring"); and (2) special surveys. Both forms are required for effective water quality management, and are carried out on rivers, lakes, wetlands, estuaries, coastal waters, and on effluents.

Routine surveys often have no set date at which they will end, but the information they generate must be published periodically (e.g., annual assessments of water quality conditions). There are a limited number of fixed sites (stations) at which samples are collected regularly (e.g., once a month). It is highly desirable that once commenced, routine surveys continue with regular sampling, since uneven sampling results in considerably less trend detection power (Lettenmaier, 1978). Comparisons over time and space and against water quality standards are the major information purpose, providing information on broad scale changes in quality over time, and between different water bodies. As a result they should give continuing information on the overall effectiveness of the total management effort and also provide information for water use planning.

Special surveys are generally short term (e.g., less than 2 weeks for rivers, up to one year for lakes) and are designed to obtain thorough knowledge of water quality conditions, usually in a relatively small area. They often consist of a high density of sampling sites, sampled at a high frequency over the short time period. Reporting is done at completion of the study as opposed to periodically as with routine surveys. They provide information for resource inventories, impact assessments, or process studies.

There is a further major difference between routine and special surveys: special surveys tend to be easier to design than routine surveys. This is because special surveys have a well-defined objective (e.g., study the impact of a sewage discharge on river dissolved oxygen, do an inventory of the invertebrates on a stream bed, assess a river reaeration rate). The detailed work required to provide the necessary information for such objectives is relatively well understood. For routine monitoring, one is faced with a number of difficulties. Specifically:

i the overall management goals against which data could be evaluated may be ambiguous. For example, there may be two data analysis goals stated in the statutes: on the one hand to maintain and improve water quality, and on the other to promote the conservation and best use of water (as in the Water and Soil Conservation Act, see Appendix A). If "water quality" is interpreted as an objective quantity (and, as we have noted, it is so regarded by many, including those in the legal profession) then the designs under each goal will be quite different. This is summarised in Table 2; in particular, under the first goal sites will be spread rather uniformly in space and selection of which water quality characteristic to measure will be somewhat arbitrary (and probably excessive), while under the second goal sites will tend to be concentrated in regions of present or anticipated conflicts of use. Not all such uses, or their water quality requirements, can be foreseen;

ii statutes change with time, as do social aspirations;

iii there may be insufficient existing data upon which to calculate the necessary frequency of sampling, in which case some initial higher-frequency sampling will be required prior to final monitoring system design;

iv some water quality standards, against which the monitoring results are to be compared, are not expressed in explicit numerical terms [e.g., "the natural colour and clarity of the waters shall not be changed to a conspicuous extent" - Water and Soil Conservation Act, 1967: Schedule 2(e)]. Definition of what is meant by "colour" and "clarity", and of what is the measure of "conspicuousness", would be desirable <u>before</u> designing a system to detect violation of this standard;

v some water quality characteristics, e.g., river dissolved oxygen, can vary dramatically in space and in time, so that only one sample per month cannot be expected to give very precise information on their variability.

If such difficulties remain unresolved, it is inevitable that the designer will be confronted with the realisation, and perhaps accusation, that no amount of post-data manipulation can cover up the lack of initial design. The challenge is to translate goals into a form that permits the effectiveness of water quality management to be assessed. It is imperative that those commissioning and designing routine monitoring systems give very careful attention to this question.

Table 2 : Implications of alternative goals for design and operation of a routine monitoring system.

ITEM	GOAL@ "Maintain or improve water quality	"Promote conservation and best use of natural water"
Information needed for design	- Objective definitions of "water quality", "maintain", and "improve".	- Objective definition all "best water uses", their water quality requirements, and "compliance".
Information expected from operation	- Changes in that water quality over time.	- Compliance with standards for those uses.
Design criteria*	- Sites "representative", tend to be spread uniformly. - Frequency related to trend detection power. - Characteristics determined by definition of "water quality".	- Sites tend to be concentrated where water use conflicts anticipated. - Frequency related to definition of "compliance". - Characteristics related to water quality requirements of all best uses.
Reporting	- Goal met when trends are either absent or improving.	- Goal met when probability of violation of water quality requirements in acceptable range.

@ Goal = "why"
* Sites = "where"; Frequency = "when"; Characteristic = "what" (e.g., BOD_5, pH, invertebrates, bacteria, ...)

Management/Monitoring Strategies

The broad spectrum of approaches to management, almost regardless of the law under which the management program is established, goes from the "crisis" approach all the way to the "no-pollutant-discharge" approach that often rarely needs information on water quality in the environment. In the former case, monitoring tends to be performed only when a problem arises. Management action is only initiated in reaction to a problem that causes sufficient political pressure (a "crisis") to warrant the attention of management. Outside of dealing with the problems as they arrive, little other management effort is undertaken. This form of management is often the result of a minimum of management resources being available, especially in the early stages of management evolution. The case of "no pollutant discharge", as a management goal, focuses management's attention on the discharges and not the quality of the water. Under such an approach, instream water quality conditions may play little role in management decision making. This strategy may result in treatment levels excessive to, or inadequate for, the needs of water quality management.

In any situation attempts to design a monitoring effort, without fully understanding the management strategy, can result in an inappropriate monitoring system. The designer of monitoring systems must understand the range of management strategies that exist and their different data, or information needs.

Role of Monitoring in New Zealand

Water quality management in New Zealand stems mainly from the Water and Soil Conservation Act 1967. The Act provides water quality managers with the tools of their trade (Table 1) and establishes NWASCA and the Regional Water Boards to oversee national and regional water quality management efforts, respectively.

While the 1967 Act provides for water quality monitoring to be performed by NWASCA and the Boards, it does not identify the exact uses of the information within management. Formulation of such policy is left to the Authority and the Boards. With respect to the management/monitoring interface, there does not appear to be a set policy (Dunford, 1973; Holm and Mulcock, 1980; and OECD, 1981). From a national perspective, NWASCA's Research and Survey Committee, at its 27 March 1979 meeting, discussed the administrative needs for establishing a technically sound monitoring program. NWASCA's GA38 grant guidelines result in funding of short term special studies to the exclusion of routine monitoring.

Thus, there are some management/monitoring policy guidelines, but they focus on administrative and funding issues and are not included in a broader perspective of the total monitoring systems (e.g., why is the information needed and how will it be reported). McColl (1983) has reviewed NWASCA funding of water quality monitoring.

Currently there are no regular, national or regional assessments of water quality conditions. This stems from both the focus on short term studies which has precluded the acquisition of a data base to support an analysis of changes in water quality over time and space, and from the lack of an effective information system. The Commission for the Environment (1984) points out the difficulty of demonstrating what is happening to the environment in New Zealand.

The Regional Water Boards have each developed their own individual approaches to establishing a management/monitoring interface. Some Boards tend to react to problems while others have established a planned approach to management and the use of monitoring. Small (one person) management efforts tend to be crisis oriented while larger efforts tend to be better planned. Some employ both routine monitoring and special surveys while others only use special surveys. This is in sharp contrast to the hydrological monitoring efforts in New Zealand where routine monitoring of flow is widespread.

The cost of measuring the quality of water, as part of a governmental water quality management effort, consumes anywhere from 25 to 50 percent of most agencies resources (from discussions the senior author has had with state water quality managers in the United States). There is no doubt that monitoring water quality is expensive. Its high expense in the US (US $275 million, at the Federal level alone, in 1978) has prompted the US Congress to ask what the public is getting for this expenditure. When it was revealed that little information was in fact being developed, there was considerable pressure to upgrade monitoring system design in the United States. The goal of monitoring was forced to shift from acquiring numbers to providing information.

New Zealand spends an estimated NZ $5 million per year on water quality monitoring. This sum of money should be adequate to provide management with the water quality information it needs if the money is spent on a well designed monitoring effort focused clearly on the information sought. Ensuring that the money is spent providing information actually required for management is a major goal of the monitoring system design procedures presented in this report.

MONITORING SYSTEM DESIGN PROCEDURES

Thus far, the two types of monitoring (routine monitoring and special studies) have been discussed in relation to the management/monitoring interface (i.e., how is monitoring used within management). The monitoring system itself, and its statistical nature, remain undefined. Prior to presenting the design procedures, the statistical nature of monitoring will be noted (due to its critical involvement in the system design) and the monitoring system (to be designed) will be defined.

Monitoring as Statistical Sampling

Monitoring water quality requires the use of statistics to extract accurate and maximum information. Because of this, water quality monitoring can be viewed as involving statistical sampling. Samples are being taken from the total water quality "population" to be statistically analysed in order to make inferences, probabilistic statements, about the total water quality "population". It is the understanding of this "population" that is required for water quality management decision making.

The question of which statistical procedures to use has plagued those involved in the design of monitoring networks for a number of years. Fortunately, is there is now more information available for the water quality monitoring system designer to use in formulating his/her own approaches to network design and data analysis.

Statistics can be effectively applied to both design and data analysis. While these applications may be distinct, they are closely related in theory. The following definitions of categories point this out.

1 In the initial effort to design a monitoring system, it is necessary to statistically analyse existing data and examine those characteristics of the population which will influence the selection of data analysis procedures. The major characteristics relate to the dependence structure, applicable frequency distributions and variance homogeneity.

2 As part of designing a monitoring system, the statistical procedures to be used to analyse the data (e.g., to compute means, trends, and standards violations) must be selected. Those procedures whose assumptions best mesh

with the population characteristics (as determined in one above) can be identified as the more appropriate statistical data analysis procedure for the monitoring programme. These procedures can, in turn, assist in establishing the most appropriate sampling frequency.

The use of statistics for initial network design and ongoing data analysis (points one and two above, respectively), is not straightforward. Many factors have to be considered prior to the choice of the appropriate statistical procedures. These factors must be dealt with in a quantitative fashion in any set of procedures employed to design monitoring systems.

Monitoring System

A water quality monitoring system can be viewed as having six major components which follow the flow of information. Table 3 lists the components, in the order of information flow, with a few of the aspects of each component listed as a means of further definition. The system as viewed in Table 3 is independent of monitoring type and water environment.

The first three components in Table 3 (sample collection, laboratory analysis, and data handling) are more "operational" in the sense that these activities are necessary to obtain the numbers in a form ready for abstracting the information. Analytical methods, and their performance in laboratories have been reported (e.g., Smith et al., 1982a, Grasse and Stevenson, 1982). The latter three components (data analysis, reporting and information utilisation) are more "informational" in that these components are converting the numbers into information that can be readily understood by those requiring knowledge of water quality conditions.

To be effective in meeting the information goals of the monitoring effort, the total monitoring system must be properly balanced. Many monitoring systems in the past have, in effect, ended after data handling. Such systems tend to let the operation of collecting data become an end in itself. As the system viewpoint in Table 3 implies, however, the informational half of the system is just as critical in developing accurate knowledge of water quality conditions. Thus, whenever a monitoring system is designed to acquire information about water quality, all six of the components listed in Table 3 must be addressed and defined in a quantitative manner. There must be no opportunity for the data to

TABLE 3 : The water quality monitoring system following the flow of information

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WATER QUALITY

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Sample Collection
- Sampling Technique
- Field Measurements
- Sample Preservation
- Sample Transport

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Laboratory Analysis
- Scheduling and Operational Procedures
- Analysis Techniques
- Laboratory Quality Control
- Data Recording

↓

Data Handling
- Computer Hardware
- Data Base Management System
- Screening and Verification of Data
- Storage and Retrieval

↓

Data Analysis
- Statistics
- Model
- Indices

↓

Reporting
- Types of Reports (Formats)
- Frequency of Reporting
- Distribution of Reports

↓

Information Utilisation
- Technical
- Program Management
- Public (News Media)

↓

Accurate Understanding of Water Quality Conditions

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lose direction as it flows along the system. Each step in the data's path must be clearly identified so that it moves quickly and effectively toward the information goals. The budgeting for monitoring must allow for effective functioning of the informational end of the monitoring system. Even a well designed system, if not funded in its entirety, will fail to meet is information goals. In other words, a balanced monitoring program is balanced in its design as well as in its funding. Quality assurance (incorporating quality control) is an over-riding concern over the entire monitoring system. Equal emphasis on quality assurance in all six components also helps create a system balanced in the accuracy of the data.

Design Procedures

The design of water quality monitoring systems has historically focused on the concept of "network design" - determining where to sample, what to measure, and when to sample (e.g., Montgomery and Hart, 1974). Network design was necessary before the activities outlined in Table 3 could begin. The activities listed in Table 3 often were not specified prior to initiation of sampling, especially the data handling, data analysis, and reporting efforts. Even the network design efforts were rarely documented, thus any change in personnel often meant a gross change in sampling procedures with a resultant loss of information. It is no wonder that many water quality monitoring efforts today are heavily criticized for their inability to supply water quality information (e.g., General Accounting Office, 1981).

Monitoring system design in the past has generally consisted of a few informal discussions regarding where samples are to be taken, what is to be measured, and how frequently. The logic and rationale for these decisions (network design) was not documented. The sampling routes were planned and laboratory methods were selected, again without documentation as to why. Over time, as the numbers began to pile up, pressure developed to "analyse" the data. The numbers (data) were often on laboratory sheets in a file cabinet. The effort to simply pull the numbers together was great and staff had difficulty in finding the time to compile the numbers in a form ready for analysis.

Since the data analysis procedures had not been identified before sampling began, they were selected after the data were in hand - most often by someone other than the person who set up the monitoring system in the first place. In selecting the data analysis procedures, the person doing the analysis had to "guess" at what statistical results best contained the information originally sought. The report was written in a manner deemed most appropriate by the staff at that time. If the information finally obtained had any bearing to what was initially expected (but not quantified or documented) it was more a matter of chance than by design.

The ad hoc nature of monitoring systems "design" described above is no longer tolerated by most water quality management efforts. Management programmes are increasingly dependent upon an accurate and timely understanding of water quality for their proper functioning. Such information can only be guaranteed by a much more systematic and scientific approach to the initial design of the monitoring system, as a total system. Designs must now be documented as to the information sought, the logic and rationale behind obtaining the required information, the data analysis procedures to be used and the frequency of publication and contents of reports to be prepared.

This more systematic approach to monitoring system design requires more formalised design procedures than have been utilised in the past. There are many ways that the systems view of monitoring, defined in Table 3, could be utilised to formulate a set of design procedures. Hoare (1983) lists ten main points that need to be addressed when planning a water quality survey. Sanders (1980) presented a twelve step process for designing monitoring systems which was later reduced to five steps (Sanders et al., 1983). These five steps, with more elaboration of what each step involves, are presented in Table 4. The design process, which was only outlined in broad terms by Sanders et al. (1983) will now be developed in detail as a means of ensuring that water quality monitoring systems are designed in a systematic and scientifically sound manner and that they are capable of producing the information initially agreed upon.

As part of initiating any design, there must be a clear purpose in mind. Step 1 of the monitoring system design process, as outlined in Table 4, involves determining what information is sought - why is the monitoring being undertaken? A major task under Step 1 is to evaluate the management's need for the type of information the monitoring system is to acquire. Such an evaluation should be designed to stimulate a discussion among information users and monitoring system designers regarding not only what the user wants, but what the monitoring system is capable of producing. This discussion will, invariably, cover the water quality goals, management strategies and monitoring's role in management if an acceptable compromise between information "demand and supply" is to be reached.

Table 4 : Steps in the design of a water quality monitoring system

STEP 1 Evaluate Information Expectations

- Water Quality Problems
- Water Quality Goals
- Management Goals and Strategy
- Monitoring's Role in Management
- Monitoring Goals
- Statistics of Future Data Analysis, Including Accuracy Sought

STEP 2 Confirm Statistical Design Criteria

- Statistically Characterise "Population" to be Sampled
    - plot flow and concentration versus time
    - test if normal distribution assumption is violated
    - test homogeneity of variance
    - test for sample independence
- Confirm that Assumptions Underlying Statistical Methods Identified in Step 1 are not "Grossly" Violated

STEP 3 Design Monitoring Network

- Where to Sample (from monitoring's role in management)
- What to Measure (from water quality goals and problems)
- How Frequently to Sample (from needs of statistical tests)

STEP 4 Develop Operating Plans and Procedures

- Sampling Routes
- Field Sampling and Analysis Procedures
- Sample Preservation and Transportation
- Laboratory Analysis Procedures
- Quality Control Procedures
- Data Storage and Retrieval hardware and Data Base Management Systems
- Data Analysis Software

STEP 5 Develop Information Reporting Procedures

- Type of Format of Reports
- Frequency of Report Publication
- Distribution of Reports (information)
- Evaluation of Reports' Ability to Meet Initial Information Expectations.

Specifics on water quality problems and goals and monitoring's role in management become input for later aspects of "network design". Likewise, a formulation of information expectations into statistical hypotheses, plays a large role in future sampling frequency determinations. Output of Step 1 is a mutually agreed upon (by information user and system designer) and carefully documented statement about the information the monitoring system is expected to produce, including the statistical data analysis methods to be used in producing the information in the future.

To illustrate the detail sought, Figure 1 contains a breakdown of the information expectations into management goals, monitoring goals, definitions of water quality, statistical methodology and the final "product" for two different management goals. The quantification contained in Figure 1, once agreed upon by the information users and monitoring system designers, provides a very strong basis for design of the total system.

Formulation of such a breakdown of information expectation, as presented in Figure 1, requires careful evaluation of water quality problems and the management structure established to "manage" the problem. Appendix A is an example of the type of evaluation needed to ultimately be able to develop information expectations for government sponsored monitoring efforts in New Zealand.

Step 2 involves two major elements: (1) evaluating the statistical characteristics (e.g., underlying frequency distributions and dependence structure) of the water quality population to be sampled; and (2) using the above information to confirm that the selected statistical tests do not have their underlying assumptions violated by the water quality population characteristics (e.g., make sure that data are independent if that property is assumed by a chosen statistical method). This, of course, assumes that sufficient data already exist to evaluate statistical characteristics. If they do not, preliminary surveys will have to be undertaken before proceeding further with the design. The statistical tests play a role in determining the sampling frequency in Step 3. Thus, in Step 2, the statistics of the monitoring programme are being dealt with in a quantitative manner, before sampling begins. Appendix B contains a thorough discussion of the role of statistics in the design of a water quality monitoring system.

Example 1

Management Goal: Maintain or improve water quality

Monitoring Goal: Detect trends in water quality

Definition of Water Quality: Variables to be measured include DO, BOD, nitrates, TDS

Statistical Methodology: Linear regression fit of water quality data versus time

Statistical Hypothesis: Slope (β) of linear regression line is zero at 95% confidence level
H_o: $\beta = 0$
H_1: $\beta \neq 0$

Monitoring System Product: Conclusions regarding slope of regression line being significantly different from zero for variables being considered (Trends are found to exist when $\beta \neq 0$)

Reporting: Management goal is met when all slopes are zero or indicate improvement

Example 2

Management Goal: Promote beneficial uses of water (Uses to be considered must be defined along with criteria-levels of water quality--which must be satisfied if each use is to be met. Use and criteria--i.e., standards--are then assigned to specific water bodies)

Monitoring Goal: Measure compliance with standards

Definition of Water Quality: From standards

Statistical Methodology: Fit water quality data to a normal or log normal probability distribution

Statistical Hypothesis: Standard is met if 15% or less of the distribution is above standard

Monitoring System Product: Conclusions regarding probability of violation at each sampling site (Violation is defined as at least 85% probability of standard being met)

Reporting: Management goal is met when all sampling sites report $\geq$ 85% probability of compliance

Figure 1. Examples of information expectation quantification required to support design of a total water quality monitoring system

Step 3 is where the monitoring network (i.e., the where, what and when of sampling) is designed. Sampling sites are identified and precisely documented as to the exact spot where the sample will be taken. The variables to be measured are derived from the water quality problems and goals of the management effort and the correlation structure between variables. It may not be necessary to measure two variables that are highly correlated - measuring one provides information on the other. The frequency of sampling, and measurements frequency of different variables (which may be different from the sampling frequency), are computed using the requirements of the statistical tests. The mechanics involved in "network design" are described in detail by Sanders et al. (1983), and will be addressed in detail by a future Water Quality Centre Handbook.

Step 4 involves defining the means by which samples will be collected, analysed, verified and the data stored and retrieved. Laboratory quality control is a major concern at this point. Computer hardware and software are specified. The monitoring system operations, as defined in Table 3, are spelled out in detail during this step. To achieve this definition of detail, literature and standard methods are utilised heavily. The key point is that in Step 4 the operations of the entire system will be defined in sufficient detail that different people working in the monitoring effort will generate identical results. Nothing, operationally, should be left open to interpretation. To do so is to generate data that may not be comparable.

Step 5 takes the evaluation to the point of having the monitoring system produce a final "product" (written reports) which is designed to convey the information expected in Step 1. To communicate the expected information effectively, the reports must be prepared in a format, at a frequency, and distributed in a manner than matches the needs of the user of the information and the ability of the monitoring system to generate information. The most appropriate reporting methods and procedures should be identified as part of the monitoring system design, but they should not be beyond future fine tuning. In fact a procedure to continuously evaluate the reporting methods, and the entire monitoring system, should be designed into the reporting procedure. Additional detail on reporting is contained in Appendix C.

The results of the entire evaluation process, all five steps, should be documented in a written report. Such a report serves to provide consistency to the monitoring effort and, therefore, greatly enhances the value of the data and information . It also helps users evaluate the quality of information.

The five steps in the monitoring system evaluation represent a large amount of work prior to initiating a new monitoring effort, or modifying an old one. This type of effort, prior to initiating monitoring for regulatory water quality management purposes, is rare. However, many management agencies are discovering that no amount of post data manipulation can cover up the lack of initial design. Also, agencies are discovering that many unrealistic information expectations are placed on monitoring programs without any counter definition of what information can actually be obtained. The systematic approach to monitoring system design should minimise such problems in the future.

CONCLUSION

A more systematic and quantitative approach to the design of water quality monitoring systems is required if water quality management, in general, and water quality monitoring, in particular, are to be accountable for their costs to society. A framework which will permit a more scientific approach to monitoring systems design has been presented and those portions not thoroughly dealt with in existing literature have been elaborated on in more detail in the Appendices.

The framework and procedures for designing a water quality monitoring system appear to require an excessive amount of work; and, compared to past practice, they do. However, when it is realised that water quality monitoring by a single agency, over a period of say 20 years, may consume $2,000,000 ($100,000/yr), the question becomes, what percent of $2,000,000 is spent initially to design the system properly? No building or bridge is built without careful design (seven to twelve percent of construction cost is an average design cost estimate often used). Seven percent represents a cost of $140,000 for initial design of the total system. It is the authors' contention that, while not saying seven percent is correct, logic concerning initial design cost considerations similar to that above, has been sorely missing from most water quality monitoring undertakings.

The monitoring system design framework is dependent upon some prior knowledge of water quality behaviour. This knowledge comes from past data collection efforts. If no such data exists, it is necessary to modify the framework for design to include some means of acquiring such knowledge (e.g. a preliminary data collection phase prior to use of the design framework).

Water quality monitoring involves many interrelated activities which require careful planning and design if an accurate and precise picture of water quality is to be obtained. The design of such systems must be approached in a more organised and scientific manner than has been practised in the past for the understanding sought to be achieved. Hopefully, this report will help those charged with the design of water quality monitoring systems to better view the tasks at hand.

APPENDICES

APPENDIX A : INFORMATION EXPECTATIONS

Information expectations placed on a water quality monitoring system draws heavily on literature published on the subject, the law which governs the management effort (i.e., the New Zealand Water and Soil Conservation Act 1967), and the personnel involved at all levels of the management effort. This latter source of information was acquired by visiting with NWASCA staff and the staff of 19 of the 20 Regional Water Boards in New Zealand.

The approach used to evaluate information expectations is presented in three discussions. The first discusses goals of management which influence information needs. The second discussion focuses on the information needs of the management tools provided by the law. In most cases these information needs are implied. The third discussion deals with those "information", or more expressly, data, provisions directly stated in the 1967 Act.

The information expectations are discussed from a general water quality monitoring perspective with the specific implications to routine, instream monitoring specified at the end of the Step 1 analysis. Thus, this discussion of information expectations is much broader than would necessarily be required for a highly focussed monitoring system design. As such, this discussion can, hopefully, provide background material for future monitoring system design efforts.

GOAL OF WATER AND CONSERVATION ACT

The following arguments have been adapted from McBride (1985).

The Water and Soil Conservation Act, 1967 (as amended) has as its long title :

> "An Act ... to make better provision for the conservation, allocation, use and quality of natural water ... for promoting and controlling multiple uses of natural water ... and for ensuring that adequate account is taken of the needs of primary and secondary industry, [community water supplies, all forms of water-based recreation, fisheries, and wildlife habitats, and of the preservation and protection of wild, scenic, and other natural characteristics of rivers, streams, and lakes]".

The bracketed section was introduced by the Amendment Act of 1981 (the "Wild and Scenic Rivers Amendment"). This changed the existing wording concerning water supplies, fisheries, wildlife habitats and recreation uses, and added the new section on preservation and protection of wild and scenic waters. The stated object (i.e., goal) for the Amendment was to "... recognise and sustain the amenity afforded by waters in their natural state" (s.2 of the Amendment Act).

Elsewhere in the Act the idea of promoting conservation and best use of water, stated in the long title, is repeated. This is contained in sections on functions and powers of the National Water and Soil Conservation Authority (NWASCA) [s.14(3)(a), (b) and (m)] and of the Regional Water Boards [s.20(5)(c)]. It is also stated as the desired effect of classifications [s.26H(1)]. A problem here is that, as Mr Justice Cooke noted, neither "conservation" nor "best use" are defined in the Act. The former term runs the danger of being interpreted as preservation of existing water quality (however defined) and may then be in conflict with the idea of promoting best uses, since a change in water use often results in a change of water quality characteristics. The latter term - "best use" - was thought by Mr Justice Cooke to call for a consideration of "... uses which should reasonably be provided for in the light of such factors as competing demands, other available water resources, and modes of waste treatment and their cost". It should be noted however that no indication is given of what criteria are to be taken into account to decide what is reasonable, nor of what uses are in prospect. In particular the above interpretation of "best use" appears to contemplate only the uses of water made by man. Yet the Act also contemplates uses by flora and fauna as well [see the long title, ss.14(4)(1) and 20(6), and the schedules].

A further function of "maintaining or improving the quality of natural water", or words to that effect, appears in another subsection on functions and powers of NWASCA [s.14(4)(m),(o),(p),(s) and (t)], and in a section on classification [s.26A(2)]. This subsection was introduced into the Act, along with classification provisions, by the Water and Soil Conservation Amendment Act (No. 2), 1971. This function does not appear in the section on functions and powers of the Regional Water Boards although, of course, NWASCA could delegate it to them [under s.16(1)]. "Quality" is not defined; nor are the terms "maintaining" and "improving".

It is apparent to us that while the Act does not contain explicit definition of its goal(s), in its actual implementation three goals are variously taken:

i to protect and preserve in their natural state those natural waters with high amenity values;

ii to promote the conservation and best use of natural water;

iii to maintain or improve the quality of natural water.

We believe it important for such goals to be in harmony, expecially when water quality data are analysed and interpretations are made relative to goals being met. Objectives (such as taking account of the needs of fisheries and also of industry) can be in conflict, in which case a plan is needed to state policies on how such conflicts will be resolved. But the overall intent of the legislation, the goal, must stand firm.

Goals (i)-(iii) can be harmonised into the statement: to <u>promote and protect desirable water uses</u>. This follows from goal (ii) by equating "conservation" with "best use", and from goal (iii) by using the definition of "water quality" given in the text ("the suitability of water for the use(s) for which the water is required"). These uses include those made by natural flora and fauna. Goal (i) also agrees with this statement, it is just that the number of uses in prospect for waters of high amenity value is limited.

INFORMATION EXPECTATIONS IMPLIED BY THE MANAGEMENT'S FUNCTIONS AND POWERS

In the Water and Soil Conservation Act (in s.14) are specific "functions and powers" of NWASCA that imply information needs. These functions and powers cover a wide variety of topics from public information [s.14(4)(p)] to establishing standards for quality of water [s.14(3)(o)]. The functions and powers of the Boards are less well defined in the Act. For the purposes of discussing the information ramifications of the Authority's functions and powers, they will be organised along the lines of the major aspects of water quality management presented at the beginning of the report - public interest, law, administration and management tools.

Public Interest

The law recognises the public interest in water quality management [ss.14(3)(d) and 14(3)(j)] when it requires the Authority to coordinate all matters relating to natural waters to the best advantage of the country and to guide national and local administration of natural waters in the best public interest. The Authority is also to promote the dissemination of information to the public [s.14(3)(p)]. While not specifying the exact nature of the information to be provided the public, monitoring information describing the quality of the waters in terms of the purpose of the Act is certainly implied. This type of information, information for the public, would be that mainly supplied by routine monitoring and would report on conditions over space and time and an achievement of goals overall and at specific sites in terms of classification compliance.

Law and Administration

Besides the above public interest information needs, the Act also lists functions and powers of the Authority related to recommending future legal changes needed to ensure the most efficient management strategies [s.14(3)(b)] and to advising the Minister about the best ways of meeting the objectives of the Act [s.14(4)(m)]. The Authority is also to advise the Minister as to the need for money and as to the effectiveness of the past expenditures [s.14(3)(h)]. The Authority, along these same lines, is to keep under review and make recommendations concerning the performance of the Regional Water Boards [s.14(3)(c)]. All these functions and powers relate to the need to constantly evaluate the effectiveness (or accountability) of water quality management in New Zealand. Again, such constant evaluation requires information on water quality conditions over time and space and in relation to classification compliance - routine water quality monitoring of receiving waters.

Classifications

Turning away from the law and administration information needs to those of the management tools, the functions and powers of the Authority cover, in general terms, most of the tools listed in Table 1. Those not covered here (under the "functions and powers") are dealt with in other parts of the Act. Section 14(3)(o) deals with classifications as do ss. 26A through 26KA. When classifications are established, their compliance needs to be measured if they are to serve a useful purpose within water quality management. As noted earlier, s.26H(1) points out that natural water so classified shall be maintained in order to promote the conservation and best use of the water. Compliance must be measured regularly to ensure that the classification is being maintained. Section 26A quite directly states that special investigations, on a "time to time" basis, may be carried out to study the waste discharges and their impacts on water quality.

Water Rights

Water rights, as a management tool, are implied in ss.14(3)(g) and 14(4)(b) and are described in detail, including enforcement procedures, in ss.21-24. There is a direct reference to information needed to implement water rights in s.14(4)(j) as well as that implied in s.26A. In all cases, the information needs related to water rights imply the need for highly site specific details on discharge and impacts on water quality. From a monitoring viewpoint this implies special investigations of a short term (e.g., one day to two weeks) nature which may be repeated at different times of the year. Such studies help define cause and effect relationships which are needed to set water right conditions. Section 24D(2) ties the use of water rights by the management agency to classifications which implies that the special investigation will also tie these two together from a quality control perspective. Routine measurement of water quality provides a check on the appropriateness of the water right conditions - again, accountability.

Enforcement

Enforcement of water rights implies [s.24G(1)] that information on water right compliance is available. While not defining how compliance will be measured, the law is requiring compliance monitoring. Compliance monitoring can be performed by the water right holder as a condition of the right (self-monitoring) and/or it can be performed by the management agency. That performed by the agency can be used as a means of verifying self-monitoring results or it can be the only compliance monitoring performed. Generally, the larger the potential effluent impact, the more self-monitoring required.

The self-monitoring data supplied to the agency should have a well defined use within the agency. In effect, this is data (numbers) that enter the agency's monitoring system at the data handling stage (as defined in the proposal) and proceed through the remainder of the system. In other words, self-monitoring data have defined data analysis procedures, reporting requirements and points in the management strategy where the information is utilised. It is incumbent upon the management agency to require only that monitoring needed to operate an effective water right programme.

Compliance monitoring is basically routine monitoring of effluents. It may not have a set termination date. Besides meeting the "process control" aspects of water right enforcement, compliance monitoring data are valuable in establishing a basis for determining future water right conditions either at the same effluent or others. This places an ongoing value of compliance monitoring data that can only be effectively exploited if the data are readily accessible through a computer system.

Planning

Planning, while directly referred to in ss.14(3)(a) and 20(5)(c), is not addressed in detail in the 1967 Water and Soil Conservation Act. There are considerable implications to the planning functions in the 1981 Amendments to the 1967 Act and in references made to the 1977 Town and Country Planning Act. Thus, while there appears to be considerable proposed interaction between water quality management and land use planning, the functions are separate and implications for the monitoring performed by and for the Authority are not clearcut. Assuming it is the role of the Authority and Regional Water Boards to develop water quality information for planning purposes, this becomes a broad information expectation that covers both routine and special investigation monitoring. In many, if not most cases, the need for water quality monitoring information for planning purposes can be met by computer storage of data used for other management purposes. The major exception relates to future use of high amenity value water - the topic dealt with in the 1981 Amendments. When plans are made with respect to future use of such waters, background information on the nature of this water is needed. To be of use, the variation in natural quality over time must be known, if future impacts are to be properly evaluated. This may require routine monitoring of high quality water over a long period of time.

Grants

Section 14(5) gives the Authority the ability to make grants for a number of purposes. However, wastewater treatment by public organisations is not one of these areas nor is non-point source control. Such grants are made by other organisations in concert [s.20(5)(c)] with the water quality management agencies (e.g., Department of Health Subsidies for sewerage). The monitoring requirements implied are that the water quality management agency, via its compliance monitoring, routine monitoring and special investigations identify where upgraded control is needed. This then leads to the planning that may result in a grant to solve a particular water quality problem. Thus, while the management agency generates documentation of a problem, it must work in cooperation with other agencies to identify a solution and get it implemented. The need for wastewater treatment grants can often be identified by negative water quality trends appearing in routine monitoring data.

Technical Assistance

Technical assistance or technical advice, when provided in a cooperative manner, can be very effective. The Water and Soil Conservation Act of 1967 provides a number of functions and powers to the Authority regarding technical assistance. Section 14(3)(1) gives the Authority the power to encourage non-point source control via means that can be inferred to be technical assistance. The same is true in ss.14(4)(g) and 14(4)(p), specifically regarding water quality. Assistance, in even broader terms is implied in s.14(4)(t). Legal assistance is noted in s.14(4)(r) regarding model bylaws.

The implications to monitoring of these and other technical assistance provisions of the Act are extremely varied. The key point is to ensure that water quality trends and problems are made known to management personnel in contact with those responsible for causing the trends and problems. Positive trends are to be discussed just as much as negative trends. In other words, the reporting of available monitoring results, not necessarily specific technical assistance sampling efforts, will drive an active discussion and eventual improvement of water quality conditions.

Research

Monitoring for research is implied in s.14(4)(o) where the Authority is given the function to organise and encourage research into ways and means of maintaining and improving water quality. The specific monitoring required is highly dependent upon the problem being addressed and the procedures being used to study the problem. In a technologically evolving society, water quality problems are constantly evolving in their sophistication and, consequently, require a constantly increasing level of management sophistication. Research plays a major role in increasing the ability of management to deal with evolving water quality problems.

Given the constantly changing nature of water quality research, it is not possible to identify, beforehand, the information expectations research will place on monitoring. It is safe to say, however, that research, in the main, uses special surveys. However the analysis of long term water quality data records derived from routine monitoring can eventually play the same role in water quality management that the current analysis of long term hydrological data records is playing in water quantity management.

The reason such a long term view of data was taken in hydrology and not water quality stems from their different evolutions over the years. Water quantity management, particularly the monitoring functions in most countries, has been retained at a national level. Water quality management has been decentralised from the start. The centralised monitoring provided a long term view while the decentralised monitoring provided a much shorter term view. As the role of accurate long term data records in water quality research, and management, become recognised, monitoring will be established to generate the much needed records. This will probably require foresight at the national level to provide direction and financial support for such water quality monitoring.

Case Law

Recent decisions of the Planning Tribunals have also highlighted the need for monitoring under the Water and Soil Conservation Act. Thus in Brown v. Waikato Valley Authority, Decision No. A2/83 (dated 26 January 1983), p 7:

> "We infer from the attitude of its (WVA) counsel and witness that it is now prepared to undertake a proper level of monitoring. It has a duty to the public to do so, and to make the test results public.
>
> "Indeed, we go further and say that it should now actively demonstrate to the public that it is an adequate guardian of the public interest in matters of water quality ..."

Also in Redwood v. Northland Catchment Commission, Decision No. A35/84, p 13:

> "It will be the respondent's responsibility, within the limits of its financial resources, to police the exercise of the right, to monitor the quality of the waters of the (Whangarei) harbour and to survey the biota of the harbour for any ill-effects from the exercise of the right."

DIRECTLY STATED INFORMATION REQUIREMENTS

In addition to the information needs implied by the law, there are several direct references to information needs. Section 14(3)(i) points out that the Authority can acquire the information it deems necessary to manage water pollution. This same point is stated again in s.27(1) in terms of the Authority acquiring information and in s.27(2) in terms of the Boards acquiring information. These sections make it clear that the Authority and the Boards should be able to get the information they need.

More specifically, s.14(4)(n) refers to the Authority's power to carry out surveys and investigations to determine water quality problems. Sections 20(5)(e) and 20(5)(f) specifically direct Boards to investigate water quality. While these sections give the Authority and Boards the responsibility to investigate water quality, the exact use of the information is left to the discretion of the Authority or Board. To ensure that the information collected via monitoring is in fact needed and utilised, it is incumbent upon the Authority and Boards to relate their monitoring to the purposes of the Act. The Act stipulates that the Authority [s.36] and the Boards [s.21(5)] shall report annually on their operations. These reports should contain the interpretation of the public bodies' understanding of the role of monitoring and its results in their operations.

APPENDIX B : ESTABLISHING STATISTICAL DESIGN CRITERIA

To obtain the information identified in Step 1 (Table 4, page 27) will require the use of statistical data analysis methods. There are many methods available for analysing water quality data. Many of the differences in the methods are associated with the fact that the populations being sampled have different characteristics (i.e., probability distributions, variance homogeneity and dependence structures). If data are normally distributed, have homogeneous variance and are independent, then this qualifies the data for theoretically correct analysis by statistical procedures developed on these assumptions. Not all these conditions are met with all data sets, so other data analysis methods have been developed to accommodate such situations. Choice of the most appropriate data analysis method, as part of a total monitoring system design, depends upon matching the data analysis methods with the underlying characteristics of the population being measured.

During Step 2 of the monitoring system design procedure, the characteristics of the underlying statistical population are evaluated (characterised) using the state-of-the-art in water quality hydrology knowledge and existing data. This, of course, assumes that such data exist; if not, they will first need to be collected. This information is then used to confirm that the data analysis procedures selected to supply the information sought in Step 1 do not have their underlying assumptions grossly violated by the nature of the population being sampled. Thus, Step 2 consists of two major sections :

1 Statistically characterising the water quality "population" to be measured; and
2 Confirming data analysis procedures chosen to provide the required information do not have their underlying assumptions violated by the "population" characteristics.

STATISTICALLY CHARACTERISING WATER QUALITY

The statistical procedures available for analysing water quality data, as part of the effort to supply the information identified in Step 1, involve assumptions with respect to the population being sampled. Different statistical procedures involve different assumptions.

There is a need to examine the nature of the statistical characteristics of a water quality population in light of the assumptions underlying the different statistical data analysis options. Once the most appropriate data analysis procedures are identified, their sampling frequency needs can be used to assist in computing the sampling frequency as part of Step 3. Correlations among water quality variables can help decide which variables to measure and statistical definitions of areas of complete mixing can assist in selecting sampling sites.

Assumptions

There are four assumptions that appear to be of most concern regarding the use of statistics in water quality. These are:

1 The variance over the record is assumed homogeneous. This implies that no new wastewater discharges, for example, have resulted in a change in the underlying variance of the process.

2 The data are assumed to be normally distributed. The water quality variable is assumed to follow a normal distribution.

3 Many statistical methods assume the data are obtained from a random sample process. In fact, however, most routine, fixed-station, water quality data is obtained via systematic sampling (i.e., random start with equally spaced samples after that). In water quality this assumption implies that the data are assumed to be independent of each other. The value of one observation is assumed to not "depend" on the previous value.

Water quality data, in general, violate most of the above assumptions (Smith et al. 1982b). Further details are given in Ward and Loftis (1985), and will be given in a forthcoming Water Quality Centre Handbook on water quality monitoring. Smith et al. (1982b), however, note that it is not possible to quantify the distortions in statistical tests caused by violation of the assumptions. It is only possible to make very general observations which the monitoring systems designer must judge for relevance. Green (1979) casts the situation as follows:

> "What is argued here is that (a) the assumptions of the method should be understood at the time it is chosen, (b) the likelihood and consequence of violation should be assessed ... , and then (c) use of the method should proceed with awareness of the risks and the possible remedies."

While the above information provides some general indication of the relative seriousness and consequences of violating assumptions, it remains for the monitoring system designer to develop an understanding of the amount of assumptions violation likely to be present in the water quality population being monitored. Examination of a water quality data record for purposes of gaining information on assumption violations is, presently an art rather than a science. The approach suggested here tends to follow the philosophy of Crovello (1970) which is to use as many methods as possible, not to get the result you want, but rather to converge on similar results.

Data Preparation

Because the reporting of water quality monitoring results in the past has often been poorly planned, designed, organised and coordinated, past data records can be difficult to find and hard to verify (Berry and Horton, 1974; Thomsen, 1984). The data record may not be computerised and it will often have missing values. Thus considerable time may often have to be spent on locating the data, verifying its accuracy and representativeness, filling in missing values (if possible) and computerising the lot. Once this effort has been accomplished, however, the monitoring program has a well established historical data base against which to compare future monitoring results. Also, as part of obtaining the information needed for monitoring system design, it is desirable to carry the work a little further and develop an assessment of water quality conditions at the time of the monitoring system design evaluation. Where past monitoring efforts have not been analysed, this is an excellent opportunity to demonstrate the value of an ongoing monitoring effort in providing an understanding of water quality.

Variable Selection

It is first necessary to select the water quality variables on which the design of the monitoring system will be based. These will depend upon statutory requirements and water resource uses, and will be specified in the precise monitoring goals (see Step 1, page 27). It is the available data records of these selected constituents (water quality variables) that will be used to statistically characterise the "water quality" population.

Of course, there has to be some compromise between selection of variables and availability of data records. Here, among many others, is where considerable judgement has to be incorporated into the monitoring system design process by the designer.

Plotting the Data

Once the water quality variables have been selected, the data needs to be plotted against time.

Time plots of the individual water quality variables, a 12 month moving average of the water quality data and corresponding flow data provide an excellent overview.

The plot should be inspected for seasonality, flow dependence, and bias. Bias can result from changed impacts on water quality in the area, past sampling and laboratory analysis practices, and the time of day, day of week, or day of month sampling took place (if flow is measured more frequently than quality). If the data are found to be biassed, any further analysis must be interpreted in light of this fact.

Testing for Normality

Whether data are normally distributed should be checked by several different tests. Several tests, all converging on the same conclusion, is strong evidence. A plot of a frequency histogram can provide initial information on the distribution of the data. The Chi-Square goodness-of-fit test can be used to test a data set for its adherence to a hypothesised distribution (normal or log normal). Sanders et al. (1983) describe this test in the context of water quality data. Velleman and Hoaglin (1981) present the "stem and leaf" and "rootogram" procedures as alternatives to the histogram.

Shapiro-Wilk and Kolmogorov-Smirnov tests for goodness-of-fit allow for testing the distribution of numbers in a data set for normality. Ponce (1980) describes the tests using water quality data and notes that the Shapiro-Wilk test should be used when the number of observations is less than or equal to 50 while the Kolmogorov-Smirnov test should be applied when the number of observations is greater than 50.

Yevjevich (1972) discusses use of the skewness coefficient, Cs, as a criterion for preliminary testing of whether the normal function is appropriate. If $-0.10 \leq Cs \leq 0.10$, then the empirical distribution underlying the data is close to being symmetrical and the normal function may be shown to be an appropriate distribution.

The skewness test of normality is described by Salas et al. (1980). This is a more formal use of the skewness coefficient to test for normality. Phien et al.

(1982) discuss a number of additional methods in testing normality.

Selection of specific procedures to use to test for normality may be heavily influenced by availability of tests in statistical packages with which the data are to be analysed.

If the data are not normally distributed, decisions must be made as to whether the non normality is sufficient to invalidate data analysis procedures based on the normality assumption; or if transformations to achieve normality are appropriate; or if non-parametric procedures should be utilised.

Testing for Variance Homogeneity

Review of the time plot will give an indication if there have been dramatic changes in the variance of a particular variable. If it is suspected that there have been changes, the record can be divided into two or more segments (depending upon the number of suspected changes) and tested. Ponce (1980) discusses these tests.

A correlation between means and variances of different groups of observations can be a sign of non-homogeneity of variance.

Again, there are several means of judging the validity of the assumptions. Use of several methods and arriving at the same conclusion is convincing evidence.

When the variances are heterogeneous to the point where serious problems exist, it may be necessary to carefully examine the data record for the causes of change. Early data may not be representative of current conditions and once removed, homogeneity of variance may be achieved. Future projections of changes in variance may dictate use of data analysis procedures which are not sensitive to violation of the homogeneity of variance assumptions.

Independence Testing

Water quality time series are almost certain to contain time dependency which leads to a violation of the assumption of independent data (Montgomery and Reckhow, 1984). Quantifying the nature of this dependency is not easy, especially in water quality situations where monthly sampling and relatively short records (compared to hydrological records) are common. However, some very rough estimates can be developed.

For most routine, fixed station water quality monitoring (e.g., monthly sampling frequency), time dependency is the result of generally predictable periodicities (e.g., seasonal changes) and those that are not readily predictable (e.g., droughts). When seasonal changes, from a water quality perspective, incorporate both natural seasonal variation (due to rotation of the earth around the sun) with society induced seasonal changes ("seasonal" manufacturing and "seasonal" cultural activities), the "generally predictable" aspects of seasonal changes may cease to be so. The level of predictability will be related to the magnitude and timing of societal impacts.

A close review of the time plot reveals considerable information about the periodic aspects and those not so periodic. The magnitude and regularity of periodic changes can be gauged. The need, and applicability, of treating the periodic components of the time series separately can be judged. Montgomery and Reckhow (1984) and Kavvas and Delleur (1975) present ways of separating seasonality from other trends in the data.

To confirm trend observations, "correlograms" can be computed for the original time series and for a standardisation series where the periodic mean and periodic standard deviation have been removed (Salas et al., 1980, page 53-55). If the correlogram for the original data shows a regular cyclic pattern, seasonality may be deemed sufficiently predictable to permit a reduced or appropriately modified sampling frequency. When the periodic component has been removed the point at which the samples appear to become independent can be determined. Loftis and Ward (1980) found this point to be between two weeks and a month for the data records they examined.

If the seasonal component appears not to be particularly pronounced or predictable, then the correlogram of the initial time series can be examined to determine the frequency at which samples are sufficiently independent. Using the correlogram in this manner makes it difficult to examine the effects of increased sampling frequency.

Another approach to examining the effects of serial correlation on network design is to compute the effective number of independent samples which can be acquired under the existing lag one correlation (correlation of samples, once removed in time). The approach of Matalas and Langbein (1962) is suggested. This requires an estimate of the lag-one correlation coefficient. The effective number of independent samples, under varying sampling frequencies, gives some indication of the impact on statistical tests that may be employed to analyse the data during monitoring operations. The effective number of independent samples can be used to then determine the number of dependent samples that must be collected.

There are other, more elegant, procedures that can be used to study the correlation structure of a water quality time series. However, the applicability of these to the monitoring system design problem is no more direct than those noted above. Montgomery and Reckhow (1984) and Salas et al. (1980) present several of these procedures.

The importance of dependence in water quality data, and yet the inability to accurately define it due to data limitations, introduce the need for careful judgement in monitoring system designs.

Correlation Between Water Quality Variables

Water quality variables that are highly correlated provide the monitoring system designer the opportunity to reduce costs of measurement while not greatly affecting the information obtained. If a large array of variables has been identified as required for the information users, it may be wise to examine correlations among them. The relationship between conductivity and total dissolved solids is a classic example of this ability to reduce measurement costs with little loss in total information. As always, considerable judgement is involved and careful documentation is required if correlations are to have a role in the final selection of which variables to measure.

Summary

Good monitoring system design will include identification of bias due to non-random sampling and analysis of the effects of non-normality, heterogeneous variances and dependent observations. The selection of procedures is as much an art as is interpretation of the results of the procedures. The procedures listed in summary fashion in Table B1 are a representative cross section which can serve as a beginning point. The extent to which such procedures are applied is again a judgement. As patterns emerge, the designer can be more selective. There is currently considerable opportunity for research into the general underlying characteristics of water quality populations.

Statistically characterising water quality populations is complex. The above material will assist those designing or evaluating a monitoring system to develop an understanding of the population to be sampled. Extreme care should

Table B1 : Summary of statistical characterisation procedures for purposes of designing a water quality monitoring system*

I	Plot of water quality variable, its twelve-month moving average, and flow against time
II	Normality Testing - Frequency histograms - Skewness coefficient test - Chi-Square or Shapiro-Wilk test
III	Variance Homogeneity Testing - Close examination of time plot - F test for one division of record - Bartlett's test for multiple divisions
IV	Independence Testing - Close examination of time plot for periodic cycles - Correlogram without seasonal adjustments - Correlogram with seasonal adjustments - Effective number of independent samples

*Sources for tests in this table are given in Ward and Loftis (1985) be taken when applying the procedures to old data records of uncertain origin, or to short records. Because of shortage of knowledge in the field of water quality hydrology, judgement is a major component in characterising water quality populations.

SELECTING DATA ANALYSIS PROCEDURES

Selecting and applying the many statistical procedures which can be used to analyse a water quality data record (Unesco/WHO, 1978) is again a matter requiring considerable judgement.

The following discussion focuses on selecting the statistical procedures to use a designed monitoring program. This does not preclude introducing other procedures in the future, but it does define those procedures, around which the design of the system is focused.

Means in Quality

Measures of central tendency for a given time period (e.g., annual) can be expressed as an arithmetic mean, median or mode. In some cases (e.g., highly skewed distributions) the geometric mean may be more appropriate. Regardless of the measure of central tendency used, it should never be reported as a unique value. To present a measure of central tendency without any indication of the uncertainty or error associated with its estimation, often leads a user of the information to put more meaning into numbers than is justified.

Uncertainty of a mean can take the form of a confidence interval, range of observations or percentile readings. Barrett and Goldsmith (1976) note that the confidence interval on the mean is valid when the sample size (n) is greater than 2 for slightly skewed data, when $n > 10$ for moderately skewed data, and when $n > 40$ for highly skewed data.

Once the measure of central tendency is computed it should be presented along with its level of uncertainty in a graphic form that readily conveys the desired spatial comparisons. A 'contour' map or chart graphically displaying the measures of central tendency quickly communicates relative water quality conditions over a management agencies' area of jurisdiction. The National Water Council (1981) demonstrates the use of measures of central tendency in developing graphical displays of water quality conditions.

Trends in Quality

Detecting trends in water quality time series has received considerable attention in recent years. This brief discussion illustrates where trend detection analyses could begin and where more detailed information on trend detection is available.

Initial analysis of water quality data, as part of a routine monitoring effort, could begin by focusing on suspected trends and/or plots of key water quality variables at all sampling points and/or performance of a statistical test for trend on all the data. Once one of the above approaches has been utilised to identify where trends are occurring more detailed analysis of significance, confidence and probable causes can take place.

Three general approaches to analysing water quality data for trends are presented:

1 Graphical display of time plots
2 Parametric tests
3 Nonparametric tests.

The need to normalise or remove seasonality may have been examined in the statistical characterisation phase.

Plots of water quality time series can yield considerable information about water quality conditions. McLeod et al. (1983) list eight forms of information that time plots can assist in supplying :

1 Detection of extreme values
2 Trends
3 Known and unknown interventions
4 Dependencies between observations
5 Seasonality
6 Need for data transformation
7 Nonstationarity (i.e. the underlying distribution is changing over time)
8 Long term cycles

Parametric tests of trend should be utilised only if the results of the statistical characterisation indicate that assumptions underlying the tests apply. If not the original data can be transformed to more closely satisfy the assumptions, pronounced seasonal effects can be removed, or dependence in the data can be accounted for in some fashion (e.g., using the effective number of independent samples).

Use of the two sample t-test implies that it is possible (due to some known change in the watershed that may affect water quality) to break the record into two parts for purposes of comparing changes over time. Graphical analysis could indicate if the record can be divided into two different sets. The t-test would then serve to confirm, in a quantitative fashion, what has already been observed. There are, however, many ways to divide a data set besides observing the graphical plot (e.g., before and after installation of treatment, before and after implementation of strict non-structural management and arbitrary year to year or five years to five years comparisons).

Linear regression over all or part of a data record can be used to assess trends within given time periods. Significance of a linear trend can be checked by testing if the slope of the line is significantly different from zero. Selection of the data and time period for linear regression is dependent upon the changes to be studied and the time periods relevant to management decision making.

Sanders et al. (1983) and Unesco/WHO (1978) describe the above procedures for water quality trend analysis using water quality examples. Most basic statistics texts present the details of the procedures (e.g., Walpole and Myers, 1978). Ponce (1980) also describes the two-sample t-test and the linear regression procedures from a water quality viewpoint.

Nonparametric trend evaluations using the numerical order of the data, avoid some of the assumption problems that plague parametric tests (e.g., normal distribution). However, they do not avoid all of them (e.g., independent samples) and are potentially less sensitive.

The Wilcoxon test for two independent samples is the non-parametric equivalent of the t-test for equality of means. Sanders et al. (1983) describe the test in a water quality context. Montgomery and Reckhow (1984) and Lettenmaier (1976) suggest using the Mann-Whitney and Spearman Rho non-parametric tests for step and linear trends, respectively. Conover (1980) provides details on the tests. Hirsch et al. (1982) and Smith et al. (1982b) describe a seasonal Kendall Tau procedure for detecting water quality trends. Again, choice of the time frame and data records for identifying trends is a function of the management decisions to be made.

A number of authors who have studied water quality trends over time point out the needs for data to be "collected at a given location, by using consistent collection and measurement techniques on a regular schedule and over a substantial number of years" (Hirsch *et al*., 1982). McLeod *et al*. (1983) and Montgomery and Reckhow (1984) make generally the same observations. There are considerable implications of this data need on the design of water quality monitoring systems, particularly that part of the system for which trend detection is a goal.

Stream Standard Violations

Traditional means of reporting stream standard violations have often focused upon the particular samples that exceed the fixed limit. Little effort was made to interpret this in the context of a total water quality picture over time or space. For immediate regulatory action, the traditional approach is probably useful. From an overall management viewpoint, however, it is useful to know how likely is a stream to violate its standard, now as compared to five years ago as compared to another stream. (Evaluation of management's success in meeting society's goals, as expressed as standards, and allocation of limited management resources to highest priority areas, are two uses of such information).

Percentages of samples exceeding a standard is a straightforward way to compute an estimate of the probability of a violation occurring at a given sampling point. A more sophisticated way would be to estimate the applicable probability distribution and, using the standard as a set value, compute the probability of a violation. Estimation of the applicable probability distribution can be difficult and uncertain. However, such an effort can build upon the initial statistical characterisations and provide additional understanding of the behaviour of the water quality random variable over time and space.

Summary

Selecting data analysis methods before routine data are collected, greatly extends the definition of monitoring system design. It forces the monitoring system designer to know what information is sought and to understand the underlying statistical behaviour of the water quality being measured. In this section a selection of procedures have been identified for the three major information needs (e.g., means, trends and standard violations). The procedures are summarised in Table B2. They represent the more basic procedures available and would find ready application within a regulatory water quality management program.

Table B2 : Summary of data analysis procedures useful for obtaining the required information from a water quality monitoring system*

I	<u>Means in Quality</u> Measure of central tendency - Arithmetic mean plus confidence interval - Median plus range - Mode plus range - Geometric mean plus confidence interval "Contour" plot of water quality over space
II	<u>Trends in Quality</u> Graphical display Parametric tests for changes over time - Two-sample t test - Linear regression Nonparametric tests for changes over time - Wilcoxon test - Spearman Rho - Seasonal Kendall Tau
III	<u>Standards Violations</u> Percentage of samples exceeding standard Probability of violation (from comparison of frequency distribution and standard)

*Further details of procedures are given in Ward and Loftis (1985)

At the end of Step 2 (Table 4, page 27) the monitoring system designer should have knowledge about the water quality population to be sampled, and particularly with respect to the assumptions underlying the statistical data analysis procedures. He/she should also be in a position to recommend those data analysis procedures which supply the information identified in Step 1 and, at the same time, are most compatable with the underlying statistical behaviour of the water quality variables.

With the statistical data analysis procedures now identified, it is now possible to continue the design to Step 3.

APPENDIX C : REPORTING OF INFORMATION

The system for reporting of water quality information must be carefully defined prior to initiation of monitoring operations. By doing so it is easier to ensure that all necessary data are obtained at the right time and information goals are established early. This latter aspect helps prevent the collection of data itself becoming an end in itself. The monitoring system becomes focused around the need to convey information, not the need to acquire numbers.

The audience for water quality reports varies from parliament to the public and includes many different agencies. Reporting of water quality conditions to those responsible for control closes the information loop within water quality management. Decisions are made in the knowledge of present trends in water quality and in light of the results of previous decisions. Similarly reporting helps managers better understand the process they are managing. Reporting is closely associated with the information expectations delineated in Step 1 of the monitoring system evaluation procedure.

NWASCA and Regional Water Board reporting needs differ. The Authority, as a national organisation, will require reports which focus on overall national water quality conditions. The Boards will focus overall conditions in their region as well as the site specific information related to specific water users. The Authority will issue fewer reports than the Boards, but the Authority's reports must synthesise considerable data to obtain the national water quality picture. On the other hand, the Boards will issue a large number of reports but each report will synthesise less data than the Authority's reports.

Reports developed from routine water quality monitoring will be serial in nature, each interpreting the most recent data in terms of current water quality conditions and how this current situation compares with changing conditions in the past. On the other hand, special investigation reporting consists of a single report issued at the end of the investigation.

Reporting can be achieved much more efficiently if the raw data, the data analysis procedures, and much of the routine wording of the reports are computerised. A computerised data base management system is a key element in the reporting of water quality information in a timely and effective manner.

The following discussion of reporting procedures is organised around the different audiences.

REPORTING TO THE PUBLIC

The public is generally interested in serial reports developed as part of the routine monitoring of receiving waters. It wants to know the quality of the receiving water and whether tax money is well spent. Reports must say in lay language what the quality of the water is (overall and in important water bodies), how it has changed or not changed and what role management has played in controlling the quality. Routine monitoring of receiving waters provides the majority of the information for this "public" report.

Frequency of reporting to the public is a matter of public relations. It could, for example, vary from an annual national report to a monthly local newspaper report perhaps based on a water quality index.

An annual report should describe quality conditions over the area of jurisdiction, changes over time and statistics on violations of classifications. Improvements should be noted and where problems continue to exist, they should be discussed. Graphs, plots, percentages and indexes should be utilised heavily in the report to the public to maximise communication of information. These reports do not have to be printed on glossy paper with extensive use of colour pictures, but they do need to communicate well and serve as the basis for news stories on water quality management (Water Pollution Control Federation, 1977).

Without having water quality data computerised, it is very difficult and expensive to prepare an annual report. Once computerised, software can be obtained to analyse the data quickly and prepare all the plots, graphs, percentages and indices automatically. The interpretative text must be prepared, but with word processing, printing of the final public information report should be rther straightforward. A standard cover could be prepared to facilitate printing and recognition of the report among the public.

In s.21(5) of the 1967 Act a direct reference is made to an annual report to be submitted by each Board to the Authority:

> "Every Board shall report annually to the Authority as to the demand and availability of natural waters within its region ..."

While not referring directly to water quality, the concept is extendible and an annual report on both the quantity and quality of water in all the regions in New Zealand is highly desirable. Such an annual report could summarise water quality changes during the past year, as compared to previous years; report on which classifications are being met; and evaluate how well the objectives of the law are being met in the particular region involved.

With respect to the Authority, the law also requires an annual report. Section 36(1) states :

> "The Authority shall ... prepare and submit to the Minister
> a report as to its operations and the operation of this Act
> for the year ..."

An annual assessment of how well the water quality goals are being achieved on a year to year basis would be a very appropriate component of such a report.

Information collected by the Boards and other agencies would have to be synthesised to develop a national assessment. This implies a very close coordination between regional and national water quality monitoring system design and operation. This is especially true with respect to the understanding of water quality developed from routine monitoring. The monitoring required regionally to develop regional assessments provides the same information required to develop national assessments. To be done economically, however, regional monitoring efforts need to have common quality control methodologies and common data storage and handling procedures.

(Relationships between regional and national water quality monitoring reporting are currently being studied in the US by the Association of State and Interstate Water Pollution Administrations (1983). The objective of this study is to improve the reporting of regional and national assessments of water quality.)

REPORTING FOR POLICY SETTING AND ADMINISTRATIVE PURPOSES

The report to the public, discussed above, will serve to meet many of the information needs of the policy-setting bodies (Authority and Boards in New Zealand). Additional reports will be needed to describe the operation and effectiveness of the various management tools in achieving overall goals and can be appended to the main water quality report. Together they would be designed to address the information needs of the top level administrators of the management program.

A combination of routine monitoring and special surveys is required for good reporting. For example, routine monitoring of effluents will determine how often water right violations occur; special investigations of effluents will say why these violations occur; and special investigations of receiving waters can describe impacts of the violations. This information facilitates short term fine tuning of the management strategy through well-planned shifts in budgets, personnel and operations.

The frequency of the reports on the operation and effectiveness of management tools will vary depending upon the management style of the public body and the administrators. Having water quality data on the computer and having software prepared to analyse the data from an operation and effectiveness viewpoint, would permit such reports to be prepared quickly and as frequently as desired. In fact, the text of such reports do not need to be as interpretive as the annual report to the public and could possibly be standardised on a word processor. In this case, the reports could be generated with a few simple commands to the computer.

REPORTS SUPPORTING TECHNICAL IMPLEMENTATION OF MANAGEMENT TOOLS

The monitoring program supports the day-to-day implementation and operation of the management tools as well as providing broader levels of information as described above. Violations of water rights and classifications need to be promptly reported to all concerned. Negative trends in quality, as soon as confirmed, need to be made known to all those responsible for controlling the trend. Special investigation summary reports need to be distributed to all who may be affected by the findings and affected by future regulatory actions.

Rapid communication of water quality conditions is a major factor in the ability of management tools to actually control the water quality processes. Thus, reports used to update the status of the system on a timely basis are usually short and to the point. Such reports can vary from a one page sheet describing one short violation to a report of many pages describing the initiation of what appears to be a deterioration in quality in a river system.

These reports can be generated on an "as required" basis, as in the case of a spill evaluation, or on a regular basis, as in a monthly summary of water right violations. The management strategy will dictate the exact type, contents, frequency and distribution of the reports.

SUMMARY

Reporting of monitoring results should be the focus of the entire monitoring system. This requires that the reporting methods be a part of the monitoring system design. The entire monitoring system can then be focussed on preparing a range of report types in a timely and efficient manner.

The main report types are:

1 Reports to the public and their elected representatives on overall water quality conditions and trends;
2 Reports to the policy setting bodies and administrators on the effectiveness of management tools; and
3 Reports to professional staff within the management agency and to others outside who are dealing with day to day technical water quality management problems.

The Authority will be most concerned with reports of the first two types on a national scale while the Boards will be interested in all types of reports on a regional scale.

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