TOWARD AN INFORMATION FRAMEWORK
FOR WATER QUALITY PLANNING:
THE FRASER RIVER MAIN STEM CASE STUDY

by

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ABSTRACT

This study examines the existing practice and legislative base for water quality management at both federal and provincial levels in British Columbia and shows that the movement toward preventative management presently underway will lead to increasing demands for systems oriented data and methods of interpreting this data for planning purposes. An information framework is developed for stream-quality assessment of flowing surface waters based on a one-dimensional representation of the water system, a finite segment approach to data organization, and a combination dilution model/ materials balance approach to system simulation and analysis. The approach is designed to use available data and the framework is computerized.

The analysis framework is applied to the main stem of the Fraser River above Hope. Although a large amount of data has been collected in this watershed, diverse agency objectives and lack of co-ordination in data collection programs limits the analysis to ten river segments and nine water quality parameters; flow, pH, temperature, specific conductance, dissolved sodium, suspended solids, total iron, total managanese, and total copper. Using the best data presently available, data gaps, in-stream behavior, assimilative capacity estimates based on standards and quality changes induced by development are discussed for several of these parameters as an illustration of the framework's use as a research and planning tool.

Water quality data collected during 1976 for regulatory and system surveillance purposes were assembled and used to simulate the behavior of conservative materials or to quantify the observed deviation from conservative behavior. These deviations identify and assist analysis of the aggregate quality influences of non-specific source inputs and/or in-stream transformation processes. They also allow limited prediction of the water quality changes associated with water and related resource developments.

The study shows that very little data has been collected in the upper reaches of the Fraser main stem, that unaccounted dilution can have as great an effect on water quality as accounted material inputs, that grab samples are not adequate representations of mean monthly quality, that quality degradation from industrial discharge below Prince George is largely offset by the dilution influence of the Nechako River, and that a scouring followed by downstream deposition phenomenon can be observed through a materials balance analysis. Also, it is shown that new waste loads and dams can have a significant effect on quality.

It is recommended that the approach developed here be adopted as an aid to water quality management, surveillance network design and data interpretation. A joint federal/provincial committee should be established under the Canada Water Act to co-ordinate management effort. The provincial government should establish a water resource planning component in the Environment and Land Use Committee Secretariat to develop planning procedures and integrate these procedures with land use planning. A pilot water resource management study should begin in each resource management region of the province. Future work should concentrate on the development of water quality standards and mechanisms of public input to water resource planning studies.

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INTRODUCTION

Purpose of the Thesis

The purpose of this thesis is to develop a method of structuring and analyzing water quality data to yield information which may assist in the prevention of unforseen impact through better understanding of stream materials behavior under changing conditions. More specific objectives are to:

(1) characterize the existing water quality management activities in the province of British Columbia;

(2) identify new information demands associated with a shift to preventative management;

(3) itemize the existing data collection activities of federal and provincial agencies;

(4) develop a conceptual framework for the organization and manipulation of water quality data, based on existing data collection practices, which will assist in meeting the new information demands;

(5) transform the conceptual framework to a computerized form which is simple and fast to use and which may be applied to any stream;

(6) apply the framework to the main stem of the Fraser River above Hope as available data permits;

(7) discuss the advantages and limitations of the approach discovered in the course of the case study;

(8) identify changes in existing water quality management practice which might assist in the generation and interpretation of water quality data for research and planning purposes.

Almost all forms of development exert some impact on stream quality. Achievement of desirable stream quality at acceptable cost requires that management decisions be based on sound impact assessments. The link between potential resource use and a management decision is a technical assessment to predict the potential water quality impacts of each planning alternative. The information framework is a first step.

Definitions

The term water quality is misleading for water is a substance of definite composition and structure. Quality, in the context of water, refers to the type and quantity of material born either in suspended or dissolved form per unit volume of water and to the quantity of energy contained represented as heat. Natural waters may be found in nearly all states of quality, from pure mountain streams to saturated salt brines. No specific quality condition is good or bad in itself. It is only when the quality condition is placed in the context of some use that it acquires value. A water quality impact is therefore the impairment or imposition of some tangible or 'hidden' cost upon the existing or potential use of the water as determined by the loss of value which accompanys some change of quality. Similarily, to say a water is polluted means that the quality condition interferes with the use of that water.

Water quality management or water pollution control is the institutional mechanism whereby general goals regarding beneficial use preservation and development-inspired degradation are translated into program objectives and specific actions of surveillance, analysis, evaluation and control. It has two prime functions, the abatement of existing impact and the prevention of future impact. The limits to management action are defined by the legislation under which it is conducted, the manager's perception of his mandate, the resources available, and the will of the electorate as represented by elected officials.

The concept upon which most management is based is that a water system has a carrying capacity or ability to absorb materials and energy through dilution, decomposition and dispersion thereby resulting in a state of water quality which will not impair other uses of the system.

Carrying capacity is a dynamic variable dependent upon natural and man-induced variations in loads and flows. Management may impose control upon all direct material and thermal inputs to and quantity withdrawals from the water system through specification of location, quantity and/or material type. Indirect influences on water quality, such as surface runoff, tributary inflows, erosion and groundwater recharge, are not readily controlled and may be the main determinants of carrying capacity. The nature and magnitude of each influence must be known so that control can be directed to the most efficient utilization of resources in ensuring that the carrying or assimilative capacity is not exceeded.

Methods

The information framework developed here is based on 'influence accounts' or tallies of the material and flow addition or subtraction rates for each well defined influence on stream quality including waste discharge, licensed withdrawals and tributary inputs. The main stem of a water basin is viewed as the sum of all inputs and outputs although the concept could be applied to each tributary individually.

The carrying capacity can vary over distance as well as time so the stream is divided into segments of varying length. A water quality and flow monitoring station is located at each segment boundary and boundaries are located so as to differentiate the effect of major influences upon beneficial use sites, generally upstream of each major confluence, waste input, withdrawal or grouping thereof.

Within each segment the material input and output rates are assumed to be constant for one point in time. Further, it is assumed that materials are instantaneously dispersed at the point of input and that once dispersed the materials behave as conservative parameters. This allows each influence to be sequentially added or subtracted to the initial parameter values observed at the upstream segment boundary station through the use of a dilution model. Total theoretical load values at the end of the segment are then compared to observed loads in a materials balance check. Differences between observed and predicted values are a quantitative measure of the net effect of unaccounted influences within the segment. This operation is performed for three different flow conditions to establish a seasonal base.

Assuming the accounted influences and the net effect of unaccounted influences determined through the materials balance are constant, a new input or withdrawal is introduced and the downstream effect is calculated through the dilution model to give predicted quality at the end of each segment.

The above calculations are performed for nine parameters over ten segments through a computer program called MATBAL.

CHAPTER 1 - APPROACHES TO WATER QUALITY MANAGEMENT

1. General Objectives of Water Quality Management

Water quality management programs are generally established by law. The intent of the legislation determines the priority assigned to particular objectives. A review of many different jurisdictions (Ward, 1973) shows two broad objectives are common, the abatement and the prevention of pollution. Six more specific activities were:

1. Regulation
2. Technical Assistance
3. Enforcement
4. Planning
5. Research
6. Aid Programs

Regulation, technical assistance and legal enforcement are usually reactive activities and can generally be classed as abatement; planning, research and aid programs are anticipatory and preventative. Each activity has separate data collection, processing and dissemination requirements leading to objective-related design and management of the surveillance network (Lettenmaier, 1974).

This representation is idealized. Each jurisdiction selects program priorities fitting its needs and might not participate in all activities. However, the above is a base upon which the consequences of alternative goals and approaches may be contrasted.

2. Alternative Goals/Approaches to Water Quality Management

The specific approach to water quality management will follow from the management goal chosen. The following goal statements are examples of the more commonly held viewpoints:

(a) Maximize Economic Efficiency - associated with the technological approach to control; abatement oriented; resource allocation determined through market demand

(b) Maximize Environmental Integrity - associated with the environmental or 'cease and desist' approach to control; focuses on prevention; resource allocation restricted to beneficial use

(c) Maximize Social Utility - associated with the ecosystem or integrated approach to control; combines abatement and prevention; resource allocation based on impact knowledge and the desires of the people affected.

The first two statements are extremes and the third incorporates aspects of both. Each will now be examined.

Maximize Economic Efficiency

To maximize economic efficiency it is necessary to minimize the costs of production. The definition of these costs drastically affects resulting water quality. From the perspective of classical economics, externalities are not considered as costs and all process and domestic wastes should be discharged without treatment because costs imposed upon other use are not related to the production costs of the source. Pareto optimality or a balanced distribution of costs and benefits would theoretically eventually develop through the supply and demand for goods previously perceived as common property resources. If the concepts of environmental economics are used, costs imposed upon other firms are considered through the perspective of a basin-wide firm (Kneese, 1968). Externalities which may be monetarized, such as the loss of fishing permit and personal incomes, costs of process feed pretreatment, taxes and multiplier effects associated are accounted.

Income loss associated with quality degradation is weighed against the income derived from the lack of degradation control and a treatment equilibrium develops at the balance point. Thus, only those items which can be quantified and assigned a dollar value are assessed and decisions are made on the basis of one standard of value. Not considered are the intangible values of aesthetic enjoyment and sentiment and the marginal utility which one may place on the impairment of some use.

The economic efficiency goal has been the traditional view to water pollution control. The U.S. Water Quality Act of 1965 and the Clean Waters Act of 1971, in Queensland, Australia, are examples of this technological approach to water quality management (Westman, 1972). The approach classes pollutants as they are affected by the control technology and imposes treatment standards by these classes to a degree which allows the carrying capacity or assimilative capacity of the stream to perform the remainder of the treatment. Control focuses on the wastes discharged directly and the receiving waters in the immediate vicinity. Standards may be directed at both.

The technological approach leads to an emphasis on abatement with regulation and technical assistance being the major areas of concern. The information systems which have developed under these objectives include waste permit systems, regular site specific monitoring, process technologies employed and costs of treatment. Little consideration is given to incremental movement toward thresholds, long term sub-lethal effects, or the impairment of future use through the buildup of residual toxics. The approach is therefore a short-term reactionary one which acts well to solve established problems but has limited application to the anticipation and identification of potential problems. Unfortunately, some impacts may not be reversed once established and many are long term.

Maximize Environmental Integrity

The environment refers to all things external to a living entity. To maximize environmental integrity is to optimize the health, welfare and safety of the entity through adjustment of its surroundings. However, one must select the entity for which the environment is to be maximized.

The proponents of this view argue that it is necessary to return the waters to natural levels of quality and perhaps even modify natural influences which may be indigenous polluters. Further, for very few substances does an effective assimilative capacity exist for our present depth of understanding of natural processes is too shallow, introduces too many uncertainties, to allow meddling with the composition of natural systems. Thus, the only logical course is to attain a state of zero discharge from all direct sources and enact land use controls for non-point sources of pollution.

The U.S. Federal Water Pollution Control Act Amendments of 1972 are an example of this approach. Its goals are to achieve, wherever possible by July 1, 1983, water that is clean enough for swimming and other recreational uses, and clean enough for the protection and propagation of fish, shellfish and wildlife. Also, by 1985, to eliminate the discharge of pollutants into the nation's waters (Kudukis, 1977). Clearly the entities for which this legislation is intended are recreation users and aquatic organisms, each of which have similar demands of quality. They will indeed benefit from this approach, but the costs imposed upon man-as-developer will be great.

Water quality management focuses on abatement to achieve prevention through elimination of all risk, but at great and perhaps needless cost.

Maximize Social Utility

To maximize social utility it is necessary to balance the trade-offs made between the value of uses which either do or do not degrade the water resource. This goal differs from the first two in that it attempts to arrive at allocations which satisfy all parties through recognition and consideration of the marginal value held by all parties affected by a decision of allocation. It recognizes carrying capacity as a useful concept and places large demands for information on the management surveillance system to provide referant groups with a basis for reaction. Effort must be placed upon all six objectives of management. However, greater emphasis will lie on the prevention of unforseen problems through programs of planning and research, for here lies the area of greatest uncertainty in the utilization of the carrying capacity concept.

The approach which follows from this goal has been labelled as the ecosystem approach (Great Lakes Research Advisory Board, 1978). It was adopted in the Great Lakes Basin after it was found that the technological approach

> "... does not, except in a curative, rather than preventative manner..... provide an adequate foundation for ensuring the rights and obligations of the Parties in respect to transboundary injury to health and property."

An ecosystem approach is similar to the environmental approach except that it considers the organism as part of the environment. Thus, all actions return via some pathway to influence the function of the ecosystem. Stress from all consequences of demographic growth will influence water quality and an understanding of the pathways and magnitudes of these stress elements is essential to the design of control and surveillance systems.

Key components of an ecosystem approach include:

1. the use of dynamic variables, such as loadings, rates of change or pathways instead of static variables such as quality or concentration;
2. recognition of a limit to the demographic carrying capacity of a water system and planning for the time when that limit is reached;
3. understanding that a long time or distance lag may exist between a cause in one part of the system and an effect in another;
4. the use of living organisms to monitor the long-term or synergistic effect of sub-lethals or low concentrations;
5. integration of data from all elements which may influence water quality;
6. encouragement and inclusion of public interest and participation in the evaluation of alternative courses of action;
7. a diagnostic approach to problem-solving;
8. flexibility in waste, receiving water and use standards which would allow modification as new knowledge is gained.

Each of the goals/approaches discussed has advantages and disadvantages in the ease of administration, creation of vested interests, maintenance of a minimum standard of quality, dealing with uncertainty, expenditures for surveillance, and adherance to the principles of democracy. It seems however, that the technological approach is best suited to situations where the resource is in much greater supply than the demand and the risks minimal, the ecosystem approach should replace the technological approach when it is perceived that man-induced stress may begin to affect the function of the system, and the environmental approach should replace the ecosystem approach if and when it is evident that the system's assimilative capacity is indeed unreliable and it is generally agreed that uses which degrade quality should be sacrificed for those which do not.

3. Water Quality Management in British Columbia

The purpose of this section is to examine the nature of water quality management as it is presently practiced, show where new directions and priorities are required and explore the information needs of these new priorities.

Historical Perspective

Water quality management in British Columbia is complicated by the division of powers created in the British North America Act of 1867. Under Section 91 of the Act, the federal government is given the responsibility for anadromous fish and may make laws in relation to all matters not assigned exclusively to the provincial legislatures. Under Section 92, the provinces may make laws in relation to all matters of a merely local or private nature (Huberman, 1965). Thus, the allocation of water use and the protection of these uses, provided these allocations do not affect waters crossing international boundaries or concern federal installations or developments or interfere with inland fisheries, is a provincial responsibility.

The federal government, after passing the Fisheries Act well over 100 years ago, has had direct responsibility for water pollution in all inland waters used for migration. In 1970, compartmentalization problems were acknowledged (D.R.E.E., 1970) in many areas and the Fisheries Act was amended. In the summer of 1971, Parliament pulled together a multitude of environmentally related activities which had been separate functions of the bureaucracy in recognition that environmental management is a function of environmental, social and economic factors (Edgeworth, 1974). This comprehensive or 'ecosystem' approach to management was a deliberate move to long-term, rational resource management through a thorough knowledge of all the variables in a given situation. It is based on identification of the finite limits of a body of water to receive wastes and, after study of all factors in a particular water basin, attempts to optimize beneficial use with application of the best practicable technology. Practicable means that the technology treats the waste to within assimilation bounds but is not economically destructive.

The federal government also set up the Environmental Management Service with the Inland Waters Directorate as the agency for planning and research. The Environmental Protection Service was formed to implement the Government's environmental protection policies and, through it's Water Pollution Control Directorate, has begun to develop regulations for the control of effluent from different industry classes. These regulations, coupled with intended receiving water standards (Harvey, 1976), could be the basis for problem identification and water pollution control enforcement.

Other legislation which affects water quality management are the Canada Water Act which enables the federal and provincial governments to co-operate in comprehensive water management programs and, the Environmental Contaminants Act which is intended to deal with contamination of the environment by chemical substances suspected as toxic to living things. The Contaminants Act is designed to enable an assessment of the total risk of harm from any particular suspect substance and presently requires that users of polychlorinated biphenyls, other chlorinated compounds, and mercury compounds in quantities in excess of one kilogram report their actions to the Minister (Department of the Environment, 1977a and 1977b).

At the provincial level, water quality management has been segmented as a consequence of historic events. Concern with water quality began in British Columbia with human health-related aspects in the latter part of the last century, later shifting to encompass organic pollution from municipal sources (Shelley, 1957). Through the same period, beneficial use demands on the water resource increased and led to enactment of the Water Act in 1914. The Water Act is mainly concerned with the regulation of the quantity of water allocated for beneficial use and does not require that decisions be made within a broad water management framework (Ward, 1976). This Act, with streamlining modifications, is still in force today.

In recognition of the growing demands for waste discharge use of the water resource, the Pollution-control Act was passed in 1956 under the Minister of Municipal Affairs. The goal of the Act is summarized in the preamble as follows:

> ... it is deemed in the public interest to maintain and ensure the purity of all waters of the Province consistent with public health and the public enjoyment thereof, the propagation and protection of wildlife, birds, game, and other aquatic life, and the industrial development of the Province
>
> ... where it is deemed expedient to require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of the waters of the Province:
>
> Pollution-control Act, B.C. Stat. (1956), c. 36.

The provisions of this Act formed a Pollution Control Board with the power to determine the qualities and properties of water that constitute a polluted condition, to conduct tests and surveys, to examine all existing and proposed means of sewage disposal, and to prescribe standards regarding the quality and character of the effluent which may be discharged. The Act also established a permit system for regulation of discharges initially only in the Lower Fraser Valley downstream from Hope and in the Lillooet River watershed. In 1961, the Board's authority was extended to include the Columbia River basin, and in 1963 the entire Fraser River basin and much of the east coast of Vancouver Island were also brought under its jurisdiction (Linn, 1966). In 1965, the administrative responsibility for the Pollution Control Board was transferred to the Water Resources Service of the Department of Lands, Forests and Water Resources.

The Pollution-control Act was replaced by the Pollution Control Act, 1967, and the Pollution Control Branch was formed to administer the new Act. Under this Act, all discharges of waste to land, air and water are required to obtain a permit from the Director. A referral process upon permit application ensures that the Ministries of Health, Recreation and Conservation, and Agriculture see the application information and have an opportunity to comment upon potential impacts to their water uses. A copy is also provided to the federal Department of Fisheries.

Permit approval is contingent upon the comments of potential impact, as forwarded to the Branch from the referral parties, and a technical assessment of the effluent in view of the criteria established in Objectives for five major effluent producing activity classes as follows:

1. Mining, Mine-milling and Smelting (P.C.B., 1973)
2. Forest Products Industry (P.C.B., 1974a)
3. Chemical and Petroleum Industries (P.C.B., 1974b)
4. Food-processing, Agriculturally Oriented, and Other Miscellaneous Industries (P.C.B., 1975a)
5. Municipal-Type Waste Discharge (P.C.B., 1975b)

It should be noted that flexibility is retained in the determination of permit stipulations. Permitted deviations from Objectives depend upon the sensitivity of the receiving environment at the specific point of discharge, based mainly on dilution. Approval conflicts are settled by the quasi-judicial powers (Lucas, 1967) of the Pollution Control Board.

It is apparent that water quality management programs have largely been concerned with pollution control through regulation of waste discharge from point sources and with assistance to dischargers in areas of process control and waste treatment. The Water Investigations Branch and the Water Rights Branch of the Water Resources Service were primarily concerned with the provision and allocation of supply quantity. No attempt was made to assess the effects of a water withdrawal allocation upon a receiving water already stressed in quality by constant and increasing waste loads, to evolve waste management plans on a regional level, to research the effects of land use and natural influences on quality under seasonal variation, or to determine the incremental quality effects of many allocation decisions isolated in time and space. In the words of Ben Marr, then Acting Associate Deputy Minister, B.C. Water Resources Service:

> " ... the Pollution Control Branch was not set up to control land use. Rather, the Branch was set up to administer the (Pollution Control) Act on a pipe-by-pipe ... basis. The Branch has never been a planning agency. ...... The Pollution Control Branch ... has been confined to making a technical evaluation of the impact of proposed discharge on the receiving environment at a particular site. "
>
> (Marr, 1974)

The above illustrates that the technological approach to water quality management has been favoured as the basis for pollutant classification, information collection, impact evaluation and decision-making.

Movement toward a more comprehensive or ecosystem approach to management began in the province with the signing of the Canada-British Columbia Okanagan Basin Agreement in October, 1969. This study was the first in Canada to recognize the need for comprehensive planning (Hunter, no date). It considered the various uses of water in the basin, their needs and values, and potential environmental quality impact (Thomson, 1978). It also assessed the capability of the basin to sustain existing and potential future demands under various water management alternatives. A review of the process employed (Province of B.C., 1975) details a deficiency in the scope of the study as follows:

> "It is recognized however, that land use planning should have been included and studied in more detail. While some land use studies were carried out to determine existing demands for water, the absence of any plan for future land use in the basin severely limited the development of quantity and quality alternatives, particularily for future tributary water management. For example, the distribution of future population increases, and the location of new industries or agricultural acreages will affect the supply-demand balance of the sub-basin from which water is drawn to meet the demands of these potential water users, and the waste products from these developments will affect the water quality of the tributary or lake to which waste effluents are discharged.
>
> The ..... improvement proposed for future basin studies therefore, is the inclusion of land use planning to the extent that such planning may affect future water management in the basin."

As resource conflicts continued to mount in other areas of the province, it was recognized that all aspects of the natural environment must be considered in resource decision-making. A process was instituted to deal with these conflicts and formalized on April 2, 1971, with assent of the Environment and Land Use (ELU) Act. The Act created a formal Cabinet committee that today includes the Ministers from nine departments (Ward, 1976). The ELUC has powerful decision-making authority because the Act supersedes all previous acts and regulations.

The ELUC, through its staff arm, the Environment and Land Use Secretariat, has begun to develop integrated approaches to inventory, planning and impact assessment. Their primary concern however, has been with the integration of land use with water resources as one factor which will either affect or be affected by land use. From the perspective of water quality management this could lead to different priorities in data collection and analysis than if concern were with the integration of water use with land use as one influence which will either affect or be affected by water use.

These changes in approach were not without influence upon those charged with water quality management. With the recent restructuring of provincial Ministries and creation of the Ministry of the Environment, opportunities exist for increased interaction between Branches. The Water Investigations Branch does now review site specific surveillance reports and waste discharge permit applications at the request of the Pollution Control Branch and water license applications referred by the Water Rights Branch. Environmental implications are assessed from a planning perspective. Environmental assessment studies, notably the Federal-Provincial study of the Fraser River Estuary, include representatives of the ELUCS, the Pollution Control Board and the Water Investigations Branch (Fraser River Estuary Study Steering Committee, 1978). Research programs include continued monitoring of the biota and water quality of select lakes and streams (Province of B.C., 1977). Attempts are being made to make the public more aware of environmental problems. The ecosystem approach to water quality management has indeed been accepted and promises to bring about wise utilization of resources as understanding and co-operation increase.

Overview and Prospects

The preceding section summarized the technological to ecosystem progression of management approaches which are beginning to occur at the federal and provincial levels of government. Efforts are being made to shift the management objectives from the abatement functions of regulation and technical assistance to programs of a diagnostic and preventative nature. Yet, with few exceptions, research and planning base assessments are site specific and oriented to a particular problem. Environmental degradation and the emergence of specific conflicts continue to be the impetus for application of integrated management. Regional or watershed resource management plans have not been developed. It is evident that transition to the ecosystem view is not complete. Many of the programs still limit their activities to abatement oriented functions.

One is prompted to ask, does the necessary legislative base exist for effective implementation of the ecosystem approach? An examination of the Pollution Control Act, 1967, reveals:

> "(3) The lieutenant-Governor in Council may direct the Board to inquire into, to determine causes of and remedies for any matter or matters relating to the polluted condition of water ... and
> (a) to take such remedial action as the Board considers necessary in the public interest; "
>
> (Province of B.C., 1976)

The Water Act does not contain such broad discretionary powers but it does allow the Lieutenant-Governor in Council to make, alter and repeal regulations for carrying out the spirit of the Act with respect to the license application procedure. Although the powers of the beneficial use allocation legislation is restrictive, the mandate of the impact prevention legislation seems adequate to institute any program deemed necessary.

Another potential source of approach transition problems lies in the structure of the institutions as they have evolved to date. The division of allocation and protection functions, both of which bear on the final state of water quality, is a barrier to co-operation and integration. A planned reorganization of the Ministry of the Environment is presently underway and is scheduled for completion in 1982. The reorganization will result in a new institutional structure (shown in Figure 1) and will occur in seven phases as follows:

Phase I	- Define the objectives and programs of each Division and Branch reporting to the Deputy Minister
Phase II to V	- Develop reorganization and implementation plans by September 1979
Phase VI	- Implementation of reorganization plans by 1982
Phase VII	- Review Executive structure by 1983

The reorganization is being carried out under a new mandate for the Ministry which includes planning, protection of biological resources and environmental quality, water basin management and regional authority (PROVINCE OF B.C., 1979). Upon completion, the new structure will remove institutional impediments to integrated resource management. Changes in legislation may well accompany reorganization.

As discussed under the maximization of social utility goal, water basin planning and research will place new demands for information on existing surveillance mechanisms. The carrying capacity of each basin, segment or sub-basin must be determined and total limits to discharge established from that base. The bounds of variation of each influence

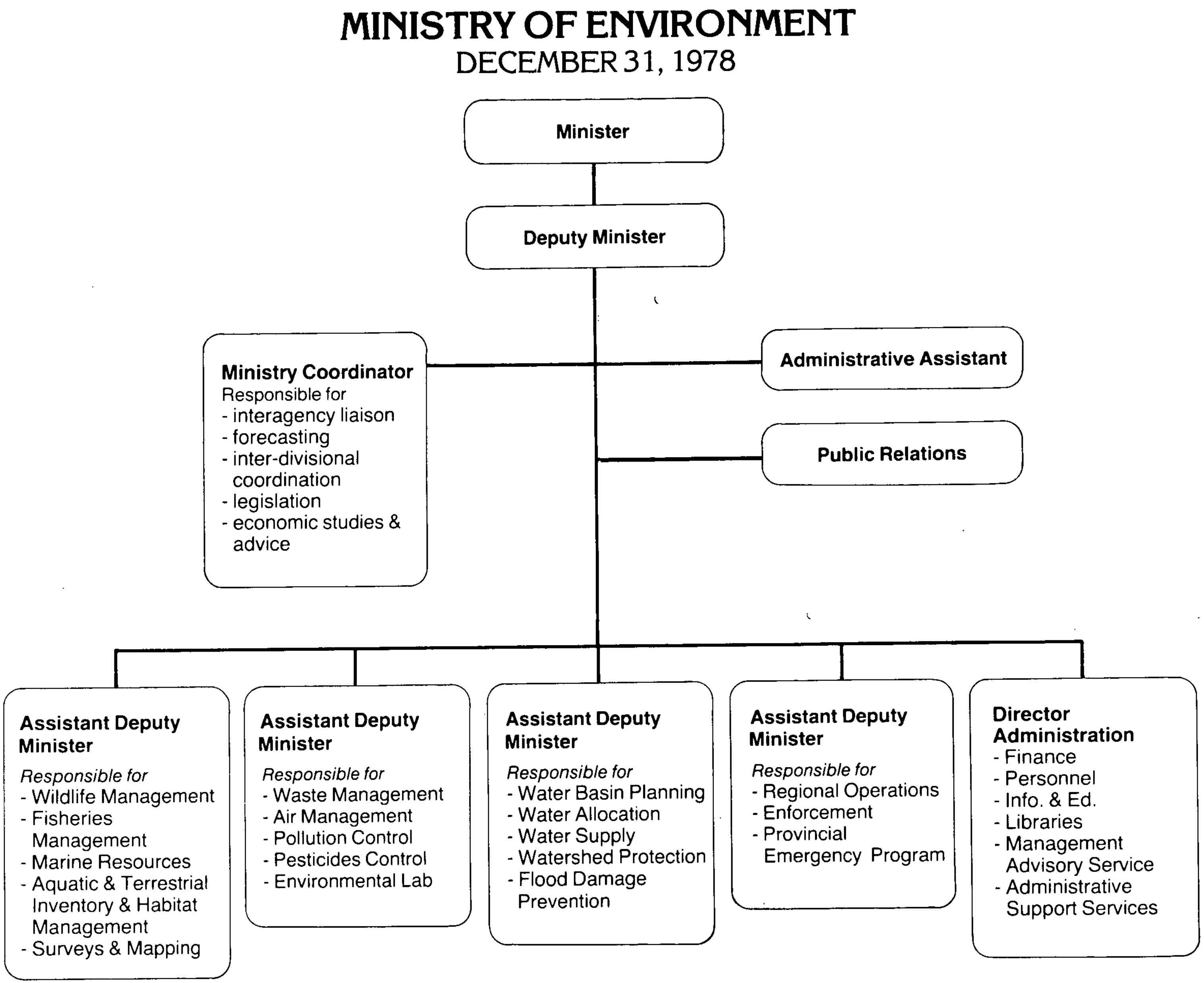


FIGURE 1 - New Structure of the Ministry of the Environment (from Province of B.C. 1978. Ministry of Environment Annual Report 1978, Ministry of Environment, Victoria, B.C.)

acting on water quality must be determined and beneficial use criteria evolved if the impacts of decisions are to be predicted and evaluated. Mechanisms for encouraging public evaluation of decision consequences must be established. These and many other needs will arise and cannot be satisfied by data collected for site specific regulation of waste discharge or technical assistance to dischargers. This is not to say that these functions should not continue. Abatement activities have been and will continue to be effective means of controlling waste discharge. What is needed is a deeper understanding of how the system behaves as a whole. Although additional expenditure will be required, data should be collected and information generated from a system perspective as a basis for planning assessment.

Summary

The purpose of this section has been to show the evolution of approaches to water quality management as it has occurred in British Columbia and to identify present and future information needs which follow from this evolution. These needs now serve as the basis for the development of an information framework which may assist in meeting these needs.

CHAPTER 2 - DEVELOPMENT OF THE INFORMATION FRAMEWORK

1. The Institutional Basis

It has been shown that there are a range of goals and approaches in water quality management. There are also a range of institutional mechanisms for water quality control available including uniform effluent or effluent treatment standards, assessment of the water quality and hence impact consequences of a proposed action at the time the action is proposed, and establishment of receiving water standards as a means of determining specific limits for activities which affect quality (Fox, 1973).

From an ecosystem perspective, establishment of stream quality standards is the only effective means of achieving a desired state of quality because it defines what the desired end state will be. Thus, control must encompass all processes which might affect that end state, such as waste discharge character and location, stream flow augmentation practices, land use practices and natural processes like erosion. Effluent standards control only one influence upon the final quality state. They are administratively simple however, they do not consider the system's assimilation limits. In effect they control demand for waste assimilation without knowing the supply of assimilative capacity. Assessment of the consequences of proposed action upon project proposal is similarily narrow because the assessment would be site specific. To assess the effects of each proposal in view of all influences acting upon the system would be administratively impossible. Also, this method does not adequately address abatement of existing pollutant sources. The only mechanism which will ensure that some agreed upon standard of quality, and hence use of the water, will be maintained now and in the future is one that defines the water system's capacity for stress based upon the desired quality end state, identifies the influences which do now and will in the future impose stress, and develops controls or limits for these influences based upon the system's available capacity. As stream quality standards define the system's end state, they are the only means of determining what the system's existing capacity for stress is. They are therefore essential to any program of preventative water quality management and planning.

The development of stream quality standards is a complex process requiring knowledge of the health or functional impairment effects of particular concentrations of contaminants, and a subjective evaluation of the benefits and costs associated with these effects by those who are potentially affected. The fixed technical estimates of risk are referred to as water quality criteria and may be developed through trial and error. For example, it may be established that a copper concentration of 20 parts per billion is lethal to rainbow trout fry while a lower level is not. This criterion for fish habitat use of the stream is a fact based on natural processes. It is not a standard for receiving water until those individuals or groups who wish to increase copper levels above it on the one hand, and those who would like to see levels lower on the other, have had a chance to negotiate their positions in full knowledge of the direct and secondary effects of accepting a higher or lower level. The quality standard therefore represents a socially accepted level of risk once adopted. It should be clear that value judgements and hence standards will vary from region to region and watershed to watershed, even though criteria may not.

In British Columbia recommended standards have been developed for drinking water and water-based recreation (Province of B.C., 1969) and federal drinking water standards and objectives (Department of Health and Welfare, 1969) also apply. No standards have been developed for agriculture, industrial feedstock or aquatic habitat. The Pollution Control Branch has established a combination of effluent standards, site specific technical assessment, and receiving water standards however, the emphasis is on control of effluents and receiving water standards are stated as the change permissable due to point discharge rather than absolute values. It is interesting to note that the Pollution Control Objectives frequently state that no significant change occur in quality, where significance is defined as a change which would have an impact on other use. Without absolute stream standards for other use it is up to the entity impacted to prove that damage has been done in seeking redress. Until standards are established, the measure of significant change is a discretionary judgement with the burden of proof upon the one suffering damage.

The information framework developed here is based on the acceptance of stream quality standards as a means of determining the stream's material assimilation capacity for planning purposes. Until such time as British Columbia has adopted standards for all beneficial uses it will be necessary to refer to water quality criteria and standards developed elsewhere as the basis for water quality planning.

2. Scope and Information Requirements of Planning and Research Activities

Water quality planning includes two activities, program planning and project planning. Both planning activities should be comprehensive and basinwide and should try to anticipate future action (Ward, 1973).

Program planning deals with transmitting broad goals into manageable units of work, organization of staff and budgets, and development of short and long range work plans. Such broad plans for future action do not require specific water quality data and may best be served by general trend information of water quantity and quality, use demand projections and administration objectives.

Project planning involves an evaluation of the effects of alternative water resource projects leading to development of a watershed plan for pollution control. This requires impact projections based on water quality estimates for various waste discharge locations, types and numbers under variable stream conditions and alternative scenarios of demand. The information requirements of project planning are therefore specific and should be examined in detail.

The project planning process may be examined under three broad activity phases; information collation, analysis and evaluation.

Information Collation

1. Inventory historic data on water quality and quantity and organize in a manner which simulates the water system's natural state.
2. Tabulate the various demands for water use over time.
3. Project demands for use into the future.
4. Identify water quality and quantity requirements of use.

Analysis

1. Impose the projected demands for waste discharge and quantity withdrawals upon the natural regime identified above.
2. Compare water use requirements with the projected conditions and thus identify problems.

Evaluation

1. Formulate alternative solutions for the anticipated problems.
2. Assess the costs and benefits to those affected.
3. Elicit reactions of those affected by the alternatives.
4. Improve and develop favoured plan.

The first two phases require historical water quality and quantity data and land use plans including population projections and economic predictions. The third phase requires knowledge of jurisdictions, legislation, control technology and hydrology with public input to aid formation of alternatives and selection of a favoured plan.

Research activities deal with technical and non-technical investigations in areas where problems are not well understood and/or response options are few. The information needed to identify priority areas comes from a variety of sources but of concern here are indications of pollutant behaviour and impact effect. For example, if a given state of effluent quality meets present technological discharge control criteria, but a fish kill occurs nonetheless, then information is needed to direct research into pollutant identification, synergism, transformation or pathway of entry. The research activity therefore requires historical and real-time data of stream conditions, an orderly monitoring of stream quality and flow at select locations and times as a guide to laboratory simulation. In short, it requires a surveillance network.

This review of planning and research activities shows the diversity of data required to perform these tasks. As this study concentrates on how water quality and quantity data may be used to assist planning and research activities, those information requirements which are based on such data are the only ones considered here. It is now possible to specify the objectives of the information framework. It should facilitate:

1. identification of trends in water quality and quantity for all supply and demand influences;
2. simulation of the relationship between water quality and quantity and the effect of artificial variations in either;
3. determination of the carrying capacity of the water system for any particular location, waste type and time of year;
4. identification of monitoring locations, parameters and frequencies for a surveillance network.

This information will assist in the direction of research, program planning, and the first two phases of project planning, collation and analysis. Demand predictions and the formation and evaluation of alternatives require different data and are beyond the scope of this study.

3. Data Constraints

In addition to the design-related objectives of the framework, the existing data collection activities of federal and provincial agencies operating in British Columbia will place limits on what can be done now with available data. These activities are summarized as follows:

Federal

The Water Survey of Canada Branch of the Inland Waters Directorate measures stream flow at various sites in response to other agency or individual requests. While some sites have been continuously monitored for over twenty-five years, these sites are major rivers or tributaries and most minor tributaries have sporadic records. Data collected is printed in historical summaries (Water Survey of Canada, 1977).

The Water Quality Branch of the Inland Waters Directorate has established a water quality surveillance network of major rivers and tributaries in the province. The parameters chosen for analysis are not oriented to the determination of the effects of waste discharge or water withdrawals. Rather, in keeping with the research objectives of this agency, the parameters have been chosen to reveal the effects of geological conditions and seasonal variations on downstream quality. All stations are not sampled regularily and a watershed may have been monitored comprehensively for only a brief time to gain the research data. Excluding special study areas such as the Okanagan Basin and the Lower Fraser River, these system surveillance activities have produced the most consistent measures of water quality from a system perspective.

It should be noted that except in special circumstances these two federal agencies do not co-ordinate their data gathering activities. Sites and frequencies are different.

Provincial

The Water Rights Branch of the Water Resources Service is charged with decisions of surface water allocation for domestic, waterworks, mineral-trading, irrigation, mining, industrial, power, hydraulicking, storage, conservation, fluming, conveying, and land improvement purposes. Stream gauging is conducted for a limited time prior to the allocation decision if data has not already been collected. The quality of the water allocated is not considered. Data collected is stored within the agency and is seldom used by other agencies.

The Pollution Control Branch of the Water Resources Service is responsible for the allocation of waste discharge use and prevention of adverse impacts. Upon permit application this agency collects all other waste discharge permits and water licenses in the area and assesses the potential impact of the proposed effluent quality loads specified on the permit application. If the application is approved a monitoring program is designed for the discharge. Sampling points are usually above and below the initial dilution zone and the effluent itself. Parameters chosen are based on the Objectives applicable and the effluent character. Sampling frequency may initially be monthly but is usually changed to quarterly if no trends or variations appear over time in significant parameters. Similarily, parameters may be dropped or added. Stream and effluent quality data are generated by PCB staff, the permittee or his agent.

The purpose of this site specific surveillance is to detect significant downstream changes in receiving water quality prior to modification of permit stipulations. To aid in data storage and retrieval, a computerized Environmental Quality Information System (EQUIS) has been developed (Clark, 1976). The structure of the data base is shown in Figure 2.

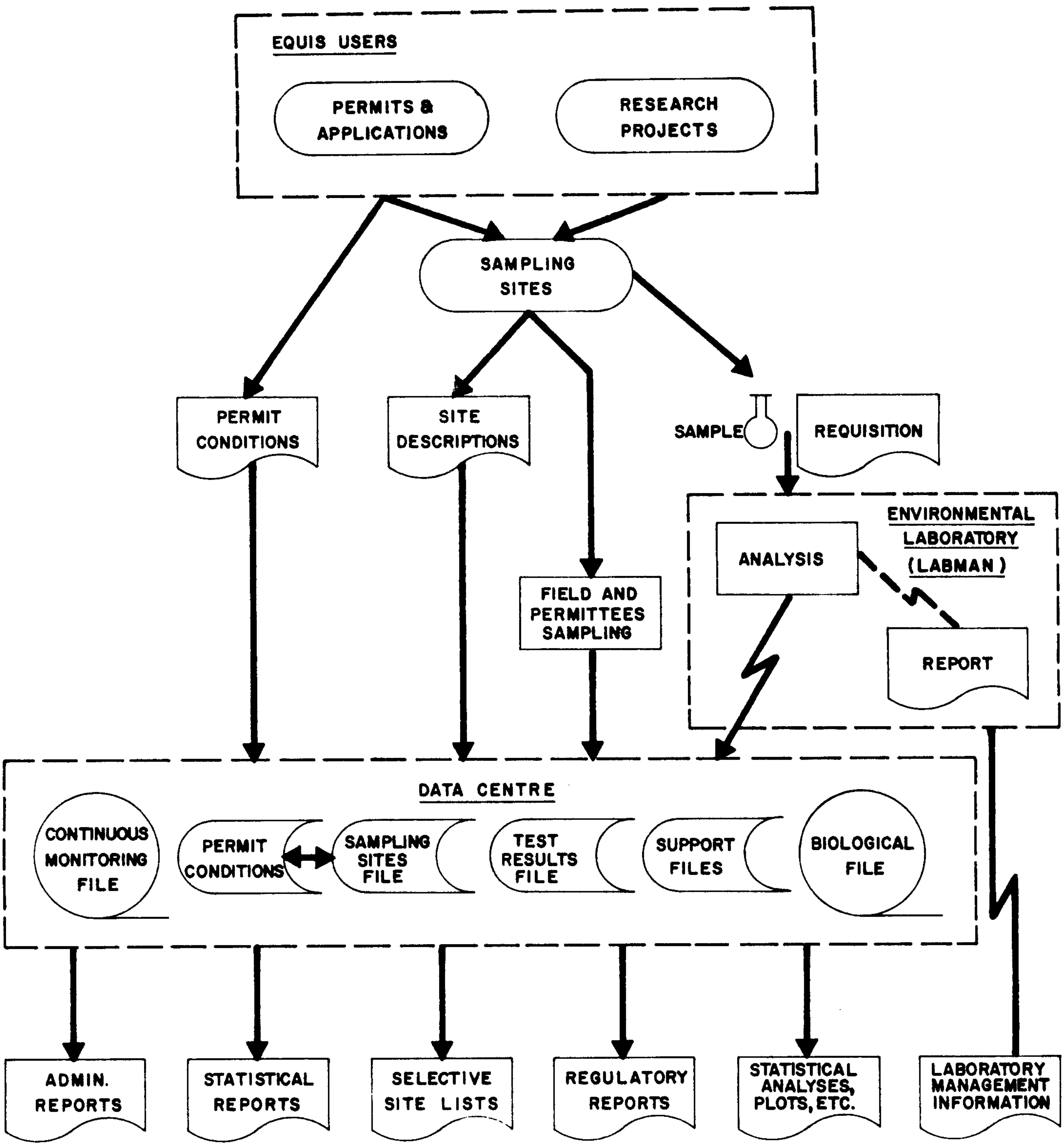


FIGURE 2 - Structure of the Environmental Quality Information System (EQUIS) (taken from Clark, 1977)

Water quality data collected for discharge site surveillance are entered in the EQUIS data base. Also, data collected by other agencies such as the federal water quality Branch and Environmental Protection Service, Westwater Research Centre, and B.C. Research, have been entered in the EQUIS system. As a result, EQUIS contains the largest collection of water quality data pertaining to British Columbia and has been estimated to contain the results of over five million analyses (Clark, 1978) for lake, river, marine, groundwater and air sites.

A number of problems arise in attempting to use the EQUIS data retrieval system for the purpose of water quality planning and research. The system was designed to assist in the day-to-day abatement activities of the Pollution Control Branch. It has the ability to recover, manipulate or summarize data on the basis of jurisdictional boundaries, watersheds, types of industry, geographical location, parameters, time of year, sampling agency and monitoring purpose but, site locations are denoted by approximate longitude and latitude only. Viewing the river as a system, the critical measure of location is the watercourse length from the site to the river mouth or headwater. River kilometer data are currently being developed as are accurate longitude and latitude measures, however, they are not yet available. A second problem is the lack of flow measures accompanying concentration data. This is essential to the calculation of loads required in an ecosystem approach. Finally, the differences in analytical methods, sampling techniques and parameters which result from diverse agency objectives make comparisons difficult and multi-collection compilations suspect.

4. Framework Concepts and Process

A systems analysis of a flowing surface water would ordinarily require that the system be delineated or bounded, that the sub-component or variable interrelationships be defined, and that these relationships be used to link the variables in a model which represents reality (Foin, 1976). The model may then be used to estimate the effects of variation in variable values. In dealing with an 'open' system like a river, it is difficult to identify which variables should be included in the definition of the system. The number of variables is so large and the linkages so poorly understood that even with a great deal of data and research the predictions of a model construct may be applicable to a discrete set of conditions only.

The traditional engineering approach to quality profile prediction in streams is based on a dilution model. A conservative waste material is assumed to be instantaneously dispersed at the point of input and loads are additive. For non-conservative materials a decay function is introduced to the dilution model through one of two methods. These methods are referred to as the differential equation method and the finite segment method (Hann, 1972).

The differential equation method requires that the decay function be expressed mathematically in terms of initial concentration, a decay rate for the stream reach, and flow time to the point of interest as follows:

$$C = C_o e^{-Kt}$$

where C_o = initial concentration
K = decay rate for the stream reach
t = flow passage time in days
C = concentration at downstream point

Downstream concentration can thus be predicted for any point provided the decay rate and flow time are known.

The finite segment method considers the stream to be made up of many short segments and uses a finite difference solution of the decay function at segment boundaries as follows:

$C = C_o K_n t_n$ where C_o = initial segment concentration
K_n = decay rate for segment n
t_n = segment n passage time in days
C = concentration at segment end

The finite segment method is useful if flow rate and decay functions change from segment to segment. It may be used for materials which follow a first order reaction rate curve, has less demand for data, and is suited to computer processing. It may also be applied to secondary parameters like dissolved oxygen through the inclusion of additional terms.

Both methods assume that the system's inputs are well defined and that decay rates and passage times are known. In most systems the inputs are not well defined and include non-point sources such as surface runoff and groundwater inflow. Also, decay rates and passage times are not known. Faced with these problems and the limited amount of systems oriented data available, a new approach to system simulation is clearly required.

The approach developed here begins with a re-examination of the conceptual representation of the water system. The variables affecting quality are thus identified but only those for which data are available are isolated and quantified. The unknown variables are aggregated into one unknown influence. A comparison of the theoretical effects of known influences based on a dilution model with the observed effect of all influences isolates and quantifies the unknown aggregated variable effects over a finite segment. Thus the effects of the decay function are estimated through a materials balance. Rather than attempting to determine decay rates from these effects, the quantified decay, which may be negative, is then used as a segment specific decay measure. Assuming that these decay measures are constant, new influences may be imposed and the resulting quality profile predicted.

The limitation of the approach is that new influences do not undergo decay because decay is incorporated as a specific and unchanging measure rather than a generally applicable function. Without detailed data regarding input locations, stream passage times and the separate effects of sedimentation, degradation and resuspension it is not possible to develop the decay function. The approach therefore allows quality profile estimates to the extent that existing data permits.

The advantage of the approach is that it forces the analyst to discover what is known about the system and places a magnitude on what is unknown. Data requirements conform to existing monitoring practice and the structure enhances interpretation of raw water quality data. With additional work, the decay measures obtained could become the basis for calibrated decay functions.

System Delineation

The watershed is the basic analysis unit of a water system. The final quality and quantity output of the system or the condition at any point is determined by the flow and materials introduced or withdrawn upstream and by the changes which these materials undergo once in the system. For any particular stream, the prime influences acting upon flow and loads are:

1. Tributaries
2. Waste Discharges
3. Water Withdrawals
4. Surface Runoff
5. Groundwater Inflows
6. In-stream Material Transformation

Each of these influences will vary with time and distance and a great number of secondary influences, such as channel character, stream bank vegetation, soil type, temperature, land use, pH, flow rate and precipitation, will act to determine the character of each influence but the prime influences are the pathways by which change occurs.

Each watershed is actually comprised of sub-watersheds of each tributary and ideally one should examine the behavior of each first-order stream, followed by second-order streams with first-order tributary input, and so on until the behavior of the entire watershed is understood through the sum of its parts. However, to simplify this procedure this study will deal only with the main stem of the water system and tributaries which discharge directly to it. This simplification allows the system to be represented as a one-dimensional water volume and material load flow. This representation is shown in Figure 3.

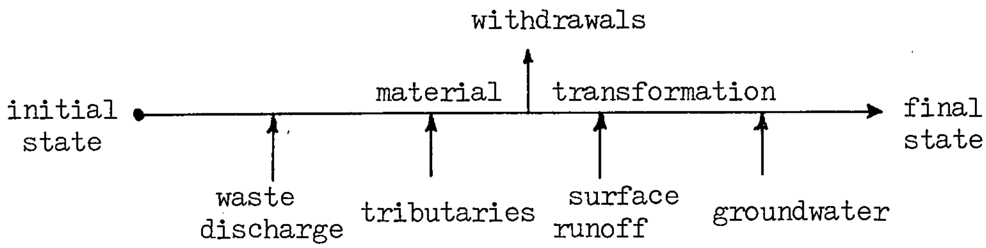


FIGURE 3 - One-dimensional Representation of Surface Water Influences

Keeping in mind that the purpose of this systems representation is ultimately to prevent or predict the impact of some action of man upon a valued use of the system, to determine the final quality state at the mouth of the main stem based upon all influences would give little information. The quality state must be determined at each point where valued use occurs or is likely to occur. This leads to the concept of river segments. By dividing the river at potential impact locations each segment becomes an analysis or management unit. Influences within each segment will affect downstream segments but,by treating the system as a series of increments information may be generated at each potential impact location.

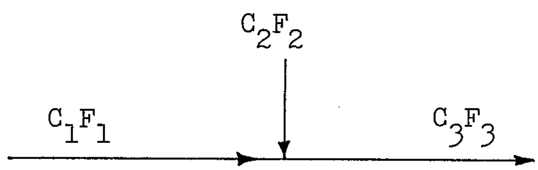
The above argument provides a basis for system surveillance site selection. In the case where little use is presently made of the stream, methods of resource analysis should be employed to identify sites potentially suited to beneficial use (Hopkins, 1978). In situations of complete system use, such as a fish spawning or rearing stream, those locations where the most pronounced quality changes occur would define the segment boundaries. Existing stream quality records should be reviewed to identify major quality changes and those existing abatement oriented monitoring sites which might also be suited to system surveillance purposes.

Component Interrelationships

Having defined the system as a stream segment with a beginning and end point and six influences acting in between, the next step is to develop a way in which they may be interrelated given available data. Of the six influences identified, the first three, tributaries, waste discharges and water withdrawals, have been the subject of surveillance for the purpose of regulation. Allocation of beneficial use has required stream gauging, a stipulated license flow and an inventory of license locations. Waste discharge flow and character are stipulated by permit and monitored regularily. The last three primary influences, surface runoff, groundwater inflow and in-stream material transformation, have not been identified and are not amenable to routine monitoring because they are non-point influences. These last three variables must be ascertained if the behavior of the water system is to be understood. They will therefore be aggregated into one unknown and be identified in that form.

The problem has now been simplified to four influences, three of which are known, and segment boundaries. Data at the segment boundaries may have been collected as upstream receiving water samples for effluent monitoring or data may have been collected as part of the existing system surveillance activities in the province. Should no data exist it would have to be collected. Data collected immediately downstream from a waste discharge should not be used as the site would have been selected to reveal the immediate effects of that discharge. Instances where a potentially impacted use is just downstream from a waste discharge are best dealt with at a site specific level. The one-dimensional approach employed here does not consider the peculiarities of channel character and lateral mixing and is best suited to regional trends.

Assuming that data are available for all but the unknown variable, the next step is to link the material and flow inputs and outputs for the segment. Distance and flow velocity data are not available so, to follow the changes of a particular parameter over time as it travels the length of the segment is not possible. The only recourse is to assume that at the point of entry of each influence all materials are perfectly dispersed. This is a common assumption used in modelling BOD/DO relationships (Joy, 1974; Koch, 1976) and nutrient loads to lakes (Moore, 1976). Further, it must initially be assumed that materials do not decay. These two assumptions are often used to determine conservative estimates of acceptable parameter loads (Enviro Control Inc., 1971; Fish, 1977) and have been proposed as a way of determining effluent guidelines for dissolved oxygen, temperature, pH, coliform bacteria, and deleterious substances in general (Luttenmaier, 1974). The relationship is a simple dilution model where, at a point of discharge, the downstream load and flow is equal to the sum of the upstream and discharge load and flow as shown below.



For a given parameter; $C_1F_1 + C_2F_2 = C_3F_3$ and

C_1 and F_1 are the concentration and river flow upstream
C_2 and F_2 are the concentration and flow of the discharge
C_3 and F_3 are the concentration and river flow downstream

If the system were only comprised of inputs the total loads per segment could be added to the load at the beginning to give the load at the potential impact point. With withdrawals it is necessary to order the influences in the way they occur on the stream.

The assumption of instantaneous dilution allows the behavior of influences to the water system to be simulated. To tie these influences to the beginning and end point of the segment is difficult because the loads and flows of all influences and the initial point change with time. However, at any particular point in time the stream may be viewed as a static water body and, provided the rates of addition and subtraction have been constant for at least one flow-through cycle of the segment, the system may be considered to be at equilibrium. That is, if the material and water volume inputs and withdrawals have been constant for the time required to travel from the beginning to the end of the segment, then the character measured at the end of the segment will be equal to the sum of the initial and influence character, also measurable. This semi-instantaneous view of the system allows calculation of a material balance for each segment. Starting with initial loads, each measurable influence is sequentially added or subtracted from the system resulting in a theoretical load value for each parameter at the end of the segment. The difference between this value and the measured value obtained from the surveillance network is an estimate of the aggregate unknown influence in that segment for that parameter.

To perform the materials balance the data employed would have to be collected at all tributaries, waste discharges and segment end points simultaneously. With the number of agencies collecting data and the different purposes of these collections it is unlikely that this would have occurred. The available data will therefore have to be grouped into monthly averages by years under the assumption that the average is representative of that month. Data gaps may then be filled with data from different years, hopefully at a time when the flow regime was similar.

Model Process

Water systems naturally exhibit diurnal, daily, monthly, seasonal and yearly variations in loads and flows. Pollution abatement activities should consider all these variations but they will focus on the short-term variations operative at a particular site. From a planning perspective, long-term trends of seasons or years are more important to the prevention of pollution which may result from incremental or seemingly unrelated decision-making.

The view of a stream afforded by the materials balance is a static determination of the influences acting on water quality. As such it is a deterministic model of the system for a particular time and set of conditions. To encompass dynamic conditions, the materials balance should be performed for successive times at the scale suited to the model objectives. This would suggest that it be run at monthly intervals over at least a one year period and possibly for several years to establish a base for pollution prevention. More frequent intervals may be useful for water systems that are severely stressed and are near the threshold of impact and where the smaller short-term variations may be critical however, this situation is one where an abatement approach is warranted and data demands would require continuous in-stream monitoring. The data base in British Columbia has been collected by grab sampling and is more suited to monthly estimates of stochastic behavior.

The information derived from the application of the above approach will be different for different parameter classes because each class has behavioral assumptions regarding in-stream processes. The assimilative capacity may be determined for conservative parameters but,only a measure of assimilation can be determined for non-conservatives. This will be discussed in detail in a later section.

Prediction

If the aggregate unknown variable load values, determined through the difference between predicted and observed segment end values, are re-introduced as a defined input to the segment the dilution model will yield predicted segment end values equal to those observed. Thus, the segment differences may be used to calibrate each segment so that new loads may be imposed and downstream concentrations predicted for that flow and quality regime.

To agree with the data input form of the other influences the calibration values must be expressed as material concentrations for the flow differences of each segment determined as follows:

$$LOAD_{observed} = LOAD_{predicted} + LOAD_{difference}$$

$$C_{obs} \times F_{obs} = (C_{pred} \times F_{pred}) + (C_{calibration} \times F_{difference})$$

$$C_{calibration} = \frac{(C_{obs} \times F_{obs}) - (C_{pred} \times F_{pred})}{F_{difference}}$$

where C_{obs} and F_{obs} are the observed segment end concentration and flow

C_{pred} and F_{pred} are the segment end concentration and flow predicted through the dilution model

$F_{difference}$ is the unaccounted flow to the segment calculated through the materials balance

$C_{calibration}$ is the concentration of the unaccounted material added or lost over the segment.

The above calibration process is similar to the application of a decay function except that the calibration is segment and regime specific. The process does not apply decay to any new inputs which might be introduced. It merely allows the dilution model to carry new load addition or loss through the segments under the assumption that all else remains constant. This is all that may be done with existing data.

5. Water Quality Parameter Selection

The degree of agreement between the behavior of water system pollutants and the assumptions made in the dilution model will determine what information can be produced for any given parameter. In addition, data are not available for all parameters and not all parameters are significant determinants of impact. These issues will now be discussed to arrive at a parameter list to which the model might be applied.

Of the many parameters of water analysis some, such as nitrate-nitrogen, dissolved copper and total sodium, are measures of a particular substance and others are indicators of the character of a group of substances. For example, BOD represents the oxygen consumption by bacteria over time as they metabolize organic material, conductivity measures the ability of dissolved and particulate material to pass an electric charge in a water matrix, filterable residue or dissolved solids is the weight of all dissolved material less than or equal to 0.45 microns in size, and TAC colour is a measure of the absorption of incident light over the visible spectrum. Each of these parameter concentrations or measures may alter with time due to some chemical, biological or physical mechanism. These mechanisms include dilution, reaction with other substances to form new compounds, spontaneous molecular rearrangement or decay, biological incorporation, precipitation, adsorption to particulate surfaces, settling and resuspension. Also, the probability of any particular mechanism occurring will vary with the concentration and type of the chemical and biological constituents and with the ambient conditions of flow rate, pH and temperature. Clearly, to compare this complexity of parameter behavior with that assumed in the dilution model requires some form of behavioral classification.

The classification employed examines each parameter for its reactivity and sediment association. Reactivity is a measure of a parameter's tendency to change with time due to chemical or biochemical processes. Sediment association refers to the tendency of a concentration to change due to settling or surface adsorption followed by settling. These two broad classes encompass most of the mechanisms referred to as in-stream material transformations and can account for most pollutant behavior. The result of this classification for a short parameter list is shown in Table 1. Parameters were first divided into reactive and non-reactive groups based on whether they required preservation prior to analysis (American Public Health Association, 1979; U.S. EPA, 1974; Feldman, 1974; Inland Waters Directorate, 1973). Each of these reactivity groups was then sub-divided as to their sediment association based on the knowledge of the author and relationships developed in the literature (Kudo, 1978; Literathy, 1978). It should be noted that assignments to any particular class assume normal stream pH and flow conditions to be operative.

The grouping of parameters in Table 1 is crude and deviations have been made from the above classification rules. For example, total metals are usually preserved prior to analysis but this is primarily to prevent their adsorption to the surface of the sampling container, BOD and coliforms are not preserved but have a restriction on time prior to analysis, and colour measures similarily may change with time. In general, those parameters not associated with sediment are those which stay in solution as dissolved ions or colloidial suspensions under normal stream conditions. Those associated with sediments are particulates, precipitates or materials which may adhere to particulate surfaces.

TABLE 1 - Water Quality Parameter Behavior Classification

SEDIMENT ASSOCIATION	REACTIVITY: NON-REACTIVE	REACTIVITY: REACTIVE
NON-ASSOCIATED	chloride (Cl^-) fluoride (F^-) sulphate ($SO_4^=$) dissolved solids conductivity dissolved sodium (Na) dissolved calcium (Ca) dissolved magnesium (Mg) dissolved potassium (K) surfactants (MBAS) hardness boron	nitrate-nitrogen (NO_3-N) nitrite-nitrogen (NO_2-N) dissolved orthophosphate-P phenol true colour total absorbance colour (TAC) total & fecal coliforms dissolved metals (Cu, Zn, Pb, As, Fe, Ni, Hg, Mn) dissolved cyanide tannin and lignin pH, acidity, alkalinity ammonia nitrogen
ASSOCIATED	nonfilterable residue settleable matter total and extractable metals (Cu, Zn, Pb, As, Fe, Ni, Hg, Mn) turbidity total fixed residue polycyclic aromatic hydrocarbons DDT, PCB's halogenated aromatics	BOD COD TOC oil & grease total cyanide apparent colour Kjeldahl nitrogen total phosphorus degradable pesticides and herbicides

It is now possible to discuss the potential application of the materials balance dilution model to these four parameter classes.

1. Non-reactive & non-sediment associated parameters fit the description of conservative substances. Conservative substance are those which are not decomposed, altered chemically, or removed physically as a result of natural processes in a receiving water. Their concentration is directly related to the extent of dilution (McKee, 1963). They will therefore behave as predicted by the dilution model and the materials balance should allow estimation of unknown influences.

2. Reactive and non-sediment associated parameters will tend to stay in solution but will degrade or change state as they are carried downstream. The dilution model is valid at the point of entry but some decay function would be required to predict downstream concentration. If assimilation is defined as the material removed from solution over a segment then, the assimilation measured through the materials balance may be low because the balance will show the net result of all inputs and subsequent decay but the contributions from non-point sources cannot be differentiated from those of point sources. It may be possible to estimate assimilation for substances originating from point sources only.

3. Non-reactive and sediment associated parameters are relatively inert and tend to be removed from solution by settling but may be resuspended during freshet. This group includes the solids, heavy metals and organic bioresistant micropollutants (Literathy, 1978). The dilution model is not valid here but a materials balance could show the amount lost to sediment over the segment, particularily for those substances which do not occur naturally and are introduced from point sources.

stable pesticides or herbicides, could go undetected if completely taken up by sediments. Without data regarding the concentration of these substances in the sediments, the mechanism for re-introduction to solution, or criteria for sediment composition it is impossible to determine the receiving water's carrying capacity for these substances. In general, they are extremely toxic and should not exist at any concentration.

4. Reactive and sediment associated parameters are usually organic particulates. The problems discussed in 3 above apply here as well as in-stream degradation. No information can be obtained from application of the materials balance.

Overall, information may be generated for non-reactive parameters by use of the framework. Reactive parameters require much more data than is presently available and should be the subject of a more detailed mathematical model.

Having narrowed the range of parameters to those which suit the model structure, it is necessary to ask which of them could cause impact upon beneficial use. The measure of impact is a complex process involving long-term observation and often, trial and error. The result of these observations are criteria for use and eventually, standards. Existing criteria should therefore be reviewed to identify those parameters which are important to the various users.

An examination of reference critieria and standards (Ontario Ministry of the Environment, 1978; U.S. E.P.A., 1973) reveals that many of the compounds listed are not routinely analyzed in this province, particularily pesticides and industrial organics. The application of the framework will therefore be restricted to traditional non-reactive substances.

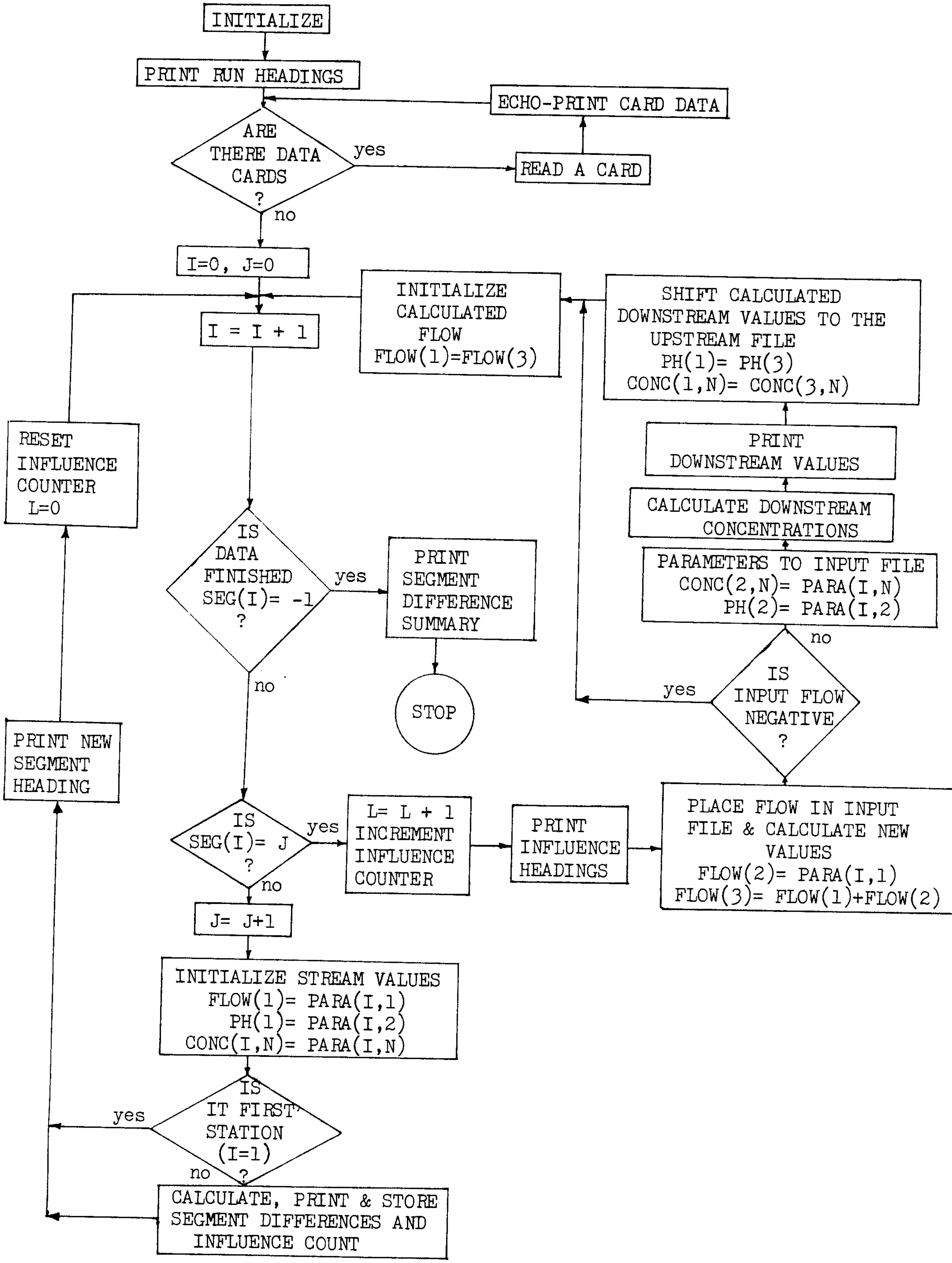
6. Computerization

The concepts developed must be translated into a method for data assembly and processing. The technical and dynamic nature of water quality management information and the amount of calculation required favours the use of a computer for data processing. Criteria for development of computerized environmental information systems have been developed (Steinitz, 1970) and, in combination with criteria for design of planning information systems (Pepper, 1972), can assist in flowcharting and program preparation. These criteria are:

1. the framework should be comprehensive, incorporating all influences on water quality in clearly defined, mutually exclusive categories;
2. it should be applicable throughout the area of interest;
3. it should establish an information base which may be used for all necessary types of analysis;
4. it should have the capacity to be updated;
5. it should be applicable at large and small scales;
6. it should have the ability to be added to in both area and influences;
7. it should be designed as a component within a decision-making process;
8. inputs and outputs should be accessible and comprehensible to a broad range of potential users;
9. data inputs to the system should be determined by the potential impact hazard associated with any particular parameter;
10. the framework should be designed to allow use of data which has been collected in the past.

The criteria advocate generality and flexibility of application with well defined data inputs. Had distance data been available it would be desirable to establish influence accounts of tributaries, effluent discharges and water withdrawals with each point keyed by distance thereby leaving segment boundaries to be imposed at will. Insteam, each segment will be fixed and treated as the base unit for data grouping and processing. Influences will be ordered as they occur in the segment and parameter values will be initialized at the headwater. Each influence will then be introduced and new values calculated for all parameters. Segment differences will be calculated at each boundary with observed values used to initialize the next segment. Segment differences will be stored and summarized at the end of a run. The flowchart of this process is shown in Figure 4. A program was written in FORTRAN IV to perform these operations and is provided in Appendix I.

FIGURE 4 - Flowchart of the MATBAL Program



CHAPTER 3 - THE FRASER RIVER CASE STUDY

1. Introduction to the Case Study

The Fraser River watershed covers 230,920 square kilometers and contains seven major sub-basins including the watersheds of the Nechako, West Road, Quesnel, Chilcotin, Bridge, Thompson and Lillooet Rivers. From its Rocky Mountain headwaters near Moose Lake to its mouth on the Strait of Georgia at Vancouver, the river is over 1350 kilometers in length. Over half the population of British Columbia lives within the Fraser basin (Statistics Canada, 1978) and the majority of these people live near the main stem of the Fraser River. The many benefits derived from the industrial, recreational, occupational and domestic use of the river establish the Fraser as the most important river in British Columbia (see Figure 5).

Existing sources of environmental stress on the Fraser are the Kemano Dam, waste effluents, and runoff from agriculture and urban centers. The Kemano Dam diverted most of the Nechako River's flow through the Nechako-Kemano Diversion to the Aluminum Company of Canada's Kitimat development on Douglas Channel (Fraser River Board, 1956). Wastes are introduced from a variety of sources but the major effluent types are domestic waste and pulp and paper effluents from mills in the Prince George and Quesnel areas. Five percent of the Fraser watershed area was utilized as farmland in 1971 and of these farmlands, approximately 260,000 acres were fertilized, 30,000 acres were sprayed with herbicides, 33,000 acres were sprayed with pesticides, and 126,000 acres were irrigated (Statistics Canada, 1978). Increased nutrient and salt saturated surface runoff and groundwater flow, soil erosion, and synthetic chemical transport to the water system are well documented effects of

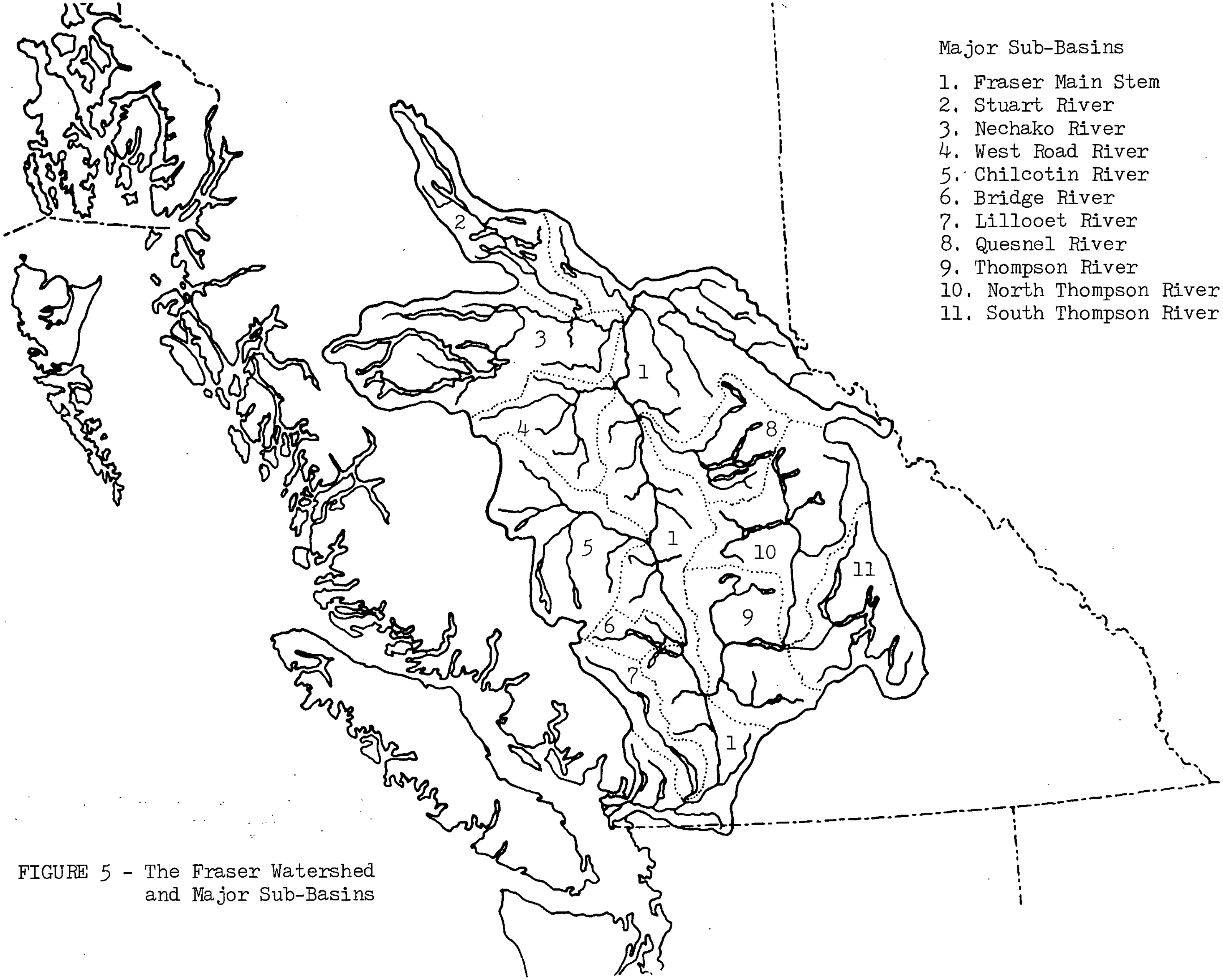


FIGURE 5 - The Fraser Watershed and Major Sub-Basins

agricultural land use in other watersheds and are likely sources of stress on the Fraser waters. Populations in urban areas adjacent to the river have increased. In the twenty year period 1956 to 1976 the population of Vancouver increased from 365,844 to 410,188, that of Prince George from 10,563 to 59,929, and Langley from 2,131 to 10,123 (Farley, 1979). Growing urbanization leads to increased surface runoff with trace metal and polycyclic aromatic hydrocarbon constituents (Pope, 1978).

Major sources of potential stress, aside from increased domestic waste loads and agricultural additives, are associated with power generation projects. The potential exists for many tributary and Fraser main stem hydro-electric power generating stations (Fraser River Board, 1958). Although it is unlikely that any main stem dam would be built under the prevailing political climate, the Aluminum Company of Canada is investigating further diversion of the Nechako River flow and the British Columbia Hydro and Power Authority is actively considering the hydro potential of the McGregor River (Halleran, 1977).
In addition to hydro-electric development, several deposits of uranium have been located in the B.C. interior. Mining of this ore could introduce radioactive material to the Thompson River system for no tailings impoundment is a 100% recycle system over time. These materials would ultimately migrate through Fraser waters and bottom sediments. Another potential source of stress lies in the proposed coal-fired thermal generation plant and open pit mine in the Hat Creek valley. If developed, the plant would draw up to 20,000 gallons per minute from the Thompson River near Ashcroft for cooling-circuit purposes. The aqueous discharge from this development would contain heat, salts,

and leachates from coal storage piles and ash dumps. Atmospheric emissions would include oxides of nitrogen, mercury, sulphur dioxide and ash particulate. This material would be dispersed over a large area and, without scrubbers, emissions could reach 400 tons per day of sulphur dioxide, 166 metric tons per day of nitrogen dioxide, and 10.5 metric tons of mercury over the 35 year expected life of the plant (Shewchuk, 1979). The potential acid rain effect of sulphur emissions on lake and stream waters within the Fraser River watershed is uncertain.

The planning context for the Fraser River watershed exemplifies the sectored agency jurisdictions discussed in Chapter 1. The watershed has been divided into six water regions for beneficial use allocation under the provincial Water Rights Branch. It is also divided into three regions for waste discharge allocation under the Pollution Control Branch. Boundaries of the two agency divisions will coincide after reorganization but are based on ease of administration rather than sub-basins. The river is therefore segmented administratively as well as geographically. The federal Inland Waters Directorate has performed surveillance monitoring of the Fraser main stem and select tributaries through it's Water Quality Branch and the Water Planning Branch is involved in flood management of the lower reaches. However, no water management plan has been developed for the basin.

The first water quality study of the Fraser River basin occurred in 1965 and was intended to explore the effect of further pulp mill development upon the quality of waters in the lower reach near Vancouver (Sylvester, 1965). This study discussed various policy approaches to water quality management for none had yet been adopted in the province.

Further, it stressed the need for water quality criteria regardless of the control approach adopted. The next major study (Goldie, 1967) focused on the lower Fraser as the major problem area. In 1968 the Pollution Control Board responded to the growing concern over water quality in the lower Fraser River. The policy then developed recognized that upstream development could adversly affect downstream quality but, was solely concerned with control of pollution from point sources in the Lower Fraser Valley (B.C. Pollution Control Board, 1968). This policy established the approach that was to be used for pollution control throughout the province. The preamble states:

> " ... it is impractical to set standards for the receiving waters of the river, but instead, (the Board) has decided to control individual effluents into the river and in this way, maintain or improve the quality of the river itself."

A later study (Dorcey, 1976) showed that this approach did not eradicate the problem. Data indicated increases in the ambient concentrations of coliforms, trace metals and chlorinated hydrocarbons in the water environment of the Fraser adjacent to greater Vancouver relative to the upstream reaches (Dorcey, 1974). Perhaps as a result of this study or perhaps due to the shift toward an ecosystem perspective, a joint federal-provincial study is currently examining the lower Fraser reach with an eye toward the effects of land use upon water quality, future development pressure, and impacts upon beneficial use (Fraser River Estuary Study Steering Committee, 1978). It appears that, even though diverse inputs and effects are being considered, the approach is abatement oriented for it ignores the transboundary effects of upstream development and the lag between cause and effect that this implies. A plan for the lower Fraser River is of little use if upstream decisions can invalidate the plan's terms of reference.

The Fraser River above Hope was chosen as the case study for this thesis because the complexity of waste inputs and beneficial use sites in the relatively short but tidally influenced lower reach does not allow application of the model assumptions. In addition, Hope marks the lowest downstream point included in the type of systematic data collection necessary to the case study. While it is recognized that present demands for waste discharge and water withdrawals are low in relation to the flow of this river, it is hoped that an information base may be established which would assist in future demand decisions for this very important water resource.

In keeping with the simplified one-dimensional water system representation discussed in the previous chapter, the analysis will be restricted to existing data on the main stem of the river as an illustration of the approach.

2. Preliminary Site and Data Source Inventory

As mentioned, analysis sites, segments, times and parameters were chosen from existing data. To do this it was necessary to inventory all inputs, outputs and potentially useful monitoring sites in the case study area. These inventories were then examined for time and parameter coverage prior to final data selection and application of the framework. The site inventories provide a summary of system oriented monitoring activities in the area and are useful for identification of data gaps.

Receiving Water Monitoring Sites

Fraser main stem sites and tributary monitoring sites close to the main stem were isolated from a listing of all receiving water monitoring stations within the Fraser watershed obtained through the Pollution Control Branch's (PCB) EQUIS system. Federal Water Quality Branch (WQB) NAQUADAT station locations for main stem and tributary flows were also obtained. Each of the potential data sites thus identified was then checked for the existence of monthly mean discharge records with the Water Survey of Canada (WSC). A summary of this receiving water site inventory is shown in Table 2. Sites and tributaries are listed in order of flow and tributaries identifiable on a 1:500,000 scale map are included for completeness even if no data has been collected for the input. The entries in Table 2 represent site numbers assigned as codes by the various agencies.

TABLE 2 - FRASER RIVER AND TRIBUTARY RECEIVING WATER STATIONS SUMMARY

SITE	WATER QUALITY PCB (EQUIS)	WATER QUALITY WQB (NAQUADAT)	FLOW WSC
Fraser River @ Red Pass	0400001 0400002 0400003 0400004 0400005	BC08KA0007	08KA007 (1955-76)
Robson River	0400006	BC08KA0010	----
McLennan River	0400007	----	----
Fraser River @ Tete Jaune Cache	----	BC08KA0005	----
Tete Creek	----	----	----
Kiwa Creek	----	----	----
Small Creek	----	----	----
Fraser River @ Dunster	----	BC08KA0011	----
Raush River	0400008	----	----
Castle Creek	----	----	----
Holmes River	0400009	----	08KA003 (1949-52)
Fraser River @ McBride	0400010 0400011 0400012 0400013 0400014	BC08KA0002	08KA005 (1953-76)
Dore River	0400250 0400016 0400481 0400482	BC08KA0012	08KA001 (1966-76)
McIntosh Creek	----	----	----
McKale River	0400015	----	08KA009 (1971-76)
West Twin Creek	----	----	----
East Twin Creek	----	----	----
Fleet Creek	----	----	----
Goat River	0400017	BC08KA0004	08NH004 (1914-76)

TABLE 2 - RECEIVING WATER STATIONS CONT'D.

SITE	PCB	WQB	WSC
Snowshoe Creek	----	----	----
Morkill River	0400018	----	----
P.O.B. Creek	----	----	----
Ptarmigan Creek	0400591	----	08LC028 (1946)
Torpy River	0400019	----	----
Fraser River @ Dome Creek	----	BC08KA0006	----
Dome Creek	----	----	----
Slim Creek	----	----	----
Driscoll Creek	----	----	----
Hungary Creek	----	----	----
Moxley Creek	----	----	----
Bowron River	0400020	BC08KD0001	08KD004 (1954-76)
Fraser River @ Hansard	0400021 0400022 0400023 0400024 0400025	BC08KA0001	08KA004 (1952-76)
McGregor River	0400026	BC08KB0002	08KB003 (1960-76)
Olsson Creek	----	----	----
Willow River	0920065 0400027	BC08KD0002	08KD006 (1976)
Salmon River North	0400028	BC08KC0001	08KC001 (1953-76)
Fraser River @ Shelley	0400029 0400030 0400031 0400032 0400033	BC08KB0001	08KB001 (1950-76)
Fraser River above Northwood Mill	0400044	----	----
Fraser River above Intercontinental	0400068	BC08KB0003	----
Fraser River @ Prince George	0400082 0400085	BC08KE0007	08KE001 (1927-30)

TABLE 2 - RECEIVING WATER STATIONS CONT'D.

SITE	PCB	WQB	WSC
Nechako River	0400040 0400455 0920666 0900187	BC08KE0010	08JC001 (1956-76)
Tabor Creek	0400782 0400233	----	08KE028 (1974-76)
Cale Creek	----	----	08KE015 (1956-74)
Fraser River @ Red Rock	0400034 0400035 0400036 0400037 0400038	----	----
Stone Creek	0400805	----	----
Naver Creek	0600081	----	08KE014 (1964-75)
Whites Landing Creek	----	----	----
West Road (Blackwater) River	0400041 0600049	BC08KG0001	08KG001 (1952-76)
Cottonwood River	0600045	BC08KE0006	08KE009 (1954-76)
Baker Creek	0600532	----	08KE016 (1963-76)
Fraser River @ Quesnel	0600019	BC08KE0001	08KE002 (1929-41)
Quesnel River	0600029 0600015 0600034 0900186	BC08KH0001	08KH006 (1939-76)
Dragon Creek	0600078	----	08KH016 (1962-76)
Narcosli Creek	0600028	----	08KE003 (1930-51)
Tingley Creek	----	----	08MC011 (1930)

TABLE 2 - RECEIVING WATER STATIONS CONT'D.

SITE	PCB	WQB	WSC
Fraser River @ Marguerite	0600011 0920141	BC08MC0001	08MC018 (1950-76)
Mackin Creek	----	----	----
Soda Creek	----	----	08MC030 (1967-75)
Hawks Creek	0600126	----	08MC024 (1964-68)
Williams Lake River	0600013 0600200 0600201 0600529	BC08MC0004	08MC005 (1968-76)
Meldrum Creek	0600111	----	08MC017 (1938-52)
Chimney Creek	0600340	----	08MC004 (1976)
Fraser River @ Chilcotin Highway	0600143	BC08MC0002	----
Riske Creek	----	----	----
Chilcotin River	0600024	----	08MB005 (1970-76)
Alkali Creek	----	----	----
Dog Creek	----	----	08MD009 (1928-30)
Gaspard Creek	----	----	08MD010 (1928)
Churn Creek	----	----	08MD012 (1928-30)
Canoe Creek	----	----	08MD008 (1929-30)
Lone Cabin Creek	----	----	----
French Bar Creek	----	----	08MD018 (1947-50)
Fraser River @ Big Bar Creek	----	----	08MD013 (1935-72)

TABLE 2 - RECEIVING WATER STATIONS CONT'D.

SITE	PCB	WQB	WSC
Big Bar Creek	----	----	08MD011 (1928-29)
Watson Bar Creek	----	----	----
Pavilion Creek	----	----	08MD002 (1915-43)
Bridge River	0300054 0920142	BC08ME0002	08ME001 (1913-48)
Fraser River @ Lillooet	0300117	BC08ME0001	----
Seton River	0300053 0301428	BC08ME0003	08ME003 (1958-76)
Fraser River above Texas Creek	----	----	08MF040 (1951-76)
Texas Creek	----	----	08MF015 (1914-21)
Stein River	----	BC08MF0009	08MF011 (1911-13)
Fraser River @ Lytton	0600010	BC08MF0004	08MF004 (1912-14)
Thompson River	0600005 0600325	BC08MF0003	08LF051 (1951-76)
Nahatlatch River	0300052	----	08MF008 (1916-21)
Anderson River	0300151	BC08MF0006	08MF001 (1945-49)
Scuzzy River	----	----	----
Yale Creek	----	----	08MF031 (1933-36)
Coquihalla River	0301117	BC08MF0008	08MF003 (1957-76)
Fraser River @ Hope	0300007 0300050 0300139 0920001	BC08MF0001	08MF005 (1912-76)

Waste Discharge Permit Inventory

Permits for all effluents discharged to the Fraser River watershed were obtained from an EQUIS permit retrieval. Permit stipulations have changed over time and are summarized in Table 3 for all discharges to the main stem above Hope. Those parameters which are common to most permits are itemized and units of flow and concentration have been converted to cubic meters per day and milligrams per liter respectively where possible (see Appendix II).

Permit stipulations represent maximum allowable objectives. In reality these effluent characteristics will fluctuate. However, they are a good indication of overall effluent character (Wong, 1977) should more detailed data not be available. It is evident that the parameters listed are oriented to technological abatement and, with few exceptions, do not specify the detailed physical and chemical makeup necessary to assess potential impact on the receiving environment. For example, domestic effluents commonly contain traces of up to twenty metals (Environment Canada, 1978) and many synthetic organics but nothing of this nature is specified on domestic effluent permits. More detailed information may have been supplied on permit applications but this information was not readily available.

Water License Inventory

An inventory of all water licenses held on the Fraser main stem above Hope was obtained from the Water Rights Branch and is shown in Table 4. Withdrawal rates have been converted to common units under the assumption that irrigation use is constant over a 100 day period.

Presently, no water licenses have been obtained on the Fraser River for aquatic habitat or recreation use. Licenses represent water withdrawals only.

TABLE 3 - FRASER RIVER MAIN STEM EFFLUENT PERMIT INVENTORY

PERMIT # (PE)	PERMITTEE	EFFECTIVE DATE	FLOW (m^3/d)	pH (units)		RESIDUE (mg/l)		BOD (mg/l)	FECAL COLIFORM	TEMPERATURE (°F)	
				min	max	total	susp.		($x10^6$/100ml)	min	max
0015	Town of Hope (mun. - untreated)	10/09/57	7,439.	6.8	8.0	800	200	180	40.	-	-
		08/02/73	7,167.	"	"	"	"	"	"	-	-
0076	Prince George Pulp & Paper Ltd. (mun. - 2°)	23/09/63	104.	6.5	7.5	150	100	50	0.005	40	60
		22/04/70	72.6	"	"	"	"	"	"	"	"
0091	Village of Lytton (mun. - 1°)	22/05/64	363.	-	-	750	150	140	5.	-	-
		10/07/73	544.	-	-	-	60	45	-	-	-
		03/01/78	550.	-	-	-	100	100	-	-	-
		01/01/79	365.	-	-	-	"	"	-	-	-
0092	Village of Lillooet (mun. - 1°)	22/06/64	1,000.	-	-	750	150	140	5.	-	-
		31/12/75	"	-	-	-	60	45	-	-	-
		01/05/78	"	-	-	-	130	130	-	-	-
		31/12/79	"	-	-	-	60	45	-	-	-
0095	School District #57 (P.G.) (mun. - 2°)	12/06/64	77.	-	-	400	100	50	0.005	-	-
		24/10/78	--------------------				dormant	--------------------			
0112	Northwood Pulp Ltd. (mun. - 1°)	04/02/65	145.	-	-	600	283	210	20.	-	-
		24/07/74	"	-	-	-	60	45	-	-	-
0146	City of Prince George (mun. - 1°)	09/11/65	11,340.	-	-	650	280	230	0.025	-	-
		29/03/71	12,247.	-	-	-	150	175	-	-	-
		09/06/72	23,134.	-	-	-	82	56	-	-	-
0152*	Prince George Pulp & paper Ltd. (kraft pulp mill - 2°)	29/03/66	125,194.	6.5	8.5	1000	63	45	0.	-	125
0157*	Northwood Pulp Ltd. (kraft pulp mill - 2°)	06/06/66	95,256.	6.5	8.5	1000	95	80	-	-	125
		20/06/73	108,864.	6.5	8.0	-	++	++	-	-	95
		31/12/74	"	6.0	8.5	-	++	++	-	-	"
		31/12/75	"	6.5	8.0	-	++	++	-	-	"
		09/05/79	118,000.	-	-	-	69+	52+	-	-	35°C

TABLE 3 - EFFLUENT PERMIT INVENTORY CONT'D.

PERMIT # (PE)	PERMITTEE	EFFECTIVE DATE	FLOW (m^3/d)	pH (units) min	pH (units) max	RESIDUE (mg/l) total	RESIDUE (mg/l) susp.	BOD (mg/l)	FECAL COLIFORM ($x10^6$/100ml)	TEMPERATURE (°F) min	TEMPERATURE (°F) max
0190	Intercontinental Pulp Co. Ltd. (chemical plant)	07/07/67	907.	-	-	1100	1000	-	0.005	-	-
0228*	Intercontinental Pulp Co. Ltd. (kraft pulp mill - 1°)	18/04/68	106,142.	6.5	8.5	1000	80	50	-	-	125
0319	Frechette, Prince George (municipal - 1°)	31/12/69	6.8	-	-	-	80	40	0.03	-	-
		15/06/71	17.7	-	-	-	20	10	0.001	-	-
		08/02/79	17.7	-	-	-	40	30	-	-	-
0354	Prince George, College Lands (municipal - 2°)	02/07/70	386.	-	-	-	70	80	2.	-	-
		72	2,270.	-	-	-	60	45	2.	-	-
0392	Canyon Aerial Tramway Ltd. (municipal - 1°)	25/03/71	25.4	-	-	-	40	30	-	-	-
0402	Village of McBride (municipal - 1°)	20/05/71	378.	-	-	-	95	75	-	-	-
1152*	Cariboo Pulp & Paper Co. Ltd. (kraft pulp mill - 2°)	03/08/72	108,864.	6.5	8.0	-	++	++	-	-	95
		01/12/78	109,100.	6.5	8.0	-	-	-	-	-	-
1720/01	Weldwood of Canada Ltd. (sawmill - 1°)	08/08/73	22.7	-	-	-	60	45	-	-	-
1720/03	Weldwood of Canada Ltd. (sawmill - 1°)	08/08/73	2,286.	-	-	-	-	-	-	-	-
		28/06/74	40.8	-	-	-	-	-	-	-	-
1763	B.C.G. Public Works (P.G.) (municipal - 1°)	26/03/73	113.	-	-	-	60	45	-	-	-
1901	Fraser-Fort George Reg. Dist. (municipal - 2°)	19/03/73	227.	-	-	-	60	45	-	-	-
		17/05/76	--------	--------	--------	--------	dormant	--------	--------	--------	--------
2017	The Ranch Hotel Ltd. (P.G.) (municipal - 1°)	15/06/73	19.6	-	-	-	60	45	-	-	-
2655	Northwood Pulp Ltd., U. Fraser (municipal - 1°)	13/09/73	272.	-	-	-	60	45	-	-	-

TABLE 3 - EFFLUENT PERMIT INVENTORY CONT'D.

PERMIT # (PE)	PERMITTEE	EFFECTIVE DATE	FLOW (m^3/d)	pH (units) min	pH (units) max	RESIDUE (mg/l) total	RESIDUE (mg/l) susp.	BOD (mg/l)	FECAL COLIFORM ($x10^6$/100ml)	TEMPERATURE (°F) min	TEMPERATURE (°F) max
3389	Iwasenko Mine, Watson Bar (placer mine - 1°)	09/10/74	136.	-	-	-	50	-	-	-	-
3868	Prince George, Airport (municipal - 1°)	22/08/74	1,247.	-	-	-	60	40	-	-	-
3900*	Intercontinental & Prince George Pulp & Paper (kraft pulp mills - 2°)	13/03/75	258,552. (mo.av.)	6.5	8.0	-	42.6+	42.6+	-	-	95
4125	Fraser-Cheam, Hope-Kawkaw** (municipal - 2°)	27/11/75 07/04/78	6,800. "	- -	- -	- -	60 100	45 100	- -	- -	- -
4905	City of Prince George (municipal - 2°)	13/07/78	1,000.	-	-	-	100	100	-	-	-
4992*	B.C. Hydro, McBride (source unknown)	01/05/78	77.3	-	-	-	-	-	-	-	-
5132	Prince George, Industrial Dev. (municipal - 2°)	18/01/79	1,400.	-	-	-	100	100	-	-	-

* permit lists other parameters (pulp mills include colour, D.O., foam, sulphide, resin acids & mercaptans).

** not yet operational.

\+ calculated from parameter rate and flow stipulations.

++ cannot be converted to concentration from permitted product rate stipulation.

NOTE: 1. Where a choice was possible the maximum average flow was taken over the maximum.
2. Data summarized from EQUIS retrieval and is subject to verification.

TABLE 4 - FRASER RIVER MAIN STEM WATER LICENSE INVENTORY

REGION & LOCATION	LICENSE HOLDER	LICENSE #	DATE	USE	VOLUME ORIGINAL UNITS	VOLUME 1000 x m^3/d
Prince George (24)						
83DNW	Saban	329750	14/10/75	domestic	500 g/d	0.0023
"	"	330765	"	"	"	"
"	"	330766	"	"	"	"
83ESW	B.C.G. - Rec. & Cons.	328339	10/02/75	industrial	20,000 g/d	0.091
93J1H	Northwood Pulp	190678	01/04/52	industrial	0 TF	-----
93J2A	Harold Rice	273991	18/08/67	irrigation	2,000 acre-ft.	24.68*
"	"	309232	29/07/69	irrigation	436 acre-ft.	5.38*
93J2B	"	309231	"	irrigation	128 acre-ft.	1.58*
93G15E	Northwood Pulp	259630	27/10/64	industrial	140 cfs	343.
6430	B.C. Land Commission	316890	08/05/73	irrigation	63 acre-ft.	0.78*
Quesnel (26)						
7240	Couldwell	256105	27/04/64	domestic	500 g/d	0.0023
"	Poitras	256106	27/04/64	"	"	"
"	Meier	256102	27/04/64	"	"	"
7240A	Carter	256103	27/04/64	"	"	"
7200	Weldwood of Canada Ltd.	264744	20/09/65	industrial	150 g/d	0.0007
7225	Luy	281426	11/07/68	irrigation	70 acre-ft.	0.864*
7221	Frechette	250007	30/05/63	domestic	500 g/d	0.0023
9007UU	Weldon	285264	27/02/69	irrigation	375 acre-ft.	4.63*
9007HH	Bourdon	300326	13/10/70	irrigation	65 acre-ft.	0.80*
9007VV	Gibraltar Mines Ltd.	300559	10/12/70	mining	2,985,000 g/d	13.54
"	"	"	"	industrial	15,000 g/d	0.068

Table 4 - WATER LICENSE INVENTORY CONT'D.

REGION & LOCATION	LICENSE HOLDER	LICENSE #	DATE	USE	WITHDRAWAL VOLUME ORIGINAL	1000 x m^3/d
Cariboo (05)						
1054	Thompson Land & Cattle Co.	257340	19/06/64	irrigation	27 acre-ft.	0.33*
1052	Deer Park Ranching Ltd.	330316	22/03/76	irrigation	990 acre-ft.	12.22*
Ashcroft (02)						
102A	Jones	300594	23/12/70	irrigation	15 acre-ft.	0.185*
"	Clark	300750	09/02/71	irrigation	45 acre-ft.	0.555*
"	Arthur	270552	16/09/66	irrigation	8.4 acre-ft.	0.104*
"	St. Dennis	340531	16/09/66	domestic	500 g/d	0.0023
"	"	"	"	irrigation	14.1 acre-ft.	0.174*
"	Arthur	330756	01/06/76	domestic	500 g/d	0.0023
"	Sunnymede Development Co.	203745	05/05/54	irrigation	208.5 acre-ft.	2.57*
"	"	330038	18/12/75	irrigation	52.8 acre-ft.	0.652*
"	"	328537	05/05/54	irrigation	562.2 acre-ft.	6.94*
"	Riverland Farms Ltd.	340578	05/05/54	irrigation	99.3 acre-ft.	1.23*
102C	Rizzuto	323228	10/06/74	irrigation	30 acre-ft.	0.37*
102C	Grossler	300668	13/01/71	irrigation	30 acre-ft.	0.37*
256	Northern Arc Ltd.	323448	25/06/74	mining	0.5 cfs	1.23
Nicola (21)						
6131	Canyon Aerial Tramways Ltd.	300549	07/12/70	industrial	20,000 g/d	0.091
New Westminister (20)						
5943B	Rivtow Marine Ltd.	198326	01/06/54	log booming	2 M.	-----
5942	Quatsino Copper-Gold Mines	296179	24/03/70	mining	360,000 g/d	1.63

* assumed 100 day withdrawal period

3. Preparation for Analysis

Segment boundaries, influences to be included in the analysis, parameters, and analysis times were chosen after an examination of the parameters and dates of collection available for each station or influence identified in the preceeding receiving water site and use allocation inventories. These decisions led to the development of a data base ready for analysis through the MATBAL program.

Segment Boundaries

As discussed in the development of the framework, segment boundaries should be selected to reflect the potential impact upon beneficial use locations. Beneficial use, as indicated by water license, is predominantly for irrigation and industrial feed. However, the Fraser is also one of the most productive Pacific salmon rivers of the world. The gross value of fisheries in 1974 was estimated at about $30 million annually and with enhancement could be about $58 million (Dorcey, 1974). Segment boundaries should therefore reflect both specific withdrawal locations and major in-stream character change points. Other considerations stem from the assumptions of the model. Sites should be sufficiently far downstream from inputs to ensure thorough mixing and should divide the inputs into groupings of similar magnitude. A balance must be struck between the desire for fine grain data and the expense and difficulty of data collection.

After examination of the potential monitoring stations on the Fraser main stem it was decided to select all boundary sites from among the Water Quality Branch surveillance system because these collections exhibit consistent collection dates, parameters and analytical methods. This led to selection of ten river segments from Red Pass to Hope as shown in Table 5.

TABLE 5 - Fraser Main Stem River Segments

SEGMENT	APPROXIMATE SEGMENT LENGTH (km)	FRASER BEGINNING AT	FRASER ENDING AT	UPSTREAM DRAINAGE AREA+ (sq.km.)	SEGMENT INPUT DRAINAGE AREA (sq. km.)
1	102	Red Pass	McBride	1,700	5,190
2	217	McBride	Hansard	6,890	11,110
3	93	Hansard	Shelley	18,000	14,375
4	47	Shelley	Red Rock	32,375	47,625*
5	153	Red Rock	Quesnel	80,000*	17,900*
6	59	Quesnel	Marguerite	97,900	15,800
7	60	Marguerite	Chilcotin Hwy	113,700	5,300*
8	174	Chilcotin Hwy	Lillooet	119,000*	31,000*
9	58	Lillooet	Lytton	150,000*	3,850*
10	113	Lytton	Hope	153,850	63,190

+ adapted from Water Survey of Canada, 1977.

* estimated values

Quality monitoring sites at Red Rock, Chilcotin Highway and Lillooet were chosen as segment boundaries without flow data because they represent a check on waste inputs near Prince George, and irrigation withdrawals for the other two. Flows for these stations were estimated by tributary flow addition to known main stem values plus a smoothing process.

Overall, the segment boundaries are located near existing water licenses and usually upstream from major inputs thus ensuring adequate distance for mixing. Without land use plans for the watershed it is not possible to consider future use sites except as extensions of past use.

Parameter Selection

Parameters should be selected to explore impacts particular to the watershed. This enhances efficiency and effectiveness of data collection and manipulation. Using available data, selection was limited to parameters with the most extensive system coverage. Since the federal Water Quality Branch collections were chosen for segment boundaries and the major tributaries were subject to similar analyses, the parameters of these collections formed the set of greatest potential. To select among them each was examined for (1) impact potential, (2) inclusion in PCB collections and (3) variation over the length of the river. This resulted in the following final parameter list:

1. Flow Volume Rate
2. pH
3. Temperature
4. Specific Conductance
5. Dissolved Sodium (Na)
6. Nonfilterable Residue (Suspended Solids)
7. Total Iron (Fe)
8. Total Manganese (Mn)
9. Total Copper (Cu)

Flow determines the reaches where specific water quality problems are most likely to occur and is the basis of the dilution model and the materials balance. It governs the concentration of material loads and, taken with flow velocity, influences many physical processes including scouring, mixing and aeration.

Aquatic life is sensitive to the pH or hydrogen ion concentration of its environment. The pH may not be toxic in itself unless the values are extreme but, the degree of formation of heavy metal hydroxides is directly related to pH (Water Pollution Control Directorate, 1975). Shifts in pH can thus affect the concentration of dissolved metals which, because they are very weakly complexed, can readily be taken up by aquatic organisms. Other materials, such as ammonia and cyanide, increase greatly in toxicity as the pH changes, again as a result of their ionization state. The receiving water objectives for the forest products industry (Pollution Control Board, 1977) state that negligable change should occur outside the initial dilution zone for pH.

Specific conductance is a measure of ion content and may be regarded as a conservative parameter. It has been proposed as a general indicator of water quality and is similar to the parameter dissolved solids but is much easier to measure. Water with a specific conductance of less than 1000 umhos/cm usually imparts no impact on use but water above this value may lead to problems if used for irrigation (Ontario Ministry of the Environment, 1978).

Temperature can influence the metabolic rate of aquatic organisms and hence toxicity because materials are more rapidly incorporated with elevated temperatures. Changes in temperature can cause mortality if of sufficient magnitude and duration. Even a change of one degree from ambient temperature may be significant for an organism if the ambient level lies close to the limit of the tolerance range (Great Lakes Water Quality Board, 1978). The objectives for the B.C. forest products industry state that no measurable change in temperature should occur in receiving waters as a result of discharge.

Sodium is the most abundant of the alkali metals and tends to remain in dissolved form once introduced through soil leaching or waste discharge. Sodium pollution can affect both domestic and agricultural use of water. Quality criteria for restricted sodium diets limit concentrations to 20 mg/l for extreme diets (U.S. Environmental Protection Agency, 1976) and 270 mg/l for moderate restrictions (U.S. Environmental Protection Agency, 1973).

Nonfilterable residue or suspended solids are high in the Fraser River and contribute to its turbidity and 'dirty' appearance. Quality criteria range from 0.05 to 0.5 mg/l for industrial use (U.S. E.P.A.,1973) to 25 mg/l for aquatic habitat (Department of the Environment, 1972). Receiving water objectives for B.C. state that negligable increase occur as a result of waste discharge (Pollution Control Board, 1977).

Total iron and manganese may be introduced from natural sources and are usually low in natural waters because dissolved oxygen oxidizes these materials to precipitate form which then settles. However, mean values may vary widely due to changing seasonal flow and dilution effects. A review of sixty-nine parameters in the main stem over the years 1970-75 (Clark, 1978) shows that B.C. drinking water standards of 0.3 mg/l for iron and 0.05 mg/l for manganese (Province of British Columbia, 1969) were frequently exceeded.

Total copper may affect aquatic life and criteria for its protection range from 0.005 mg/l (Ontario Ministry of the Environment, 1978) to 0.03 mg/l (Department of the Environment, 1972). The British Columbia standard for drinking water is 1.0 mg/l and the objective is 0.01 mg/l (Province of British Columbia, 1969).

Many parameters could not be considered due to lack of data in either federal or provincial collections. Examples include fecal coliforms, true colour, dissolved boron, magnesium and calcium, cyanide, the dissolved form of copper, iron and manganese, and the total and dissolved forms of arsenic, cadmium, lead, mercury, molybdenum, nickel and zinc. All of these parameters may have an impact on some use. Similarily, parameters which will gain in importance as development increases should be examined now to establish a data base prior to future load increases. These would include synthetic organics, such as pesticides, herbicides and industrial process components; coal associated parameters, such as strontium, sulphate, lithium and the abovementioned metals; and radionuclides including radium 226, strontium 90, and gross beta activity. Very little data, with the exception of spot checks for mercury, zinc, lead and a few pesticides, have been generated for these parameters. Nutrients were not perceived to be a problem in the Fraser due to the large dilution capacity and were not considered. Dissolved oxygen levels are near saturation in all reaches of the river above Hope (Clark, 1978) thereby eliminating concern over DO/BOD/COD behavior. Also, these parameters do not fit the assumptions of the dilution model and would require a more complex model for investigation.

Temporal Considerations

The most extensive monitoring coverage of the Fraser main stem, its tributaries, and waste inputs occurred during the 1974 to 1976 period. During 1975 and 1976 the Water Quality Branch conducted twelve system collections although not all stations listed in the site inventory of Table 2 were included. In view of the magnitude of the data compilation task it was decided to restrict the analysis to three conditions of flow, the extremes and an intermediate point within one year. The months February, April and July of 1976 were selected.

Data Retrieval, Assumptions and Inventory

In preparation for data retrieval all segment check stations, waste inputs, tributary inputs and water license locations were identified on a 1:500,000 scale map. An illustration of the result for Segment 10 (Lytton to Hope) is shown in Figure 6. The order of influences shown was determined from approximate latitude and longitude measures of PCB sites and the lot designations of water licenses. The ordering of other segments may be ascertained from the detailed data base.

Water quality data were obtained for all NAQUADAT stations identified in the schematic. Data retrieval from the EQUIS system was structured to reveal monthly mean values for each year from 1972 to 1977, for all parameters available in the data base, and for all receiving water sites or site groupings and waste discharges. The comprehensiveness of the EQUIS retrieval allowed system coverage for parameters not here considered to be examined and ensured that backup data would be available to fill gaps in federal collections or provincial collections for the year 1976. Receiving water flow data were collected from federal records (Water Survey of Canada, 1977). Relevant data were compiled in three tables based on the influence schematic as shown in Tables 6, 7 and 8. These tables form the detailed data base upon which the MATBAL program was run.

A large number of data gaps appeared while compiling the data base. These gaps were filled, as data permitted, from adjacent months in the same year, the proper month mean value for all years, other years and adjacent months, mean value for all years, permit stipulations, and theoretical literature values for similar waste types. The selection rules and assumptions employed for each data type are now summarized.

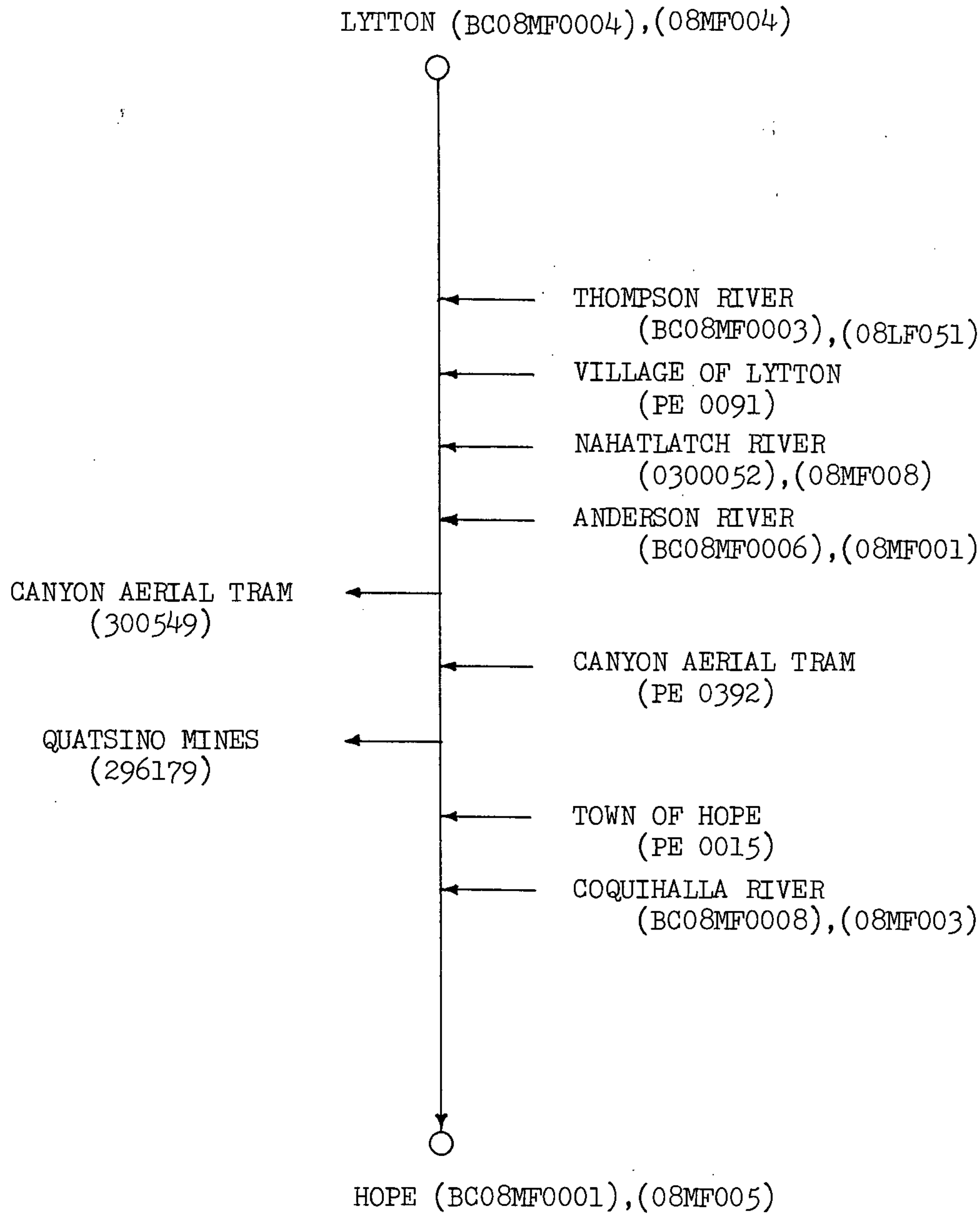


FIGURE 6 - INFLUENCE SCHEMATIC OF SEGMENT 10, LYTTON TO HOPE

TABLE 6

FRASER RIVER MATERIALS BALANCE

DATE OF DATA - FEBRUARY 1976

	FLOW X1000M3/D	PH (UNITS)	TEMP(C)	SP COND (UMHOS/CM)	DISS NA (MG/L)	NF RESIDUE (MG/L)	TOT FE (MG/L)	TOT MN (MG/L)	TOT CU (MG/L)
PARAMETER CRITERIA	----	----	----	----	270.00	25.000	0.300	0.050	1.000
SEGMENT 1									
1 FRASER AT REC PASS	551.250	8.00	0.50	142.	0.80	1.2	0.029	0.010	0.001
2 3WL SABAN - DOMESTIC	-0.007								
3 WL328339 BCG REC&CCN	-0.091								
4 HOLMES R. (PCB)	269.500	7.90	1.00	178.	2.40	15.2	0.500	0.010	0.003
SEGMENT 2									
5 FRASER AT MCBRIDE	2989.000	7.80	0.50	114.	1.70	4.4	0.400	0.060	0.001
6 PE0402 MCBRIDE STP	0.195	7.00	0.0	426.	78.00	17.0	0.820	0.040	0.060
7 CORE RIVER - HWY16BR	151.165	8.10	0.0	183.	1.10	3.6	0.033	0.010	0.001
8 MCKALE RIVER (PCB)	115.640	7.60	1.00	175.	1.35	1.0	0.0	0.0	0.001
9 GOAT RIVER	548.800	8.10	0.50	196.	1.20	4.0	0.022	0.010	0.001
10 PTARMIGAN CREEK PCB	0.171	8.10	******	4.	******	7.0	******	******	******
11 BOWRON RIVER	1607.200	8.10	1.00	168.	1.20	2.0	0.430	0.060	0.001
SEGMENT 3									
12 FRASER AT HANSARD	7766.496	8.20	0.50	204.	1.80	3.2	0.180	0.010	0.003
13 PE02655 NORTHWOOD	0.008	7.20	0.50	411.	78.00	37.0	0.820	0.040	0.060
14 MCGREGOR RIVER (PCB)	2768.500	7.80	0.0	250.	1.70	2.9	0.070	0.0	0.004
15 WILLOW RIVER	1031.450	7.40	0.0	130.	2.30	3.7	0.300	0.050	0.003
16 N SALMON R AT HWY97	808.500	8.10	0.50	162.	2.40	3.3	0.600	0.050	0.001
SEGMENT 4									
17 FRASER AT SHELLEY	16120.996	7.80	1.00	216.	2.10	5.6	0.310	0.060	0.002
18 WL259630 NORTHWOOD	-343.000								
19 PE0112 NORTHWOOD	0.030	6.80	9.00	248.	78.00	23.5	0.820	0.040	0.060
20 PE0157 NORTHWOOD	92.967	7.22	22.20	2050.	294.00	103.0	0.840	******	******
21 PE0190 INTERCON.	0.907	8.80	9.00	878.	76.00	1000.0	******	******	0.100
22 PE0228 INTERCON. KPM	80.528	6.97	24.00	2080.	261.00	40.6	0.840	******	******
23 PE3900 INTER & PGP&P	197.065	6.86	25.20	1390.	265.00	35.7	0.840	******	******
24 PE0076 PG PULP&PAPER	0.073	7.20	13.00	145.	78.00	13.0	0.820	0.040	0.060
25 PE0152 PG PULP&PAPER	98.205	6.77	27.90	1780.	268.00	90.7	0.840	******	******
26 PE1763 BCG PUB WORKS	0.113	7.30	12.00	1180.	78.00	8.0	0.820	0.040	0.060
27 NECHAKO RIVER	9187.496	7.40	0.50	98.	2.00	1.0	0.058	0.010	0.001
28 PE1901 FRASER-FT.GEO	0.227	*****	******	******	78.00	60.0	6.580	0.150	0.300
29 PE0095 SCHOOL DIST57	0.077	*****	******	******	78.00	100.0	0.820	0.040	0.060
30 PE2017 RANCH HOTEL	0.020	7.63	******	1170.	78.00	60.0	0.820	0.040	0.060
31 PE0354 P.G. COLLEGE	0.295	7.22	17.00	1020.	78.00	29.0	0.820	0.040	0.060
32 PE0146 P.G. CITY	16.368	7.30	13.00	748.	78.00	95.0	0.820	0.040	0.060
33 PE3868 P.G. AIRPORT	0.182	8.30	******	1180.	78.00	6.6	0.820	0.040	0.060
34 PE0319 FRECHETTE	0.008	7.20	9.00	988.	78.00	16.0	1.400	2.980	0.030
35 TABOR CREEK (PCB)	26.215	7.40	******	94.	******	26.0	1.800	******	0.007
36 GALE CREEK	31.115	*****	******	******	******	********	******	******	******
SEGMENT 5									
37 FRASER AT RED ROCK	26785.848	7.70	0.50	189.	5.90	9.0	0.070	0.020	0.002
38 NAVER CREEK (PCB)	105.350	7.00	0.0	90.	******	8.0	0.900	0.030	0.005
39 BLACKWATER (WR) RIV.	1180.900	8.00	0.0	215.	6.60	3.9	0.080	0.0	0.002
40 COTTONWOOD R.(COMB)	516.950	7.50	0.0	134.	******	2.0	0.300	0.020	0.007
41 4WL QUESNEL - DOM	-0.007								
42 PE1152 CARIBOO PULP	81.838	7.29	27.90	2030.	373.00	72.5	0.840	******	******
43 BAKER CREEK (PCB)	122.745	7.70	0.0	214.	******	18.0	0.300	0.050	0.004
SEGMENT 6									
44 FRASER AT QUESNEL	32942.695	7.80	0.0	165.	3.50	37.0	0.160	0.020	0.001
45 QUESNEL RIVER	5855.496	7.90	0.50	140.	1.10	23.0	0.130	0.020	0.001
46 WL264744 WELDWOOD	-0.001								
47 PE1720/01 WELDWOOD	0.025	6.35	10.00	360.	******	19.0	******	******	******
48 PE1720/03 WELDWOOD	0.041	6.90	12.50	589.	******	182.0	******	******	******
49 NARCOSLI CREEK (PCB)	24.500	8.20	0.50	339.	******	********	0.100	0.020	0.002
SEGMENT 7									
50 FRASER AT MARGUERITE	40424.996	7.90	0.50	170.	5.80	62.0	0.100	0.020	0.006
51 WL250007 FRECHETTE	-0.002								
52 WL300559 GIBRALTAR	-13.610								
53 HAWKS CREEK (PCB)	3.920	7.60	0.50	566.	******	7.0	0.0	0.080	0.004
54 WILLIAMS LAKE RIVER	109.270	8.35	1.00	587.	37.50	********	5.550	0.010	0.031
55 MELDRUM CREEK (PCB)	2.450	7.90	0.0	809.	******	22.0	0.170	0.0	0.010
56 CHIMNEY CREEK (PCB)	1.715	9.00	******	729.	******	********	******	******	******
SEGMENT 8									
57 FRASER AT HIGHWAY 20	43477.695	8.00	0.50	163.	4.10	62.0	0.160	0.010	0.003
58 CHILCOTIN RIVER(PCB)	2646.000	8.00	1.00	178.	******	4.0	0.260	0.0	0.008
59 CHURN CREEK (PCB)	66.150	*****	******	******	******	********	******	******	******
60 PE3389 IWASENKO MINE	0.136	7.00	******	******	******	50.0	0.300	0.050	0.050
61 BRIDGE RIVER	1305.850	8.20	2.00	304.	5.90	2.0	0.017	0.010	0.001
62 WAT.LIC.LILLOOET-DOM	-0.005								
SEGMENT 9									
63 FRASER AT LILLOOET	56043.742	7.90	0.0	176.	4.40	10.9	0.150	0.010	0.001
64 SETON RIVER	882.000	7.90	4.00	119.	1.80	2.0	0.130	0.010	0.001
65 PE0092 LILLOOET STP	1.000	7.30	17.50	717.	78.00	77.0	0.820	0.040	0.060
66 TEXAS CREEK	68.355	*****	******	******	******	********	******	******	******
67 WL323448NORTHERN ARC	-1.230								
68 STEIN RIVER AT MOUTH	455.700	7.70	3.00	92.	1.90	********	0.180	0.010	0.001
SEGMENT 10									
69 FRASER AT LYTTON	60294.492	7.80	2.00	154.	4.00	114.0	0.180	0.010	0.001
70 THOMPSON RIVER	19967.496	7.80	3.00	118.	3.50	3.0	0.050	0.010	0.001
71 PE0091 LYTTON STP	0.544	7.15	14.50	434.	78.00	72.0	0.600	0.040	0.050
72 NAHATLATCH RIVER-PCB	1347.500	8.00	6.00	96.	******	********	******	******	******
73 ANDERSON RIVER	568.400	7.60	3.00	108.	1.90	2.0	0.140	0.010	0.003
74 WL300549 CANYON TRAM	-0.091								
75 PE0392 CANYON TRAM	0.025	7.60	20.00	213.	78.00	30.0	0.820	0.040	0.060
76 WL296179 QUATSINO CU	-1.630								
77 PE0015 HOPE STP	7.167	7.40	******	******	105.00	200.0	6.580	0.150	0.300
78 COQUIHALLA RIVER	1660.700	7.60	3.00	73.	1.20	********	0.043	0.010	0.001
SEGMENT 11									
79 FRASER AT HOPE	89424.938	7.80	2.00	130.	3.30	3.0	0.048	0.010	0.001

***** NO DATA OR ESTIMATE AVAILABLE, ASSUME THE VALUE IS ZERO (7.0 FOR PH)

FRASER RIVER MATERIALS BALANCE

DATE OF DATA - APRIL 1976

	FLOW X1000M3/D	PH (UNITS)	TEMP(C)	SP COND (UMHOS/CM)	DISS NA (MG/L)	NF RESIDUE (MG/L)	TOT FE (MG/L)	TOT MN (MG/L)	TOT CU (MG/L)
PARAMETER CRITERIA	----	----	----	----	270.00	25.000	0.300	0.050	1.000
SEGMENT 1									
1 FRASER AT RED PASS	735.000	7.80	4.00	144.	0.90	0.7	0.034	0.010	0.0
2 3WL SABAN - DOMESTIC	-0.007								
3 WL328339 BCG REC&CON	-0.091								
4 HOLMES R. (PCB)	441.000	7.90	6.00	182.	2.00	40.2	0.500	0.010	0.003
SEGMENT 2									
5 FRASER AT MCBRIDE	5463.496	8.00	5.00	176.	1.60	28.4	0.500	0.030	0.002
6 PE0402 MCBRIDE STP	0.195	8.40	5.00	426.	78.00	30.0	0.820	0.040	0.060
7 DORE RIVER - HWY16BR	262.150	7.80	3.00	165.	0.90	4.0	0.080	0.0	0.002
8 MCKALE RIVER (PCB)	180.320	8.00	5.00	173.	1.30	12.0	0.350	0.010	0.001
9 GOAT RIVER	3258.500	8.00	3.00	173.	1.00	20.0	0.070	0.0	0.001
10 PTARMIGAN CREEK PCB	0.367	8.10	******	148.	******	286.0	11.000	0.230	0.010
11 BOWRON RIVER	4091.500	7.40	0.50	105.	0.80	36.2	0.590	0.040	0.002
SEGMENT 3									
12 FRASER AT HANSARD	13719.996	7.90	0.50	134.	1.20	71.5	0.685	0.045	0.006
13 PE02655 NORTHWOOD	0.025	7.20	0.50	411.	78.00	40.0	0.820	0.040	0.060
14 MCGREGOR RIVER (PCB)	6957.996	8.10	0.50	235.	1.80	12.0	0.0	0.0	0.0
15 WILLOW RIVER	3136.000	7.10	1.00	68.	1.20	76.0	0.600	0.050	0.004
16 N SALMON R AT HWY97	7129.496	7.20	1.00	92.	1.70	2.0	1.200	0.130	0.005
SEGMENT 4									
17 FRASER AT SHELLEY	31849.996	7.70	3.70	147.	1.40	36.7	0.550	0.020	0.002
18 WL259630 NORTHWOOD	-343.000								
19 PE0112 NORTHWOOD	0.055	6.80	12.00	248.	78.00	24.0	0.820	0.040	0.060
20 PE0157 NORTHWOOD	89.694	7.50	23.40	1934.	294.00	81.0	0.840	******	******
21 PE0190 INTERCON.	0.907	7.60	19.00	228.	33.60	102.0	******	******	0.100
22 PE0228 INTERCON. KPM	93.622	6.91	24.00	2230.	261.00	61.0	0.840	******	******
23 PE3900 INTER & PGP&P	204.266	6.80	25.90	1410.	265.00	42.8	0.840	******	******
24 PE0076 PG PULP&PAPER	0.073	7.20	13.00	145.	78.00	13.0	0.820	0.040	0.060
25 PE0152 PG PULP&PAPER	96.241	7.07	29.00	1820.	268.00	154.0	0.840	******	******
26 PE1763 BCG PUB WORKS	0.113	7.80	12.00	1140.	78.00	16.0	0.820	0.040	0.060
27 NECHAKO RIVER	30134.996	7.40	0.50	91.	2.30	129.7	1.300	0.170	0.004
28 PE1901 FRASER-FT.GEO	0.227	*****	******	******	78.00	60.0	6.580	0.150	0.300
29 PE0095 SCHOOL DIST57	0.077	*****	******	******	78.00	100.0	0.820	0.040	0.060
30 PE2017 RANCH HOTEL	0.020	7.63	******	1170.	78.00	60.0	0.820	0.040	0.060
31 PE0354 P.G. COLLEGE	1.231	7.22	17.00	850.	78.00	49.0	0.820	0.040	0.060
32 PE0146 P.G. CITY	15.516	7.50	13.00	683.	78.00	258.0	0.820	0.040	0.060
33 PE3868 P.G. AIRPORT	0.167	8.30	******	1180.	78.00	36.2	0.820	0.040	0.060
34 PE0319 FRECHETTE	0.010	7.20	14.00	1196.	78.00	83.5	1.400	2.980	0.030
35 TABOR CREEK (PCB)	521.850	7.20	******	75.	******	27.0	1.600	******	0.004
36 CALE CREEK	534.100	*****	******	******	******	********	******	******	******
SEGMENT 5									
37 FRASER AT RED ROCK	72304.375	7.90	9.30	116.	1.30	188.0	0.230	0.030	0.002
38 NAVER CREEK (PCB)	1869.350	6.90	0.0	224.	******	20.0	0.900	0.210	0.002
39 BLACKWATER (WR) RIV.	5144.996	8.00	4.80	209.	5.70	29.5	2.300	0.120	0.010
40 COTTONWOOD R.(COMB)	3969.000	7.00	1.00	52.	1.00	126.0	1.100	0.090	0.007
41 4WL QUESNEL - DOM	-0.007								
42 PE1152 CARIBOO PULP	79.219	7.62	27.80	2030.	373.00	112.0	0.840	******	******
43 BAKER CREEK (PCB)	1501.850	8.10	1.00	238.	******	18.0	0.300	0.050	0.004
SEGMENT 6									
44 FRASER AT QUESNEL	114584.000	7.60	0.50	118.	2.00	580.0	4.000	0.260	0.020
45 QUESNEL RIVER	13499.496	7.80	3.00	153.	1.90	332.3	2.050	0.170	0.020
46 WL264744 WELDWOOD	-0.001								
47 PE1720/01 WELDWOOD	0.030	6.35	10.00	360.	******	19.0	******	******	******
48 PE1720/03 WELDWOOD	0.041	6.90	12.50	589.	******	182.0	******	******	******
49 NARCOSLI CREEK (PCB)	84.770	8.20	0.50	339.	******	********	0.100	0.020	0.002
SEGMENT 7									
50 FRASER AT MARGUERITE	139649.938	7.70	2.50	126.	2.40	627.3	4.000	0.400	0.030
51 WL250007 FRECHETTE	-0.002								
52 WL300559 GIBRALTAR	-13.610								
53 HAWKS CREEK (PCB)	13.720	8.20	4.00	502.	******	24.0	0.0	0.030	0.007
54 WILLIAMS LAKE RIVER	955.500	8.60	10.00	526.	30.70	8.5	0.200	0.020	0.007
55 MELDRUM CREEK (PCB)	12.985	7.70	0.50	844.	******	2.0	0.100	0.0	0.004
56 CHIMNEY CREEK (PCB)	8.575	9.00	******	729.	******	********	******	******	******
SEGMENT 8									
57 FRASER AT HIGHWAY 20	142452.750	7.70	3.00	133.	2.70	623.7	7.300	0.680	0.030
58 CHILCOTIN RIVER(PCB)	3381.000	7.70	0.50	180.	******	70.0	0.260	0.0	0.008
59 CHURN CREEK (PCB)	693.350	*****	******	******	******	********	******	******	******
60 PE3389 IWASENKO MINE	0.136	7.00	******	******	******	50.0	0.300	0.050	0.050
61 BRIDGE RIVER	2866.500	8.20	10.50	314.	6.30	10.0	0.070	0.0	0.002
62 WAT.LIC.LILLOOET-DOM	-0.005								
SEGMENT 9									
63 FRASER AT LILLOOET	154685.625	7.70	5.00	150.	3.40	912.8	5.000	0.480	0.030
64 SETON RIVER	3136.000	7.50	6.00	97.	1.80	2.0	0.100	0.0	0.001
65 PE0092 LILLOOET STP	1.000	7.40	17.50	765.	78.00	70.0	0.820	0.040	0.060
66 TEXAS CREEK	78.400	*****	******	******	******	********	******	******	******
67 WL323448NORTHERN ARC	-1.230								
68 STEIN RIVER AT MOUTH	1310.750	7.50	9.00	95.	1.80	********	0.070	0.010	0.001
SEGMENT 10									
69 FRASER AT LYTTON	160974.750	7.80	6.00	148.	3.40	696.0	4.800	0.420	0.030
70 THOMPSON RIVER	28664.996	7.70	7.00	126.	3.80	6.3	0.120	0.010	0.001
71 PE0091 LYTTON STP	0.544	7.15	14.50	434.	78.00	72.0	0.600	0.040	0.050
72 NAHATLATCH RIVER-PCB	2670.500	8.00	6.00	96.	******	********	******	******	******
73 ANDERSON RIVER	1200.500	7.60	6.00	109.	1.70	62.0	0.320	0.020	0.003
74 WL300549 CANYON TRAM	-0.091								
75 PE0392 CANYON TRAM	0.025	7.60	20.00	213.	78.00	30.0	0.820	0.040	0.060
76 WL296179 QUATSINO CU	-1.630								
77 PE0015 HOPE STP	7.167	7.40	******	******	105.00	200.0	6.580	0.150	0.300
78 COQUIHALLA RIVER	2474.500	7.30	6.00	67.	1.10	********	0.160	0.0	0.003
SEGMENT 11									
79 FRASER AT HOPE	199429.938	7.60	6.00	139.	3.50	557.5	3.600	0.300	0.020

***** NO DATA OR ESTIMATE AVAILABLE. ASSUME THE VALUE IS ZERO (7.0 FOR PH)

TABLE 7

TABLE 8

FRASER RIVER MATERIALS BALANCE

DATE OF DATA - JULY 1976

	FLOW X1000M3/D	PH (UNITS)	TEMP(C)	SP COND (UMHOS/CM)	DISS NA (MG/L)	NF RESIDUE (MG/L)	TOT FE (MG/L)	TOT MN (MG/L)	TOT CU (MG/L)
PARAMETER CRITERIA	----	----	----	----	270.00	25.000	0.300	0.050	1.000
SEGMENT 1									
1 FRASER AT RED PASS	14552.996	7.90	10.00	117.	0.60	1.1	0.041	0.0	0.005
2 3WL SABAN - DOMESTIC	-0.007								
3 WL328339 BCG REC&CON	-0.091								
4 HOLMES R. (PCB)	4507.996	7.80	10.00	101.	0.70	16.0	0.800	0.020	0.002
SEGMENT 2									
5 FRASER AT MCBRIDE	57084.992	8.00	10.00	105.	0.50	67.2	0.430	0.025	0.004
6 PE0402 MCBRIDE STP	0.195	10.50	10.00	380.	78.00	133.0	0.820	0.040	0.060
7 DORE RIVER - HWY16BR	4042.500	7.80	0.0	80.	0.40	111.8	0.190	0.0	0.003
8 MCKALE RIVER (PCB)	2572.500	7.60	11.00	87.	0.50	5.0	0.700	0.020	0.001
9 GOAT RIVER	3405.500	8.10	0.0	125.	0.50	6.0	0.105	0.0	0.002
10 PTARMIGAN CREEK PCB	1.690	8.03	******	172.	******	25.0	1.350	0.040	0.004
11 BOWRON RIVER	12764.496	7.90	10.00	111.	0.60	30.5	0.310	0.015	0.004
SEGMENT 3									
12 FRASER AT HANSARD	115639.938	8.00	10.00	112.	0.60	65.7	0.515	0.030	0.004
13 PE02655 NORTHWOOD	0.011	7.50	10.00	401.	78.00	88.0	0.820	0.040	0.060
14 MCGREGOR RIVER (PCB)	49979.996	7.80	12.00	135.	0.40	50.0	2.000	0.020	0.003
15 WILLOW RIVER	5316.496	7.50	10.00	55.	0.70	12.0	0.260	0.015	0.004
16 N SALMON R AT HWY97	1996.750	7.90	10.00	123.	1.80	15.0	0.395	0.030	0.005
17 3WL RICE - IRRIG.	-31.640								
SEGMENT 4									
18 FRASER AT SHELLEY	184484.938	7.80	13.30	120.	0.44	78.7	2.860	0.066	0.003
19 WL259630 NORTHWOOD	-343.000								
20 PE0112 NORTHWOOD	0.077	6.40	17.00	206.	78.00	14.0	0.820	0.040	0.060
21 PE0157 NORTHWOOD	103.443	7.32	64.80	1880.	294.00	77.8	0.840	******	******
22 PE0190 INTERCON.	0.907	7.80	18.00	687.	119.00	17.0	******	******	0.100
23 PE0228 INTERCON. KPM	129.631	6.92	25.00	1930.	261.00	53.5	0.840	******	******
24 PE3900 INTER & PGP&P	234.383	6.85	33.40	1370.	265.00	102.0	0.840	******	******
25 PE0076 PG PULP&PAPER	0.073	7.20	13.00	145.	78.00	13.0	0.820	0.040	0.060
26 PE0152 PG PULP&PAPER	117.846	6.88	34.50	1650.	268.00	48.0	0.840	******	******
27 PE1763 BCG PUB WORKS	0.113	7.70	12.00	1100.	78.00	5.0	0.820	0.040	0.060
28 NECHAKO RIVER	48999.996	7.60	10.00	84.	2.00	15.5	0.180	0.010	0.005
29 PEC095 SCHOOL DIST57	0.077	*****	******	******	78.00	100.0	0.820	0.040	0.060
30 PE2017 RANCH HOTEL	0.020	7.63	******	1170.	78.00	60.0	0.820	0.040	0.060
31 PE0354 P.G. COLLEGE	1.342	7.20	17.00	760.	78.00	55.0	0.820	0.040	0.060
32 PE0146 P.G. CITY	14.272	7.20	13.00	611.	78.00	19.0	0.820	0.040	0.060
33 PE3868 P.G. AIRPORT	0.151	8.10	******	847.	78.00	67.2	0.820	0.040	0.060
34 PE0319 FRECHETTE	0.014	7.30	20.00	1370.	78.00	305.0	1.400	2.980	0.030
35 TABOR CREEK (PCB)	50.470	7.90	******	159.	******	17.0	1.200	******	0.004
36 CALE CREEK	67.375	*****	******	******	******	********	******	******	******
SEGMENT 5									
37 FRASER AT RED ROCK	241592.000	8.00	13.00	116.	1.10	72.7	3.470	0.057	0.003
38 WL316890 BC LAND COM	-0.780								
39 NAVER CREEK (PCB)	448.350	6.40	10.60	70.	******	8.0	0.300	0.040	0.006
40 BLACKWATER (WR) RIV.	7129.496	7.50	19.00	141.	4.90	11.0	0.200	0.040	0.0
41 COTTONWOOD R.(CCMB)	2940.000	7.40	10.00	49.	0.80	4.0	0.380	0.010	0.007
42 4WL QUESNEL - DOM	-0.007								
43 PE1152 CARIBOO PULP	76.600	7.50	32.00	1790.	392.00	77.5	0.840	******	******
44 BAKER CREEK (PCB)	610.050	7.70	13.00	123.	******	40.0	0.300	0.050	0.012
SEGMENT 6									
45 FRASER AT QUESNEL	277957.375	7.80	10.00	107.	1.30	113.0	0.595	0.050	0.007
46 QUESNEL RIVER	62474.992	7.90	10.00	118.	1.00	156.8	0.920	0.065	0.009
47 WL264744 WELDWOOD	-0.001								
48 PE1720/01 WELDWOOD	0.021	7.30	17.00	310.	******	35.0	******	******	******
49 PE1720/03 WELDWOOD	0.041	6.90	12.50	589.	******	182.0	******	******	******
50 NARCOSLI CREEK (PCB)	212.415	8.40	15.00	248.	******	16.1	0.100	0.015	0.009
SEGMENT 7									
51 FRASER AT MARGUERITE	350349.938	7.80	10.00	111.	1.40	130.0	0.775	0.060	0.007
52 3WL IRR. BELOW MARG.	-6.290								
53 WL250007 FRECHETTE	-0.002								
54 WL300559 GIBRALTAR	-13.610								
55 HAWKS CREEK (PCB)	45.325	8.25	15.00	444.	******	56.0	0.100	0.060	0.001
56 WILLIAMS LAKE RIVER	347.900	8.90	19.00	537.	32.30	5.3	0.167	0.0	0.010
57 MELDRUM CREEK (PCB)	4.900	8.40	13.00	839.	******	17.0	0.100	0.0	0.003
58 CHIMNEY CREEK (PCB)	18.130	9.00	******	763.	******	********	******	******	******
59 WL257340 THCMPSCN CO	-0.330								
SEGMENT 8									
60 FRASER AT HIGHWAY 20	357254.063	8.00	10.00	112.	1.40	180.3	0.790	0.070	0.008
61 WL330316 DEER PARK	-12.220								
62 CHILCOTIN RIVER(PCB)	25479.996	7.30	14.00	67.	******	40.0	0.100	0.020	0.010
63 CHURN CREEK (PCB)	379.750	*****	******	******	******	********	******	******	******
64 PE3389 IWASENKO MINE	0.136	7.00	******	******	******	50.0	0.300	0.050	0.050
65 BRIDGE RIVER	24499.996	8.10	10.00	157.	2.20	9.0	0.295	0.0	0.004
66 WAT.LIC.LILLOOET-IRR	-13.150								
67 WAT.LIC.LILLOOET-DOM	-0.005								
SEGMENT 9									
68 FRASER AT LILLOOET	426466.563	8.00	10.00	112.	1.60	168.3	0.625	0.055	0.006
69 SETON RIVER	1097.600	7.80	10.00	75.	0.90	9.0	0.370	0.020	0.005
70 PE0092 LILLOOET STP	1.000	7.20	17.50	727.	78.00	76.0	0.820	0.040	0.060
71 TEXAS CREEK	683.550	*****	******	******	******	********	******	******	******
72 WL323448NORTHERN ARC	-1.230								
73 STEIN RIVER AT MOUTH	4287.496	7.80	10.00	38.	0.80	********	0.100	0.0	0.0
SEGMENT 10									
74 FRASER AT LYTTON	438143.250	8.00	10.00	110.	1.50	154.8	0.625	0.055	0.007
75 THOMPSON RIVER	197469.938	7.70	10.00	77.	1.50	10.7	0.170	0.0	0.004
76 PEC091 LYTTON STP	0.544	7.00	14.50	428.	78.00	98.0	0.600	0.040	0.050
77 NAHATLATCH RIVER-PCB	10338.996	7.40	12.80	26.	0.30	6.0	0.200	0.0	0.0
78 ANDERSON RIVER	610.050	7.50	10.00	39.	0.80	111.0	0.245	0.0	0.005
79 WL300549 CANYON TRAM	-0.091								
80 PE0392 CANYON TRAM	0.025	7.50	20.00	315.	78.00	440.0	0.820	0.040	0.060
81 WL296179 QUATSINO CU	-1.630								
82 PE0015 HOPE STP	7.167	7.40	******	******	105.00	200.0	6.580	0.150	0.300
83 COQUIHALLA RIVER	5120.496	7.50	10.00	40.	0.70	********	0.075	0.0	0.002
SEGMENT 11									
84 FRASER AT HOPE	663949.938	7.90	10.00	96.	1.60	103.3	0.635	0.070	0.007

***** NO DATA OR ESTIMATE AVAILABLE, ASSUME THE VALUE IS ZERO (7.0 FOR PH)

In each data type the order describes the order of preference:

1. Licensed Withdrawals
   - withdrawal flows taken from water licenses

2. Receiving Water Flows
   (a) proper month and year mean value
   (b) proper year but mean value of adjacent months
   (c) calculated from the percentage change exhibited for the mean monthly values for all years and data available in 1976
   (d) mean monthly values for all years
   (e) mean monthly values from other years
   (f) calculated from the percentage change exhibited at the downstream Fraser check station and data available

   NOTE: All Fraser check station flow values were either taken from the proper months for 1976 or calculated from these values by addition or subtraction of tributaries. This was necessary to ensure continuity from segment to segment. Other flows need only describe the approximate magnitude.

3. Receiving Water Quality
   (a) WQB data for the proper month and year
   (b) PCB mean for the proper month and year
   (c) proper year but mean value of adjacent months
   (d) proper month mean value for all years
   (e) proper year but adjacent month
   (f) mean of adjacent months in other years
   (g) mean of all months and all years

   NOTE: (1) WQB extractable metals values were used as total metals. The two analyses are similar in that they show up all but refractory materials.

   (2) If no total metal values were available dissolved metals values were used in their stead as a minimum value.

   (3) Values less than the minimum detectable concentration were assumed to be zero.

4. Effluent Flow and Quality
   (a) proper month and year mean value
   (b) proper year and adjacent month mean value
   (c) annual mean value for 1976 (if little variation is apparent)
   (d) mean value of the proper month for other years
   (e) other months and other years
   (f) permit data (primarily for flow)
   (g) theoretical values

   NOTE: (1) Theoretical values for municipal type discharge were calculated from total metal analyses for 20 sewage plants in Ontario of varying types and sizes (Environment Canada, 1978).

   (2) Metals in kraft mill wastes are taken from Rogers (1973).

Due to the large number of data gaps and assumptions made to fill them, no particular value of Tables 6, 7 and 8 should be regarded as accurate without verification. Even in those instances where data were available for the proper year and month it is not certain that the result of a few grab samples adequately describes the mean monthly character of the water. However, through use of the selection rules and a consistent approach to data compilation, the values derived should portray the character of the water system in a relative sense and be sufficient for illustration of the analysis approach.

Summary

The purpose of this section was to detail the procedure used to prepare a data base ready for analysis through the MATBAL program. The activities performed follow from the conceptual approach developed in Chapter 2 and included the following:

1. All accountable main stem inputs and outputs were inventoried by type;
2. The river was segmented based on potential impact sites and existing monitoring station locations;
3. Chemical parameters were chosen for detailed examination;
4. Times were chosen to run the materials balance;
5. Water quantity and quality data were collected for the above sites, parameters and times.

4. Model Outputs and Observations

The MATBAL program operates on one data month at a time and performs calculations on two levels, site specific and segment. Site specific information is summarized at the segment level and segment information is summarized at the end of the system. There are thus three output levels; site specific, segment and system.

Site Specific

Site specific output is generated at each input or withdrawal point. At an input point parameter loads are added to the upstream loads determined either through segment initialization or previous input load calculations. The resultant loads are then used to calculate downstream concentrations through dilution. An example of the theoretical influence of three sequential inputs to Segment 4 of the Fraser for February 1976 is given in Table 9. The upstream values shown in Table 9 are the result of serial dilution of the various influences between the segment initialization point, Fraser at Shelley, and the appropriate input. Parameters are divided between those which may only be represented as a concentration, such as pH, temperature and specific conductance, and those which may be expressed as both concentraion and load. The percentage change in main stem concentrations and loads is calculated for all parameters except pH because this parameter is a logarithmic measure. The downstream theoretical available assimilative capacity is calculated from the difference between the calculated downstream concentration and criteria for beneficial use as stated at the top of Table 6. The available capacity may thus be calculated for any input criteria set.

TABLE 9 - Example of Site Specific Output Generated for Three Sequential Inputs to Segment 4 During February 1976.

******* INFLUENCE OF PE0152 PG PULP&PAPER *******

	UPSTREAM VALUE	INPUT VALUE	DOWNSTREAM VALUE (CALC)	PERCENT CHANGE
FLOW (X1000M3/DAY)	16150.	98.205	16248.	0.61
PH (UNITS)	7.7	6.8	7.7	----
TEMPERATURE (C)	1.5	27.9	1.7	10.40
SP CONDUCTANCE (UMHOS/CM)	250.	1780.	259.	3.70

	UPSTREAM VALUE		INPUT VALUE		DOWNSTREAM VALUE (CALC)		PERCENT CHANGE		AVAILABLE CAPACITY*
	MG/L	TONS(M)/D	MG/L	TONS(M)/D	MG/L	TCNS(M)/D	CONC	LOAD	TONS(M)/D
DISSOLVEC SODIUM	8.28	133.8	268.00	26.319	9.85	160.1	18.95	19.67	4226.793
SUSPENDED SOLIDS	6.76	109.1	90.70	8.907	7.27	118.1	7.51	8.16	288.141
TOTAL IRCN	0.322	5.202	0.840	0.082	0.325	5.285	0.97	1.59	-0.411
TOTAL MANGANESE	0.059	0.947	0.0	0.0	0.058	0.947	-0.60	-0.00	-0.134
TOTAL COPPER	0.002	0.032	0.0	0.0	0.002	0.032	-0.60	-0.00	16.216

* BASED ON INPUT CRITERIA

******* INFLUENCE OF PE1763 BCG PUB WORKS *******

	UPSTREAM VALUE	INPUT VALUE	DOWNSTREAM VALUE (CALC)	PERCENT CHANGE
FLOW (X1000M3/CAY)	16248.	0.113	16249.	0.00
PH (UNITS)	7.7	7.3	7.7	----
TEMPERATURE (C)	1.7	12.0	1.7	0.00
SP CONDUCTANCE (UMHCS/CM)	259.	1180.	259.	0.00

	UPSTREAM VALUE		INPUT VALUE		DOWNSTREAM VALUE (CALC)		PERCENT CHANGE		AVAILABLE CAPACITY*
	MG/L	TONS(M)/D	MG/L	TONS(M)/D	MG/L	TONS(M)/D	CONC	LOAD	TONS(M)/D
DISSOLVED SODIUM	9.85	160.1	78.00	0.009	9.85	160.1	0.00	0.01	4226.813
SUSPENCED SOLIDS	7.27	118.1	8.00	0.001	7.27	118.1	0.00	0.00	288.143
TOTAL IRCN	0.325	5.285	0.820	0.000	0.325	5.285	0.00	0.00	-0.411
TOTAL MANGANESE	0.058	0.947	0.040	0.000	0.058	0.947	-0.00	0.00	-0.134
TOTAL COPPER	0.002	0.032	0.060	0.000	0.002	0.032	0.02	0.02	16.216

* BASED ON INPUT CRITERIA

******* INFLUENCE OF NECHAKO RIVER *******

	UPSTREAM VALUE	INPUT VALUE	DOWNSTREAM VALUE (CALC)	PERCENT CHANGE
FLOW (X1000M3/CAY)	16248.	9187.496	25435.	56.55
PH (UNITS)	7.7	7.4	7.6	----
TEMPERATURE (C)	1.7	0.5	1.3	-25.45
SP CONDUCTANCE (UMHCS/CM)	259.	98.	201.	-22.48

	UPSTREAM VALUE		INPUT VALUE		DOWNSTREAM VALUE (CALC)		PERCENT CHANGE		AVAILABLE CAPACITY*
	MG/L	TONS(M)/D	MG/L	TONS(M)/D	MG/L	TONS(M)/D	CONC	LOAD	TONS(M)/D
DISSOLVED SODIUM	9.85	160.1	2.00	18.375	7.02	178.5	-28.79	11.48	6689.059
SUSPENDED SOLIDS	7.27	118.1	1.00	9.187	5.00	127.2	-31.15	7.78	508.644
TOTAL IRCN	0.325	5.285	0.058	0.533	0.229	5.818	-29.68	10.08	1.813
TOTAL MANGANESE	0.058	0.947	0.010	0.092	0.041	1.039	-29.92	9.70	0.233
TOTAL COPPER	0.002	0.032	0.001	0.009	0.002	0.041	-17.58	29.02	25.395

* BASED ON INPUT CRITERIA

At each withdrawal point the theoretical concentration of the withdrawal water is printed based on upstream calculations. The volume of the withdrawal is used to reduce downstream material loads.

It should be noted that the calculated downstream concentrations assume input materials to be instantaneously and perfectly dispersed. In reality, a large distance may be required before complete mixing occurs however, the calculated values provide a basis for estimation. This is particularily true for waste effluent inputs where material concentrations are higher than ambient. In this case the calculated values represent a very conservative estimate of downstream effect. It should also be noted that the calculated values do not include the effects of surface runoff, groundwater inflow or in-stream material transformations which may have occurred upstream. These effects will be considered later.

Segment Summary Output

At the end of each segment all influences and their effect on downstream concentration are tallied as shown in Table 10 for Segment 4 for February 1976. This summary allows significant influence induced change points to be identified and provides a quick check on how close the predicted values are to measured end values as well as an indication of the overall effect of unaccounted influences. For example, for the parameter specific conductance it is apparent that the pulp mill effluents above Prince George exert a degrading influence resulting in a shift from 216 to 259 umhos/cm however, the dilution effect of the Nechako River, as detailed in Table 9 for the same period, more than offsets this effect leading to a value of 201 umhos/cm. The difference between the observed and the calculated value is negative

TABLE 10 - Example of Segment Level Concentration Summary Output

SEGMENT 4 - CONCENTRATION SUMMARY FEBRUARY 1976

	FLOW X1000M3/D	PH (UNITS)	TEMP (C)	SP COND (UMHOS/CM)	DISS NA MG/L	NF RESIDUE MG/L	TOT FE MG/L	TOT MN MG/L	TOT CU MG/L
INITIAL VALUE									
FRASER AT SHELLEY	16120.996	7.8	1.0	216.	2.10	5.6	0.310	0.060	0.002
INFLUENCE INPUT VALUES									
1 WL259630 NORTHWOOD	-343.000								
2 PEC112 NORTHWOOD	0.030	6.8	9.0	248.	78.00	23.5	0.820	0.040	0.060
3 PEC157 NORTHWOOD	92.967	7.2	22.2	2050.	294.00	103.0	0.840	0.0	0.0
4 PEC190 INTERCON.	0.907	8.8	9.0	878.	76.00	1000.0	0.0	0.0	0.100
5 PEC228 INTERCON. KPM	80.528	7.0	24.0	2080.	261.00	40.6	0.840	0.0	0.0
6 PE3900 INTER & PGP&P	197.065	6.9	25.2	1390.	265.00	35.7	0.840	0.0	0.0
7 PE0076 PG PULP&PAPER	0.073	7.2	13.0	145.	78.00	13.0	0.820	0.040	0.060
8 PE0152 PG PULP&PAPER	98.205	6.8	27.9	1780.	268.00	90.7	0.840	0.0	0.0
9 PE1763 BCG PUB WORKS	0.113	7.3	12.0	1180.	78.00	8.0	0.820	0.040	0.060
10 NECHAKO RIVER	9187.496	7.4	0.5	98.	2.00	1.0	0.058	0.010	0.001
11 PE1901 FRASER-FT.GEO	0.227	7.0	0.0	0.	78.00	60.0	6.580	0.150	0.300
12 PEC095 SCHOOL DIST57	0.077	7.0	0.0	0.	78.00	100.0	0.820	0.040	0.060
13 PE2017 RANCH HOTEL	0.020	7.6	0.0	1170.	78.00	60.0	0.820	0.040	0.060
14 PE0354 P.G. COLLEGE	0.295	7.2	17.0	1020.	78.00	29.0	0.820	0.040	0.060
15 PE0146 P.G. CITY	16.368	7.3	13.0	748.	78.00	95.0	0.820	0.040	0.060
16 PE3868 P.G. AIRPORT	0.182	8.3	0.0	1180.	78.00	6.6	0.820	0.040	0.060
17 PE0319 FRECHETTE	0.008	7.2	9.0	988.	78.00	16.0	1.400	2.980	0.030
18 TABOR CREEK (PCB)	26.215	7.4	0.0	94.	0.0	26.0	1.800	0.0	0.007
19 CALE CREEK	31.115	7.0	0.0	0.	0.0	0.0	0.0	0.0	0.0
PREDICTED DOWNSTREAM VALUES									
1 WL259630 NORTHWOOD	15777.996	7.8	1.0	216.	2.10	5.6	0.310	0.060	0.002
2 PEC112 NORTHWOOD	15778.023	7.8	1.0	216.	2.10	5.6	0.310	0.060	0.002
3 PE0157 NORTHWOOD	15870.988	7.8	1.1	227.	3.81	6.2	0.313	0.060	0.002
4 PE0190 INTERCON.	15871.895	7.8	1.1	227.	3.81	6.2	0.313	0.060	0.002
5 PE0228 INTERCON. KPM	15952.422	7.8	1.2	236.	5.11	6.4	0.316	0.059	0.002
6 PE3900 INTER & PGP&P	16149.484	7.7	1.5	250.	8.28	6.8	0.322	0.059	0.002
7 PE0076 PG PULP&PAPER	16149.555	7.7	1.5	250.	8.28	6.8	0.322	0.059	0.002
8 PE0152 PG PULP&PAPER	16247.758	7.7	1.7	259.	9.85	7.3	0.325	0.058	0.002
9 PE1763 BCG PUB WORKS	16247.867	7.7	1.7	259.	9.85	7.3	0.325	0.058	0.002
10 NECHAKO RIVER	25435.363	7.6	1.3	201.	7.02	5.0	0.229	0.041	0.002
11 PE1901 FRASER-FT.GEO	25435.590	7.6	1.3	201.	7.02	5.0	0.229	0.041	0.002
12 PE0095 SCHOOL DIST57	25435.664	7.6	1.3	201.	7.02	5.0	0.229	0.041	0.002
13 PE2017 RANCH HOTEL	25435.684	7.6	1.3	201.	7.02	5.0	0.229	0.041	0.002
14 PE0354 P.G. COLLEGE	25435.977	7.6	1.3	201.	7.02	5.0	0.229	0.041	0.002
15 PE0146 P.G. CITY	25452.344	7.6	1.3	202.	7.06	5.1	0.229	0.041	0.002
16 PE3868 P.G. AIRPORT	25452.523	7.6	1.3	202.	7.07	5.1	0.229	0.041	0.002
17 PE0319 FRECHETTE	25452.531	7.6	1.3	202.	7.07	5.1	0.229	0.041	0.002
18 TABOR CREEK (PCB)	25478.746	7.6	1.3	201.	7.06	5.1	0.231	0.041	0.002
19 CALE CREEK	25509.859	7.6	1.3	201.	7.05	5.1	0.231	0.041	0.002
OBSERVED END VALUE									
FRASER AT RED ROCK	26785.848	7.7	0.5	189.	5.90	9.0	0.070	0.020	0.002
DIFFERENCE (OBS-CALC)*	1275.988	0.1	-0.8	-12.	-1.15	3.9	-0.161	-0.021	0.000

* A NEGATIVE VALUE INDICATES DEPOSITION OR LOSS & A POSITIVE INDICATES UNACCOUNTED INPUT

and almost as great as the change induced by accounted inputs alone. This indicates that unaccounted dilution has as great an influence on the water quality of this segment as do accounted inputs for this conservative parameter. Similar trends are apparent for temperature, dissolved sodium, and total iron and manganese however, for parameters which are not conservative it is not clear whether concentration reduction is due to dilution or deposition. Non-filterable residue exhibits a larger observed end value than that observed initially or predicted. This indicates introduction of suspended material either from scouring or unaccounted inflows. Total copper concentrations in the Fraser River are close to detection levels and lack sufficient significant figures for the detection of change.

To assist in the interpretation of the behavior of those parameters which may be expressed as loads, a load summary table is also produced at the end of each segment as shown in Table 11 for the same segment and time as Table 10. Predicted end loads are calculated by adding the input of each influence to that observed initially. The difference between the observed and calculated end loads is more meaningful here than that of the concentration table because loads are strictly additive and dilution plays no part. The mechanisms operating may be particulate suspension or settling and unaccounted input. In the case of a negative difference unaccounted input may be present as well as those loads tallied however, the difference indicates that at least that amount was lost to sediments over the segment. Similarily, in the case of a positive difference deposition may have occurred and the amount shown is a minimum measure of input from unaccounted sources and bottom scouring.

TABLE 11 - Example of Segment Level Load Summary Output

SEGMENT 4 - LOAD SUMMARY FOR FEBRUARY 1976

	FLOW X1000M3/D	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
INITIAL FLOW & LOAD						
FRASER AT SHELLEY	16121.	33.9	90.3	5.00	0.97	0.032
INPUT LOADS						
1 WL259630 NORTHWOOD	-343.000	-0.720	-1.921	-0.106	-0.021	-0.001
2 PE0112 NORTHWOOD	0.030	0.002	0.001	0.000	0.000	0.000
3 PE0157 NORTHWOOD	92.967	27.332	9.576	0.078	0.0	0.0
4 PE0190 INTERCON.	0.907	0.069	0.907	0.0	0.0	0.000
5 PE0228 INTERCON. KPM	80.528	21.018	3.269	0.068	0.0	0.0
6 PE3900 INTER & PGP&P	197.065	52.222	7.035	0.166	0.0	0.0
7 PE0076 PG PULP&PAPER	0.073	0.006	0.001	0.000	0.000	0.000
8 PE0152 PG PULP&PAPER	98.205	26.319	8.907	0.082	0.0	0.0
9 PE1763 BCG PUB WORKS	0.113	0.009	0.001	0.000	0.000	0.000
10 NECHAKO RIVER	9187.496	18.375	9.187	0.533	0.092	0.009
11 PE1901 FRASER-FT.GEO	0.227	0.018	0.014	0.001	0.000	0.000
12 PE0955 SCHOOL DIST57	0.077	0.006	0.008	0.000	0.000	0.000
13 PE2017 RANCH HOTEL	0.020	0.002	0.001	0.000	0.000	0.000
14 PE0354 P.G. COLLEGE	0.295	0.023	0.009	0.000	0.000	0.000
15 PE0146 P.G. CITY	16.368	1.277	1.555	0.013	0.001	0.001
16 PE3868 P.G. AIRPORT	0.182	0.014	0.001	0.000	0.000	0.000
17 PE0319 FRECHETTE	0.008	0.001	0.000	0.000	0.000	0.000
18 TABOR CREEK (PCB)	26.215	0.0	0.682	0.047	0.0	0.000
19 CALE CREEK	31.115	0.0	0.0	0.0	0.0	0.0
PREDICTED END VALUE	25510.	179.8	129.5	5.88	1.04	0.042
OBSERVED END VALUE						
FRASER AT RED ROCK	26786.	158.0	241.1	1.88	0.54	0.054
DIFFERENCE (OBS-CALC)*	1276.	-21.8	111.6	-4.01	-0.50	0.011
MEAN AVAILABLE CAPACITY+ (AV.CALC.CAP - LOAD DIFF)	-----	5618.4	302.1	4.87	0.57	21.218

* A NEGATIVE VALUE INDICATES DEPOSITION OR LOSS & A POSITIVE INDICATES UNACCOUNTED INPUT
\+ A NEGATIVE VALUE INDICATES LOAD IN EXCESS OF CRITERIA

A further use of the load summary materials balance is illustrated by the behavior of dissolved sodium in Table 11. The calculated negative load difference indicates that dissolved sodium was lost to to sediments and/or total form over the segment. Monovalent sodium can exchange with bivalent calcium and magnesium on particulates. However, I believe this mechanism cannot account for a loss of 21.8 metric tons per day. Even if the total theoretical assumed inputs from municipal discharges (1.36 metric tons per day) are removed this still leaves more than 20 tons/day lost over the segment. The magnitude of this loss for a parameter which is often assumed to be conservative leads to the conclusion that the data used were not representative of mean monthly character. With an accurate data base it would thus be possible to identify errors which arise from incorrect flow measurement or unrepresentative sampling locations.

The final entry in Table 11 is the mean available capacity for the segment. This figure is calculated from the average of the site specific capacities referred to earlier minus the difference between the observed and predicted end load. The difference is subtracted to account for the minimum load lost to sediments or added from unaccounted inputs over the segment. The resulting figure is an estimate only and is provided to establish some basis for inter-segment comparisons. For example, it may be possible to discharge more than 4,870 kilograms of total iron per day to the segment in addition to existing inputs without exceeding beneficial use criteria however, the figure allows the capacity of this segment to be compared to another in a decision of new discharge location. As the capacity varies over the segment, the site specific capacity should be examined for a more detailed location decision.

Output of System Summary

The system summary has five aspects, each of which has a different purpose as discussed below.

(i) Concentration Summary

At the end of each month's data all calculated segment concentration differences are summarized as shown in Table 12. Output for all three months are included for comparison. While no more than three significant figures are appropriate, the output format was fixed to ensure that no significant figures would be lost due to the large variation in load and flow over the length of the system.

Flow differences are included in Table 12. These differences indicate the average amount of water which flows unmeasured each day into the segment during the month considered, as shown in Figure 7. These unmeasured flows include surface runoff, groundwater inflow and the contributions of minor tributaries. In addition, Segments 1 and 2 include the flow of five major tributaries; the Robson, McLennan, Raush, Morkill, and Torpy Rivers. These and other tributaries have no flow data and are quickly identified by reference to Table 2. It appears that these major unmeasured rivers exert a strong influence on flow during the month of July but are less significant during February and April. In other segments all major tributaries have been incorporated in the data base. Flow differences for Segments 3 to 10 therefore display the magnitude of the many minor inputs which are difficult to quantify individually. For example, approximately 30 million cubic meters entered Segment 5 each day from these sources during July of 1976. This unaccounted flow is about three times the accounted flow input and is 10.8% of the flow observed leaving the segment. Figure 7 may therefore

TABLE 12 - System Concentration Difference Summary for Three Months of 1976.

RIVER SYSTEM SUMMARY - FEBRUARY 1976

1. CONCENTRATION DIFFERENCES (OBS-CALC)

	FLOW X1000M3/D	PH UNITS	TEMP(C)	SP COND UMHOS/CM	DISS NA MG/L	NF RES. MG/L	TOT FE MG/L	TOT MN MG/L	TOT CU MG/L
SEGMENT 1	2168.	-0.16	-0.16	-39.8	0.37	-1.4	0.216	0.050	-0.001
SEGMENT 2	2354.	0.30	-0.15	62.4	0.32	-0.4	-0.172	-0.042	0.002
SEGMENT 3	3746.	-0.15	0.65	10.6	0.24	2.4	0.117	0.046	-0.001
SEGMENT 4	1276.	0.13	-0.77	-12.2	-1.15	3.9	-0.161	-0.021	0.000
SEGMENT 5	4149.	0.10	-0.54	-29.1	-3.32	28.1	0.079	0.001	-0.001
SEGMENT 6	1602.	0.09	0.42	8.7	2.66	27.1	-0.055	0.000	0.005
SEGMENT 7	2949.	0.10	-0.00	-8.2	-1.78	0.2	0.045	-0.010	-0.003
SEGMENT 8	8548.	-0.10	-0.57	8.5	0.48	-46.1	-0.011	0.001	-0.002
SEGMENT 9	2845.	-0.09	1.91	-20.3	-0.34	103.3	0.030	0.000	0.000
SEGMENT 10	5561.	0.00	-0.33	-12.5	-0.46	-79.7	-0.096	0.000	-0.000

RIVER SYSTEM SUMMARY - APRIL 1976

1. CONCENTRATION DIFFERENCES (OBS-CALC)

	FLOW X1000M3/D	PH UNITS	TEMP(C)	SP COND UMHOS/CM	DISS NA MG/L	NF RES. MG/L	TOT FE MG/L	TOT MN MG/L	TOT CU MG/L
SEGMENT 1	4288.	0.17	0.25	17.7	0.29	12.9	0.291	0.020	0.001
SEGMENT 2	463.	0.19	-2.58	-19.1	0.01	43.5	0.273	0.020	0.004
SEGMENT 3	906.	0.18	3.03	6.7	-0.05	-5.9	-0.091	-0.035	-0.002
SEGMENT 4	9104.	0.39	7.02	-14.9	-2.59	107.0	-0.684	-0.061	-0.001
SEGMENT 5	25716.	-0.12	-7.80	-7.0	0.15	411.3	3.587	0.217	0.017
SEGMENT 6	11482.	0.08	1.74	4.2	0.41	73.8	0.208	0.150	0.010
SEGMENT 7	1826.	-0.00	0.45	4.1	0.11	0.8	3.327	0.283	0.000
SEGMENT 8	5292.	0.00	1.93	13.1	0.70	316.3	-1.968	-0.168	0.001
SEGMENT 9	1764.	0.11	0.95	-0.4	0.05	-190.9	-0.060	-0.046	0.001
SEGMENT 10	3439.	-0.17	-0.15	-3.8	0.12	-15.5	-0.364	-0.047	-0.005

RIVER SYSTEM SUMMARY - JULY 1976

1. CONCENTRATION DIFFERENCES (OBS-CALC)

	FLOW X1000M3/D	PH UNITS	TEMP(C)	SP COND UMHOS/CM	DISS NA MG/L	NF RES. MG/L	TOT FE MG/L	TOT MN MG/L	TOT CU MG/L
SEGMENT 1	38024.	0.13	0.00	-8.2	-0.12	62.6	0.209	0.020	-0.000
SEGMENT 2	35768.	0.05	0.90	7.0	0.09	6.7	0.121	0.009	0.000
SEGMENT 3	11584.	-0.11	2.72	3.0	-0.12	19.8	1.925	0.039	-0.001
SEGMENT 4	7730.	0.26	0.34	-0.3	-0.35	7.3	1.178	0.003	-0.000
SEGMENT 5	25162.	-0.13	-3.14	-9.4	-0.02	43.0	-2.733	-0.006	0.004
SEGMENT 6	9705.	-0.02	-0.00	1.9	0.16	9.0	0.121	0.007	-0.000
SEGMENT 7	6508.	0.20	-0.01	0.5	-0.03	50.4	0.016	0.010	0.001
SEGMENT 8	18878.	0.10	-0.24	0.2	0.24	7.2	-0.091	-0.008	-0.002
SEGMENT 9	5609.	0.01	0.02	-1.0	-0.09	-11.2	0.007	0.001	0.001
SEGMENT 10	12262.	0.04	-0.04	-2.0	0.12	-4.2	0.159	0.033	0.001

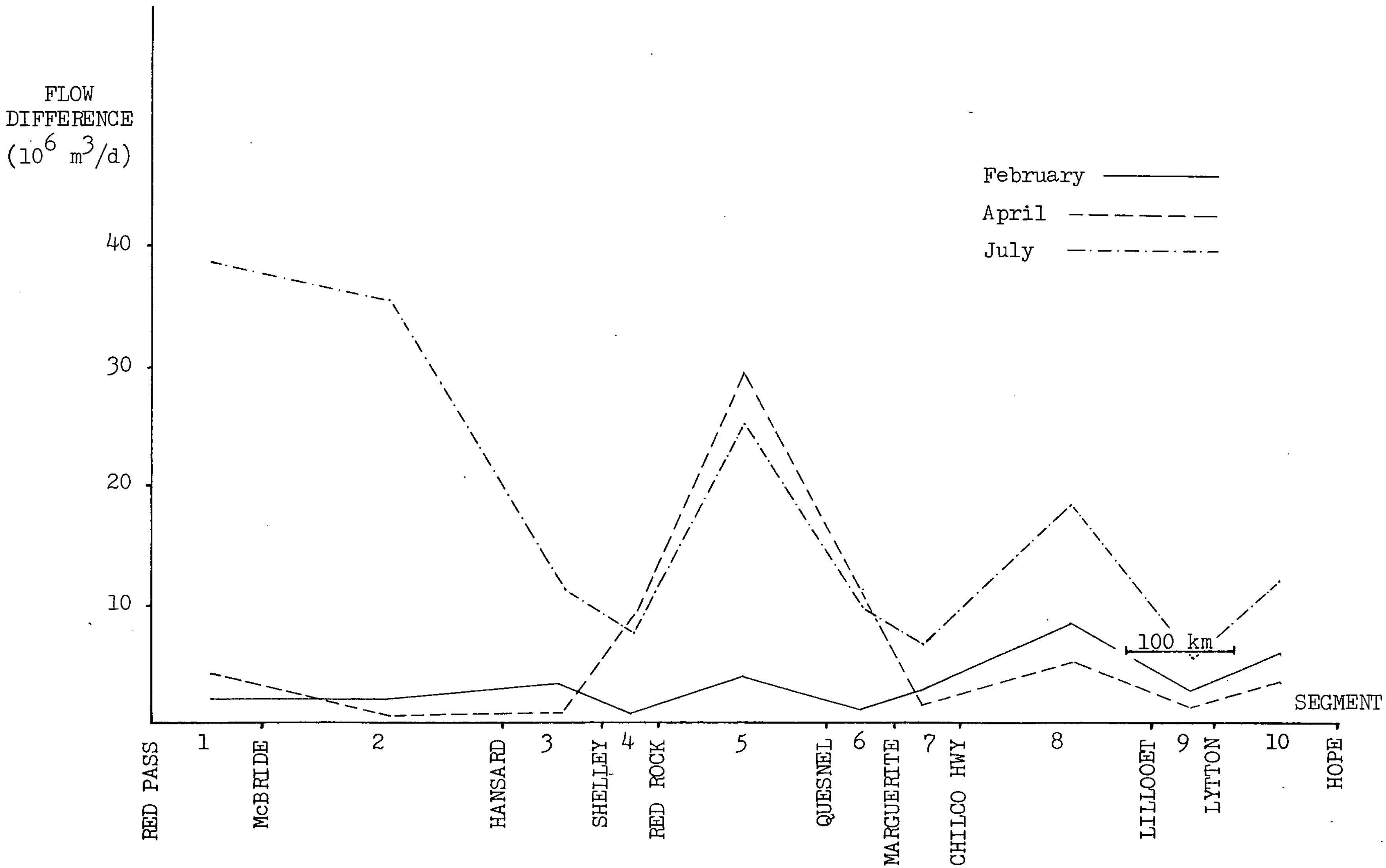


FIGURE 7 - FRASER MAIN STEM UNACCOUNTED FLOW INPUTS

be used to determine where new flow measurement is required to increase knowledge of the inputs which make up the system and thereby reduce the uncertainty that these peaks represent. As more data are generated the flow differences will diminish.

The remaining concentration differences of Table 12 indicate regional concentration changes which result from unaccounted dilution and/or loss or input of unaccounted materials. For example, temperature differences reflect unaccounted energy gain or loss depending on sign. A negative difference indicates heat lost to the atmosphere and a positive indicates heat gained. More detailed interpretation of these differences is made complicated by the magnitude of unaccounted input flows and the number of unknown mechanisms operating. Overall there appears to be no consistent pattern over distance and time with the exception of total iron and manganese. These two parameters behave similarily in magnitude and sign over time and will be discussed in more detail under the next output type.

It is interesting to note that the dilution model predicts the behaviour of specific conductance more closely during the summer than the winter even though unaccounted flow input, and presumably the dilution errors it should create, is much greater in the summer. This indicates that unaccounted input flow in winter, though much smaller in magnitude than in the summer, must either have a larger proportionate effect or is of a higher concentration. A clear delineation of influence effect is not possible from this output.

As previously discussed, total copper data lacked sufficient significant figures to allow detection of meaningful change.

(ii) Load Difference Summary

The load differences calculated in the segment summaries are also collated in the system summary as shown in Table 13. As mentioned in the segment summary discussion, dilution does not affect the sign of the load difference values. The values therefore represent the net weight of material either added through runoff and/or scouring or lost due to settling within each segment.

Dissolved sodium appears to be lost to sediments in some segments during each month examined. Again, this indicates that the data were not representative of mean monthly character because the parameter is close to conservative in behavior.

Total iron and manganese load differences display addition and loss in the same segments within each month with the exception of Segments 6 and 7 for February. This similarity of behavior for two parameters which are usually introduced to streams simultaneously by nature and can undergo similar reaction suggests that the data are consistent, if not spatially and temporally representative. It therefore seems peculiar that non-filterable residue values do not exhibit a similar addition and loss pattern over distance. Unaccounted suspended solids appear to be added to the water in all segments except those furthest downstream, primarily below Lillooet, where significant deposition occurs in both April and July. This apparent anomaly might be due to a different particle size associated with the particulate metals than with suspended solids generally. If the metals were associated with larger particles they would be prone to faster settling according to Stokes Law.

Copper values are erratic due to reasons discussed earlier.

TABLE 13 - System Load Difference Summary for Three Months of 1976.

LOAD DIFFERENCES* FOR FEBRUARY 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	3.994	8.4	1.04	0.171	0.002
SEGMENT 2	5.974	5.6	-0.51	-0.205	0.018
SEGMENT 3	10.855	50.9	2.61	0.798	-0.006
SEGMENT 4	-21.788	111.6	-4.01	-0.504	0.011
SEGMENT 5	-81.056	963.2	2.95	0.104	-0.028
SEGMENT 6	112.725	1152.8	-1.99	0.032	0.204
SEGMENT 7	-60.225	190.0	2.31	-0.375	-0.115
SEGMENT 8	60.630	-2097.9	0.74	0.113	-0.097
SEGMENT 9	-7.940	6260.9	2.25	0.029	0.003
SEGMENT 10	-19.848	-6667.6	-7.76	0.068	0.004

LOAD DIFFERENCES* FOR APRIL 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	7.198	136.9	2.49	0.152	0.010
SEGMENT 2	0.705	609.2	3.94	0.288	0.059
SEGMENT 3	-0.284	-148.2	-2.32	-1.064	-0.067
SEGMENT 4	-151.546	8473.6	-41.13	-3.585	-0.042
SEGMENT 5	72.329	52140.3	423.31	26.180	2.058
SEGMENT 6	80.343	16657.9	72.58	23.772	1.628
SEGMENT 7	20.162	1245.6	481.17	40.994	0.078
SEGMENT 8	123.250	52084.1	-267.56	-22.618	0.334
SEGMENT 9	13.306	-29163.8	-1.15	-6.652	0.184
SEGMENT 10	36.211	-1111.4	-58.99	-8.091	-0.882

LOAD DIFFERENCES* FOR JULY 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	16.655	3748.0	20.34	1.337	0.147
SEGMENT 2	28.562	2886.8	28.12	1.799	0.162
SEGMENT 3	-15.519	4328.7	365.94	7.568	-0.090
SEGMENT 4	-72.575	2266.5	302.30	1.127	-0.074
SEGMENT 5	28.281	13721.5	-675.86	-0.236	1.190
SEGMENT 6	66.671	4336.9	48.64	3.059	-0.057
SEGMENT 7	-1.542	18865.6	10.66	3.985	0.402
SEGMENT 8	128.309	6124.1	-25.45	-2.061	-0.652
SEGMENT 9	-29.624	-3959.4	6.46	0.620	0.503
SEGMENT 10	100.934	-1482.4	111.55	22.378	0.775

* A NEGATIVE VALUE INDICATES DEPOSITION OR LOSS & A POSITIVE INDICATES UNACCOUNTED INPUT

(iii) Normalized Load Difference Summary

In examining the load differences of Table 13 it is difficult to compare the magnitude of the observed addition or loss between segments because each segment is of a different length. To assist inter-segment comparison each load difference was divided by its respective segment length to arrive at normalized load differences as shown in Table 14.

The normalized values are useful in displaying the behavior of the system graphically as shown in Figure 8 for total iron. It appears that very little unaccounted iron addition or loss occurred within any segment in February. Load differences are small indicating that the total loads carried may be described by accounted inputs alone. In April though, unaccounted load inputs are evident in Segments 5,6 and 7 with settling in Segment 8. In July, inputs occurred in Segments 3 and 4 followed by settling in Segment 5. This suspension/loss curve shift behavior parallels the northern movement of freshet from spring to summer and one might speculate that freshet flows exert a localized scouring effect followed by deposition a relatively short distance downstream. Total manganese values display a similar though more erratic behavior.

TABLE 14 - Normalized Load Difference Summaries

NORMALIZED LOAD DIFFERENCES* (PER KILOMETER) FOR FEBRUARY 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	0.026	0.1	0.02	0.001	0.000
SEGMENT 2	0.039	0.1	-0.01	-0.001	0.000
SEGMENT 3	0.071	0.9	0.04	0.005	-0.000
SEGMENT 4	-0.142	1.9	-0.07	-0.003	0.000
SEGMENT 5	-0.530	16.3	0.05	0.001	-0.000
SEGMENT 6	0.737	19.5	-0.03	0.000	0.004
SEGMENT 7	-0.394	3.2	0.04	-0.002	-0.002
SEGMENT 8	0.396	-35.6	0.01	0.001	-0.002
SEGMENT 9	-0.052	106.1	0.04	0.000	0.000
SEGMENT 10	-0.130	-113.0	-0.13	0.000	0.000

NORMALIZED LOAD DIFFERENCES* (PER KILOMETER) FOR APRIL 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	0.047	2.3	0.04	0.001	0.000
SEGMENT 2	0.005	10.3	0.07	0.002	0.001
SEGMENT 3	-0.002	-2.5	-0.04	-0.006	-0.001
SEGMENT 4	-0.990	143.6	-0.69	-0.021	-0.001
SEGMENT 5	0.473	883.7	7.06	0.150	0.035
SEGMENT 6	0.525	282.3	1.21	0.137	0.028
SEGMENT 7	0.132	21.1	8.02	0.236	0.001
SEGMENT 8	0.806	882.8	-4.46	-0.130	0.006
SEGMENT 9	0.087	-494.3	-0.02	-0.038	0.003
SEGMENT 10	0.237	-18.8	-0.98	-0.047	-0.015

NORMALIZED LOAD DIFFERENCES* (PER KILOMETER) FOR JULY 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	0.109	63.5	0.34	0.008	0.003
SEGMENT 2	0.187	48.9	0.47	0.010	0.003
SEGMENT 3	-0.101	73.4	6.10	0.043	-0.002
SEGMENT 4	-0.474	38.4	5.04	0.006	-0.001
SEGMENT 5	0.185	232.6	-11.26	-0.001	0.021
SEGMENT 6	0.436	73.5	0.81	0.018	-0.001
SEGMENT 7	-0.010	319.8	0.18	0.023	0.007
SEGMENT 8	0.839	103.8	-0.42	-0.012	-0.011
SEGMENT 9	-0.194	-67.1	0.11	0.004	0.009
SEGMENT 10	0.660	-25.1	1.86	0.129	0.013

* A NEGATIVE VALUE INDICATES DEPOSITION OR LOSS & A POSITIVE INDICATES UNACCOUNTED INPUT

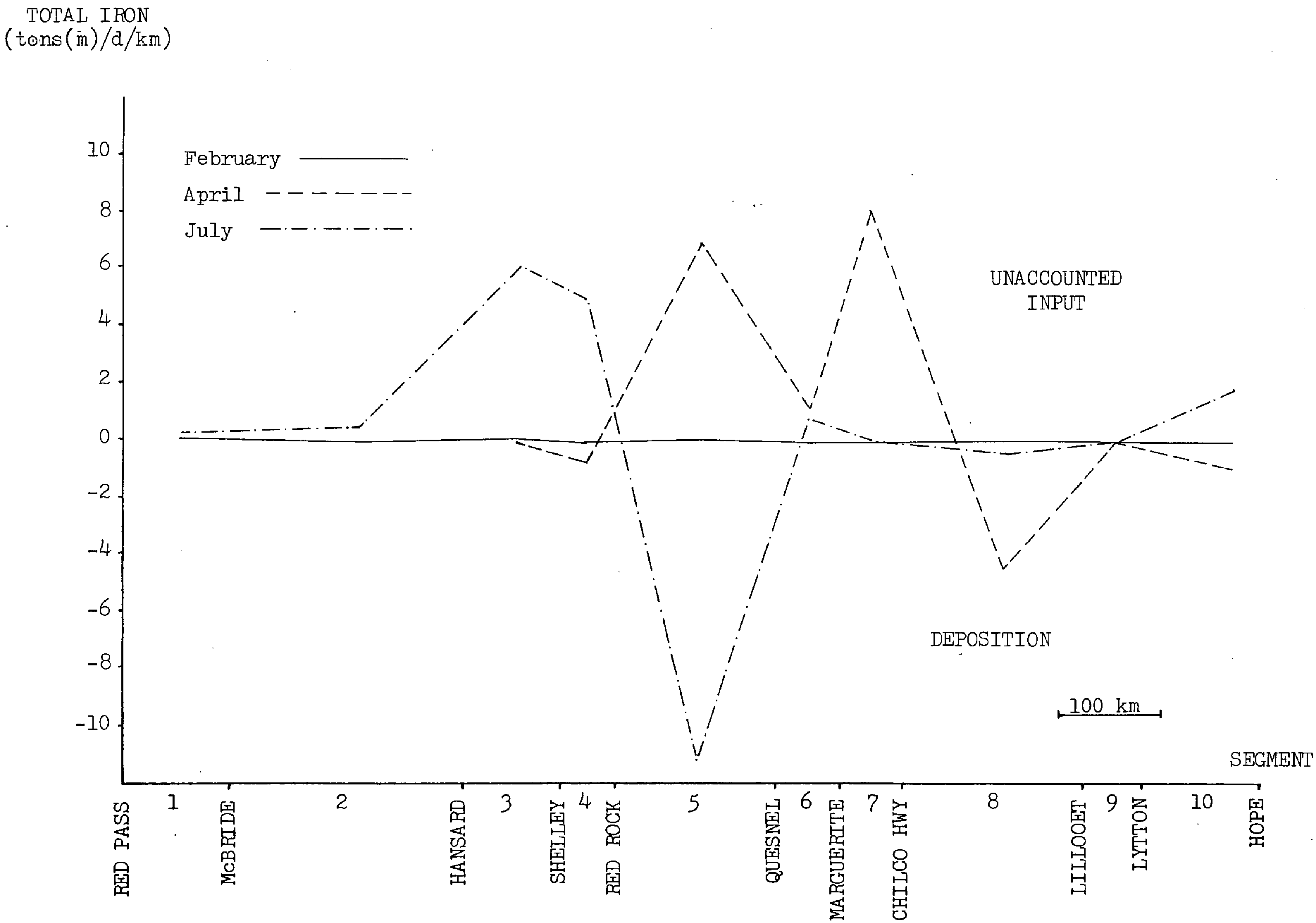


FIGURE 8 - NORMALIZED TOTAL IRON LOAD DIFFERENCES SHOWING NET UNACCOUNTED INPUT OR DEPOSITION WITHIN EACH SEGMENT

(iv) Mean Available Capacity Summary

In addition to concentration and load differences, the mean available capacities calculated for each segment are also summarized for the system as shown in Table 15. These values are based on the concentration criteria shown in Table 6 and may be changed to reflect any input criteria set. A negative capacity value indicates load in excess of criteria.

Available capacity, as used here, refers to the dilution capacity available as calculated from the difference between existing and criteria concentrations. It should not be interpreted to mean that no impact would result from, for example, the location of a new discharge of 81 metric tons of copper per day somewhere in Segment 10. While such a discharge might not cause criteria to be exceeded fifty kilometers downstream, it would certainly cause site specific problems which this framework does not attempt to explore. Instead, the capacity values should be interpreted as indicating that, in February of 1976, Segment 10 had four times the dilution capacity for a copper discharge than Segment 4. This allows inter-segment comparisons to be made.

Use of this output type is illustrated for total manganese in Figure 9. By graphing the capacities over time and distance it is clear that, even though some dilution capacity existed for downstream segments in February, loads are predominantly in excess of criteria. Further, it shows that a significant change occurred in April between Segments 4 and 5. Examination of the manganese load differences of Table 13 shows that this change is due to large unaccounted input in Segment 5. This illustrates that the typical calculation of allowable discharge loads based on a condition of minimum flow is not valid for

TABLE 15 - System Mean Available Capacity Summary for Three Months of 1976.

MEAN AVAILABLE CAPACITIES* FOR FEBRUARY 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	216.495	7.4	-0.95	-0.138	0.818
SEGMENT 2	996.373	72.4	0.31	0.192	3.713
SEGMENT 3	2821.355	179.7	-1.26	-0.383	10.533
SEGMENT 4	5618.367	302.1	4.87	0.569	21.218
SEGMENT 5	7519.477	-507.1	3.34	0.760	28.173
SEGMENT 6	10242.695	-1536.2	7.60	1.132	38.562
SEGMENT 7	10757.457	-1683.1	5.35	1.590	40.369
SEGMENT 8	12314.125	553.6	5.56	1.774	46.445
SEGMENT 9	15169.527	-5446.7	6.33	2.254	57.014
SEGMENT 10	21791.223	1777.9	20.37	3.213	81.705

MEAN AVAILABLE CAPACITIES* FOR APRIL 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	308.751	-125.8	-2.38	-0.105	1.165
SEGMENT 2	2178.690	-621.2	-4.81	-0.075	8.040
SEGMENT 3	5987.504	-460.9	-3.47	1.251	22.258
SEGMENT 4	13120.465	-10614.2	16.24	2.545	48.639
SEGMENT 5	21666.793	-64176.3	-429.52	-25.415	78.737
SEGMENT 6	34253.063	-84399.8	-520.16	-49.453	123.915
SEGMENT 7	37523.961	-85336.3	-997.74	-89.844	136.103
SEGMENT 8	39196.543	-137498.8	-729.16	-66.896	142.434
SEGMENT 9	42165.395	-108084.4	-725.16	-59.691	153.360
SEGMENT 10	51304.598	-106335.4	-659.64	-50.189	188.609

MEAN AVAILABLE CAPACITIES* FOR JULY 1976

	DISS NA TONS(M)/D	NF RESIDUE TONS(M)/D	TOT FE TONS(M)/D	TOT MN TONS(M)/D	TOT CU TONS(M)/D
SEGMENT 1	5117.891	-3359.6	-18.83	-0.474	18.833
SEGMENT 2	17758.414	-5533.3	-35.55	0.008	65.586
SEGMENT 3	42124.547	-9932.8	-454.47	-4.027	155.784
SEGMENT 4	56665.410	-11932.0	-770.84	-3.012	209.949
SEGMENT 5	67072.563	-25124.3	-89.57	-1.322	247.728
SEGMENT 6	91440.438	-37030.8	-169.36	-3.994	338.034
SEGMENT 7	94176.125	-55646.3	-177.02	-7.476	347.786
SEGMENT 8	104423.500	-61880.7	-144.38	-3.999	386.646
SEGMENT 9	115169.313	-57100.3	-144.82	-2.649	425.911
SEGMENT 10	172843.875	-52436.4	-227.37	-14.272	639.443

* BASED ON INPUT CRITERIA

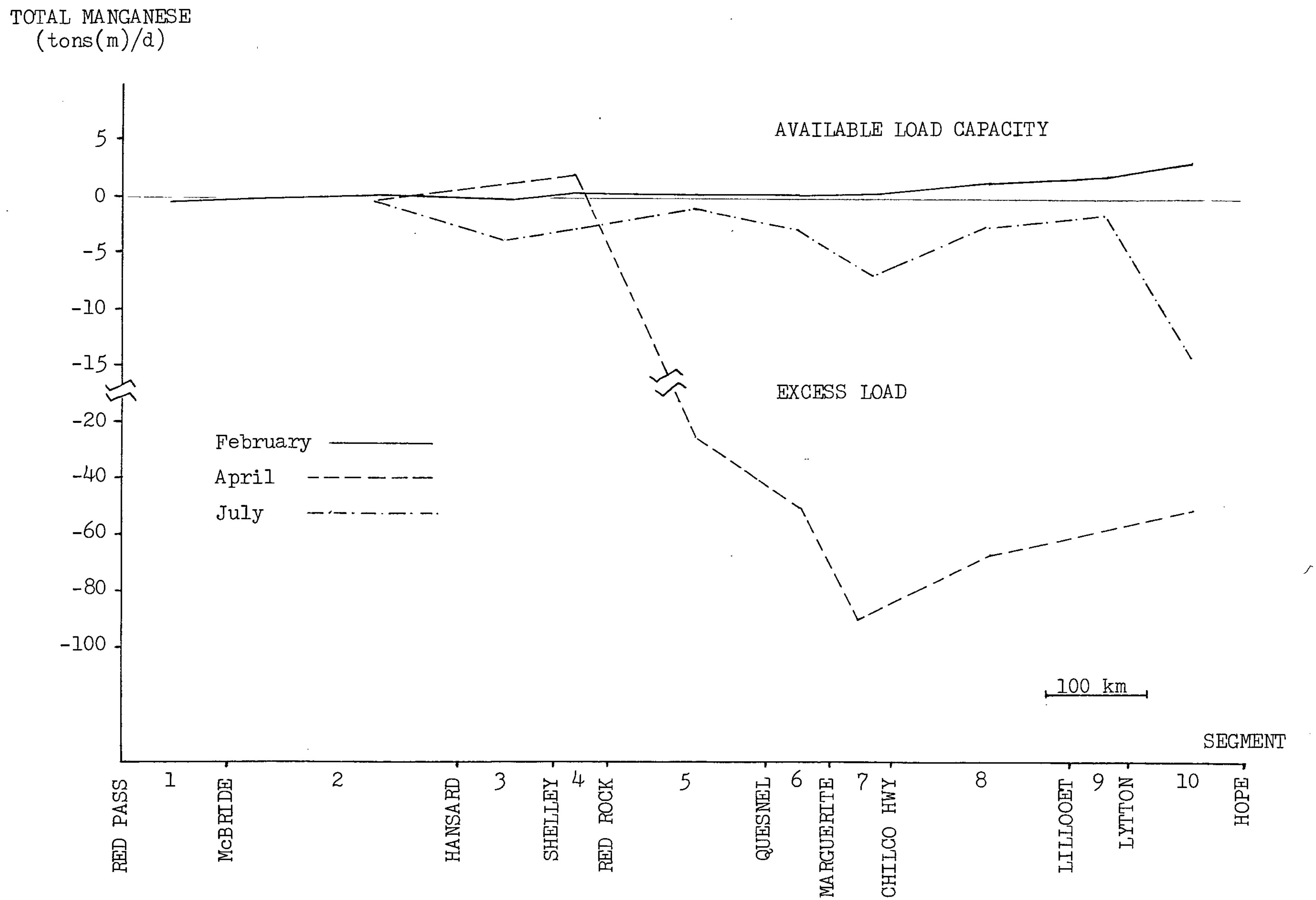


FIGURE 9 - TOTAL MANGANESE MEAN AVAILABLE LOAD CAPACITIES BY FRASER RIVER MAIN STEM SEGMENTS FOR THREE MONTHS IN 1976.

this parameter. The system is most severely stressed in April due to natural processes. Similarily, of those months considered, April is the critical flow condition for total iron and suspended solids.

(v) System Calibration Values

The final output of the system summary is a table of calibration values as shown in Table 16. These values are the flow and associated parameter concentrations which would bring the calculated predicted end values within each segment to the observed levels. They thus represent the average flow and concentration of all unaccounted inputs and losses and may be used to calibrate or 'zero' unaccounted processes.

The calibration values are used in the system prediction process and are discussed in the next section. However, they reveal further insight into the function of the system. For example, from the concentration summary it was impossible to tell what was causing the observed prediction discrepancies because concentration differences were expressed in terms of main stem changes. Table 16 characterizes the unknown inputs and processes, allows further calculations to be performed and facilitates error detection. For example, temperature and flow values could be used to calculate ergs gained or lost within each segment. These values might then be related to more detailed atmospheric and stream flow conditions. As a conservative parameter, specific conductance should not be negative. A negative value in Table 16 therefore indicates either data which were not representative of mean monthly character or deviations from conservative behavior.

TABLE 16 - System Calibration Values Showing the Net Flow and Concentration of Unaccounted Influences

5. SYSTEM CALIBRATION VALUES FOR FEBRUARY 1976

	FLOW X1000M3/D	PH UNITS	TEMP(C)	SP COND UMHOS/CM	DISS NA MG/L	NF RES. MG/L	TOT FE MG/L	TOT MN MG/L	TOT CU MG/L
SEGMENT 1	2168.	7.75	0.44	98.9	1.84	3.9	0.482	0.079	0.001
SEGMENT 2	2354.	8.08	0.17	347.5	2.54	2.4	-0.215	-0.087	0.008
SEGMENT 3	3746.	7.51	3.16	251.1	2.90	13.6	0.697	0.213	-0.002
SEGMENT 4	1276.	6.95	-14.82	-54.0	-17.08	87.4	-3.139	-0.395	0.009
SEGMENT 5	4149.	7.86	-3.78	-36.6	-19.54	232.1	0.710	0.025	-0.007
SEGMENT 6	1602.	7.26	10.78	379.8	70.35	719.5	-1.243	0.020	0.127
SEGMENT 7	2949.	7.60	0.48	50.0	-20.42	64.4	0.783	-0.127	-0.039
SEGMENT 8	8548.	7.57	-3.16	223.3	7.09	-245.4	0.087	0.013	-0.011
SEGMENT 9	2845.	7.11	40.66	-255.1	-2.79	2200.7	0.791	0.010	0.001
SEGMENT 10	5561.	7.87	-2.96	-59.2	-3.57	-1199.1	-1.395	0.012	0.001

5. SYSTEM CALIBRATION VALUES FOR APRIL 1976

	FLOW X1000M3/D	PH UNITS	TEMP(C)	SP COND UMHOS/CM	DISS NA MG/L	NF RES. MG/L	TOT FE MG/L	TOT MN MG/L	TOT CU MG/L
SEGMENT 1	4288.	8.06	5.07	180.9	1.68	31.9	0.580	0.035	0.002
SEGMENT 2	463.	6.75	-73.29	-412.1	1.52	1314.4	8.492	0.621	0.128
SEGMENT 3	906.	6.49	107.27	374.2	-0.31	-163.5	-2.557	-1.174	-0.074
SEGMENT 4	9104.	6.93	58.01	12.8	-16.65	930.7	-4.518	-0.394	-0.005
SEGMENT 5	29716.	7.37	-21.79	98.1	2.43	1754.7	14.245	0.881	0.069
SEGMENT 6	11482.	7.57	21.89	172.5	7.00	1450.8	6.321	2.070	0.142
SEGMENT 7	1826.	7.54	37.60	452.1	11.04	682.2	263.536	22.452	0.043
SEGMENT 8	5292.	7.77	59.39	519.3	23.29	9841.8	-50.557	-4.274	0.063
SEGMENT 9	1764.	6.41	91.70	108.9	7.54	-16528.6	-0.651	-3.770	0.104
SEGMENT 10	3439.	6.30	-2.32	-77.6	10.53	-323.2	-17.153	-2.353	-0.257

5. SYSTEM CALIBRATION VALUES FOR JULY 1976

	FLOW X1000M3/D	PH UNITS	TEMP(C)	SP COND UMHOS/CM	DISS NA MG/L	NF RES. MG/L	TOT FE MG/L	TOT MN MG/L	TOT CU MG/L
SEGMENT 1	38024.	8.08	10.00	100.9	0.44	98.6	0.535	0.035	0.004
SEGMENT 2	35768.	8.12	12.01	127.7	0.80	80.7	0.786	0.050	0.005
SEGMENT 3	11584.	7.17	53.93	164.5	-1.34	373.9	31.594	0.653	-0.008
SEGMENT 4	7730.	6.63	23.23	107.8	-9.39	293.2	39.105	0.146	-0.010
SEGMENT 5	25162.	7.24	-21.50	12.9	1.12	545.3	-26.860	-0.009	0.047
SEGMENT 6	9705.	7.43	9.89	177.5	6.87	446.9	5.012	0.315	-0.006
SEGMENT 7	6508.	6.52	9.51	138.5	-0.24	2898.7	1.638	0.612	0.062
SEGMENT 8	18878.	7.36	4.80	116.6	6.80	324.5	-1.348	-0.109	-0.035
SEGMENT 9	5609.	8.18	11.22	33.1	-5.28	-706.0	1.152	0.111	0.090
SEGMENT 10	12262.	7.34	7.65	-12.8	8.23	-120.9	9.098	1.825	0.063

Prediction Output

Two operations were performed to give the MATBAL program predictive ability. First, the data base was calibrated by inserting the system calibration values of Table 16 at the end of the appropriate segments. MATBAL was then run on the calibrated data base to ensure that all resulting concentration and load differences were zero. Second, the data base was prepared for imposition of artificial change by removing all segment boundary stations except the initialization station at Red Pass and final station at Hope. The data base thus became one segment incorporating all former influences as well as calibration inputs at locations corresponding to former segment boundaries.

The above operations structure the data so that MATBAL's segment level dilution calculation and summary process can operate for the complete system with output provided at segment station locations. Influences could then be changed or inserted at will and MATBAL would carry the water quality effect through the system based on dilution.

To illustrate prediction output, the February data base of Table 6 was calibrated with the appropriate values from Table 16. After a calibration check, four changes were made in the data base which are likely consequences of future development:

1. A new pulp mill was inserted downstream from Hansard with waste flow and quality characteristics equal to the average of existing mills.
2. The flow of the McGregor River was reduced from 1129 to 500 cfs to simulate the effect of a dam.
3. The flow of the Nechako River was reduced to one half the original value to simulate the effect of a dam.
4. The waste flow from the Prince George sewage treatment plant was doubled while retaining the same quality characteristics.

The results of these changes are shown in Table 17 for select parameters.

TABLE 17 - FRASER MAIN STEM QUALITY BEFORE AND AFTER NEW DEVELOPMENT

QUALITY STATION	TEMPERATURE (C)		SPECIFIC CONDUCTANCE umhos/cm		DISSOLVED SODIUM mg/l		TOTAL IRON mg/l	
	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.
Red Pass	0.5	0.5	142	142	0.8	0.8	0.029	0.029
McBride	0.5	0.5	114	114	1.7	1.7	0.40	0.40
Hansard	0.5	0.5	204	204	1.8	1.8	0.18	0.18
* new pulp mill * reduce McGregor								
Shelley	1.0	1.3	216	225	2.1	4.3	0.31	0.34
* reduce Nechako * double domestic waste								
Red Rock	0.5	0.7	189	214	5.9	8.6	0.070	0.077
Quesnel	0.	0.	165	179	3.5	5.1	0.160	0.185
Marguerite	0.5	0.6	170	182	5.8	7.4	0.10	0.109
Highway 20	0.5	0.6	163	173	4.1	5.3	0.16	0.18
Lillooet	0.	0.	176	185	4.4	5.3	0.15	0.16
Lytton	2.0	2.2	154	160	4.0	4.8	0.18	0.195
Hope	2.0	2.2	130	132	3.3	3.8	0.048	0.048

The parameters pH and temperature are not appreciably affected by the developments because at this time of year these parameters are very similar in all tributaries. Dissolved sodium and, to a lesser extent, specific conductance are affected for a long distance downstream as shown in Figures 10 and 11. It is worthy of note that the induced effect is greatly diminished at Hope due to the large dilution influence of the Thompson River.

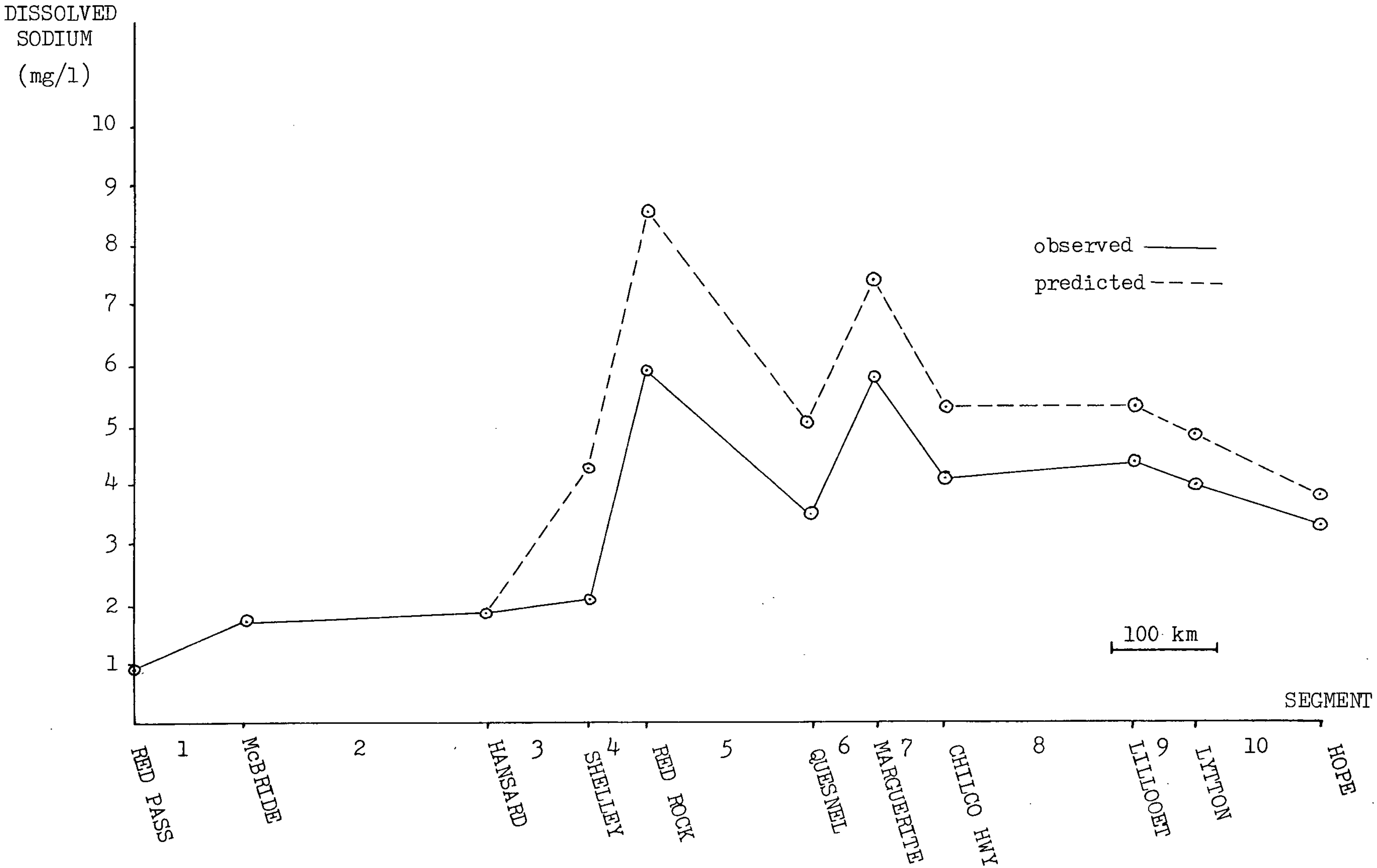


FIGURE 10 - PREDICTED EFFECT OF NEW DEVELOPMENTS ON DISSOLVED SODIUM CONCENTRATION

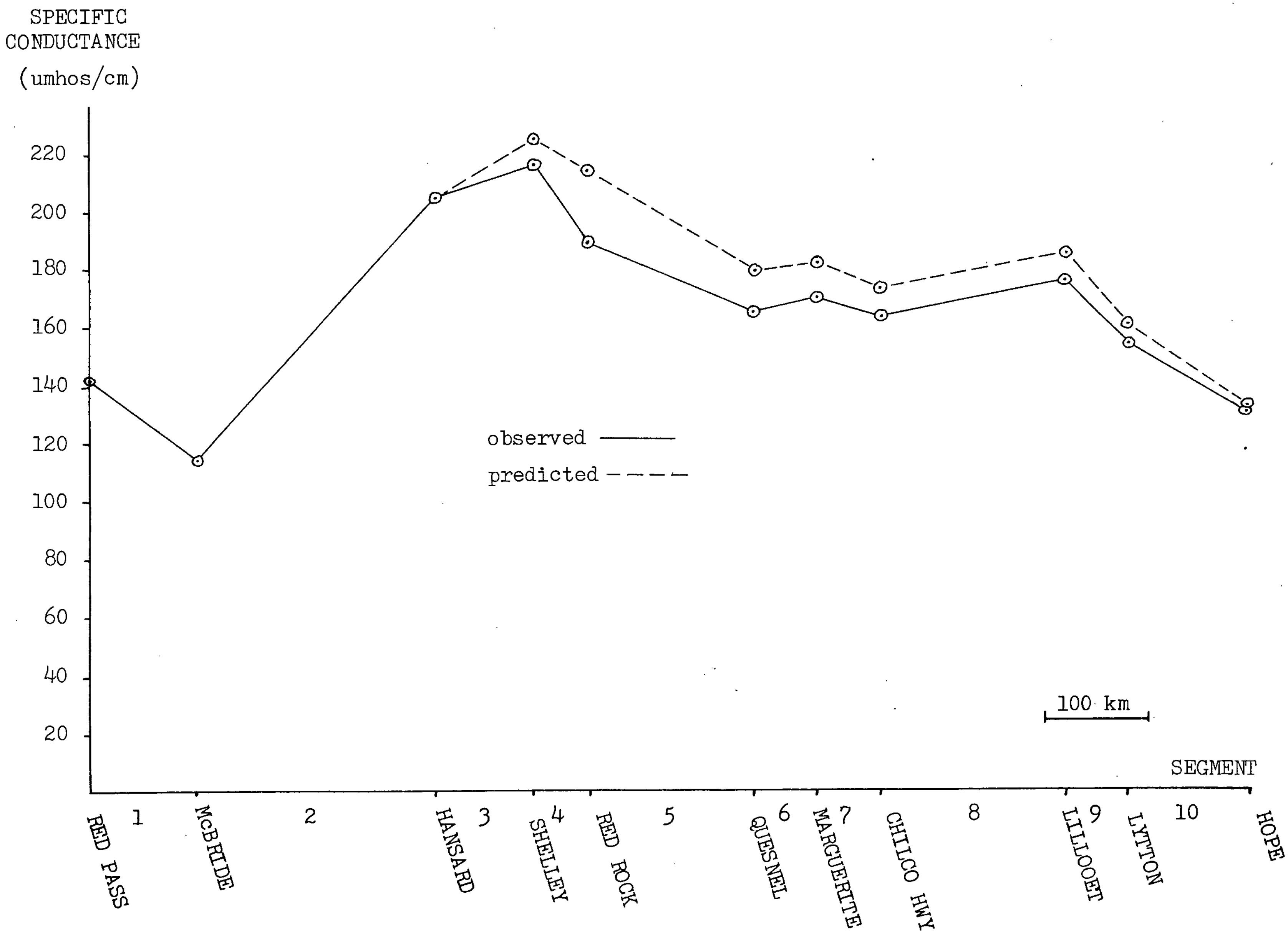


FIGURE 11 - PREDICTED EFFECT OF NEW DEVELOPMENTS ON SPECIFIC CONDUCTANCE

For sediment associated materials, such as total iron, prediction values are suspect because the framework assumes the same weight of material is added or deposited within each segment regardless of the changes made to the system. This leads to two types of errors. In instances where a flow has been reduced, such as the Nechako River, the reduction in material input should be compensated by a reduction in the weight of material that settles downstream. In instances where new materials have been introduced, such as the new pulp mill discharge, some of the new load should settle downstream. Under the assumptions of the framework new materials are simply diluted. Predicted values are therefore low from the first type of error and high from the second.

The above sediment associated errors could be reduced by introducing a decay constant for each parameter and segment. These decay constants would take the place of the segment calibration values but must be coupled with passage time from each influence point to the segment boundary. As these data were not available, the use of calibration values and the assumptions implicit in them were the only recourse. It should be noted that the load differences generated from the materials balance approach are the first step in evolving decay constants.

5. Discussion and Summary

Advantages of Use

The framework developed and applied here is an intermediate step between single purpose data collection and exhaustive systems modelling. As an intermediate designed to use data collected for other purposes it cannot answer all questions which might arise in the assessment of quality effects or during the development of river basin plans. It can be used to aid in the interpretation of data and establish a crude representation of the system that allows some estimates to be made. Advantages in its use lie in the simplicity, flexibility and speed of application and in benefits associated with an integrated approach as discussed below:

(i) Identification of Data Gaps

Data gaps in both quality and flow became apparent during inventory of tributaries and receiving water monitoring sites. The five rivers in Segments 1 and 2 about which nothing is known and yet which influence that reach of the Fraser River to a large extent are a case in point. Data organization, such as shown in Table 2, provides a quick reference of what data exists and what does not. This is a major advantage of a materials balance approach even though it is not a defined output of the analysis.

(ii) Error Detection

Errors were detected both during assembly of the data base and through the analysis.

To assemble the data base all monitoring site locations in the Fraser watershed had to be examined as potential segment boundaries or tributary data stations. Several errors were detected in station location designations. It was also apparent that many site descriptions did not have sufficient detail to allow location of the same sampling point by a new field agent. During collection of waste permit and quality data, errors were found that likely represent keypunching errors or incorrect conversion to metric units. In a more humorous vein, a water license flow unit abreviation was encountered which no one knew the meaning of.

From the materials balance aspect of the analysis it was possible to conclude that dissolved sodium and specific conductance measures were not representative of mean monthly quality at some segment stations. Another inconsistency was discovered in Water Survey of Canada flow figures. One would expect that the Fraser River flow at some point plus a downstream tributary flow would add up to something less than what was observed even further downstream. In both April and July of 1976 the flow of the Fraser River measured at Marguerite (57,000 and 143,000 cfs respectively) plus major downstream tributaries (approximately 4,700 and 21,100 cfs respectively) added up to more than was observed further downstream above Texas Creek (58,300 and 163,000 respectively). These figures include flow estimates for the Bridge River as no data was available for 1976 however, even if the estimates are excluded the flow values for April still are inconsistent and unaccounted flows have not been considered. This indicates either one or more of the flow measures are incorrect or an underground distributary exists.

The lack of representative data describing the Fraser River system led to the conclusion that an attempt to establish standard quality conditions for MATBAL calibration and for verification with an independent data set would be premature. It is felt that the large number of errors detected were a direct result of the approach to data collection. Diverse data was required that cut across the single purpose activities of the agencies involved. This, plus the materials balance approach, made most inconsistencies obvious.

(iii) Inter-Agency Co-ordination

The prediction output of the dilution model shows how decisions made by one jurisdiction or agency can affect the range of options available to another. Even in a river the size of the Fraser, additional waste loads reduce downstream available capacity as would major flow diversions. From the point of view of water quality management waste discharge and beneficial use allocations cannot be separated. The framework provides a mechanism for testing the downstream consequences of decisions of both types.

Opportunities exist for the co-ordination of agency activities. During the compilation of the data base it became apparent that many users of the system obtain a water license to withdraw process feed and a waste permit to discharge process effluent. Instances where one occurred without the other were readily apparent. Thus, it was possible to identify a development which did not have a discharge permit for wastes generated through its water license. This suggests that some referral process from the Water Rights Branch to the Pollution Control Branch is warranted. As discussed previously, most agencies have their own data collection programs suited to their objectives and little shared use of information occurs. In collecting data from these agencies for a pooled data base several obstacles were encountered. Sites, parameters, analysis techniques, and sampling times were different and peculiar to each agency. Another major obstacle was the use of different units.

If these agencies were to agree to a common parameter list, standard forms of analysis, and consistent sampling locations and times, as is required for application of MATBAL, some duplication of effort could be avoided and a great deal more would be known about the character of the water system.

(iv) Establish Research and Monitoring Priorities

By knowing the magnitude of unaccounted flows and parameter loads over distance and time it is possible direct monitoring and research activities to those segments and processes which affect downstream quality. A base is established through the dilution model and deviations from it as shown by the materials balance lead to questions of particle size behavior, composition and sedimentation rates, thermal exchange, the effects of land use types on surface runoff, sub-basin water and chemical budgets, the composition and rate of groundwater inflow and in-stream reactions.

The percentage change in downstream concentration provided in the site specific output allows the relative effect of each input to be placed in perspective. As previously mentioned, this percentage change is the theoretical minimum because it is based on instantaneous dispersion. The actual change induced by an input might be higher or lower due to unaccounted upstream influences and would certainly be larger in the initial dilution zone. The unknown effect of unaccounted influences could be offset by inserting a portion of the of the observed segment load differences upstream based on distance or through the use of decay constants however, without detailed data on sedimentation rates or location this could not be attempted.

In addition, it was felt that the scale of this analysis and uncertainty in data did not warrant further manipulation. The theoretical percentage change values are indicators, not absolutes. In British Columbia, where receiving water standards for the control of waste discharge are based primarily on negligible change resulting downstream, these percentage change measures could be used to priorize monitoring, technical assistance and enforcement activities. Although it might reduce administrative flexibility, it would certainly add clarity if the ambiguous term 'negligible' were defined in terms of percentage change.

An additional advantage of organizing data as in Tables 6, 7 and 8 is that influences with poor parameter coverage stand out as data gaps in the table. For example, no data had been generated for metal concentrations in pulp mill, sawmill or domestic waste effluents and it was necessary to use theoretical values from the literature. It has been demonstrated that manganese and iron loads are in excess of criteria in most reaches of the Fraser River at some time during the year and any additional loads from waste discharge should be known. Similarily, the enhanced interpretability of load data as opposed to concentration data has been demonstrated and suggests that flow should be monitored any time quality data is collected. Finally, by identifying which parameters are or are likely to be sources of impact and then examining existing data for these parameters it is possible to request analyses at locations where impact is likely to occur and for those influences which are likely to cause it.

Knowing the location and magnitude of each influence affecting the system, a monitoring scheme could be evolved to suit the unique behavior of the particular system under study. The lack of necessary parameter coverage and the small sample in time examined for the Fraser prevent establishment of a surveillance network based on the case study. It is felt that the segment boundary stations selected are suited to the assessment of forseeable development demands, are easily accessible, and make the best use of historical records. They should therefore be maintained in future investigations.

(v) Trend Detection

Simply having the mean monthly flow and quality measures of segment boundaries, tributaries, waste inputs and withdrawals in a central organized form using common measurement units is a good first step in the detection of trends. Were the values truly mean values they should be accompanied by a variance or standard deviation measure so that statistical tests, such as a T-test of pooled variance, could be employed to detect statistically significant change in mean values over time and distance. A significant change at a segment boundary might then be related through regression analysis to change in some waste input, grouping of waste inputs, or tributary. This type of analysis requires much more data than are presently available but, as the data base grows over time and in validity as true representations of mean character, it could allow causal links to be established.

Throughout this thesis water quality criteria have been used as a measure of impact under the assumption that acceptable harm or risk thresholds have been established. Due to the process of bioaccumulation and metals migration through bed sediments, organisms may suffer impact even though water quality criteria have not been exceeded. The in-stream population, species diversity and tissue metal content of benthic organisms should be routinely determined at each segment boundary as an on-going and direct indicator of sub-lethal impact trends. Water quality criteria and standards may have to be revised to reflect the peculiarities of the water system.

(vi) A Tool For Planning Calculations

The goal of a water management plan is to determine what use should be made of the resource so that maximum benefit may be derived at minimum cost now and in the future. The planner must develop a procedure which defines the existing supply of the resource for various uses, assesses the demand for future use, and allocates the supply amoung the various and variable demands in a manner which ensures that no existing or potential use is lost unless it has been determined that it should be lost. There are therefore many policy decisions, such as agreement upon standards, the extent to which natural processes should be modified, the value of alternative uses and equity in distribution, which rely upon a technical assessment of the present and predicted future behavior of material loads in the water system.

Two aspects of the framework assist in defining the system's assimilative capacity and in a technical evaluation of alternative scenarios of distribution and use of that capacity. First, MATBAL's mean available capacity output provides an estimate by parameter of the additional load each segment can assimilate before use criteria are exceeded. Second, the prediction output provides an estimate of the quality effect downstream for any combination of load additions or flow subtractions associated with a use allocation.

As has been pointed out, in its present form MATBAL is limited to flowing surface waters and to non-reactive parameters. Also, the planning calculations operate at the segment level. It is therefore best used for inter-segment comparison decisions which are dependent upon these parameters. In systems where nutrient or dissolved oxygen are limiting factors a decision would have to be made to either develop a new framework structure for reactive materials or modify MATBAL for the assessment and prediction of these materials through the addition of decay formula. For those systems where the framework may be used, the following steps show how MATBAL can assist the planning process:

(1) Determine the mean available capacities for each segment for the flow condition which represents the river's lowest assimilative capacity.

(2) Based on the mean available capacities and reserving a margin of safety, allocate the available capacity to the demand which has been determined (through other weighting methods not here discussed) to have highest priority or determine the source of material loads in excess of criteria.

(3) Either insert the new allocation influence concentrations and flow or reduce the offending influence in the data base and predict the resulting downstream quality at each segment station.

(4) Update the original segment station values with the predicted downstream values.

(5) Run MATBAL to generate new mean available capacities for each segment which is affected by the allocation or reduction.

(6) Repeat steps (2) through (5) for each allocation demand.

The process is an incremental addition or reduction of loads which should result in a project plan that ensures quality criteria are not exceeded. There are many economic and functional factors which have not been considered here however, it should be evident that a great deal of laborious manual calculation can be performed quickly and cheaply through the approach which are necessary for a technical evaluation of the effect of alternative management decisions and plans. With minor modifications, much of the above process could be automated. It might also be linked to economic evaluation models.

Data Limitations

Through the course of this investigation it has become clear that the validity of the framework output is dependent upon the accuracy of the data base as a representation of mean monthly character. If the data are not representative then the framework incorporates the deviations in the aggregate effect of unknown influences. Unrepresentative data for conservative parameters may be detected through the materials balance however, application of the approach to sediment associated parameters does not provide an internal check. To be confident of the results of analysis, confidence must be established in the data base.

Investigation of multiple samplings for nutrients in the Squamish River (Kleiber, 1977) has shown that:

> " ... single samples collected monthly or quarterly would provide imprecise measures of mean monthly or quarterly concentrations. Loading estimates derived from these concentration values would also be imprecise. "

Further, it has been suggested (Oguss, 1976) that a single grab sample taken as an indicator of water quality is meaningless without an estimate of errors associated with either getting a high single sample when the mean concentration is in fact much lower or getting a low single sample when the mean concentration is high. Sampling errors may arise from sample container contamination, spatial non-homogeneity across the stream cross-section, and from temporal variation over the period of interest. Contamination can be controlled through rigorous cleaning procedures, spatial differences can be averaged if sufficient samples are taken along a transect, and temporal variation can be determined if sufficient sampling trips are made over time. To determine the sufficient number of replicate samples and trips required to minimize uncertainty in water quality values under budget constraints one must first estimate the variance in the values through intensive sampling, then use statistical relationships to determine optimum sampling frequency based on levels of discrimination and probability acceptable to the analysis objectives. Ultimately, one must balance the losses associated with an inaccurate answer with the cost of data collection necessary to decrease uncertainty in the estimate. Relationships developed in the literature (Nielsen, 1975; Moore, 1976; Kleiber, 1978) show that sampling costs rise exponentially with decreasing uncertainty.

To establish error limits for MATBAL outputs each datum should be accompanied by a variance measure determined through repetitive sampling trips each month and replicate samples at each site in the surveillance network. At the very least this should be done for the major influences identified and segment boundary check stations. Outputs could then be expressed as ranges and statistically significant changes identified. With available data one cannot be sure whether the calculated load differences reflect non-point influences or simple data errors.

Summary

Though similar in nature, the information requirements of pollution abatement activities are much different than those of impact prevention activities. Both fall under the umbrella of water resource management but abatement focuses on point discharge control while prevention requires understanding of system behavior. With recognition of the need for both types of activities information systems may be designed to maximize shared use of water quality data for both purposes. MATBAL structures diverse regulatory agency data to reveal new insight into system behavior and opportunities for enhanced agency co-operation.

Most water quality models deal strictly with conservative parameters and BOD/DO or nutrient behavior (Enviro Control Inc., 1971). The major industrialized rivers of the world, including the Thames, the Rhine, and the lower Fraser, have been the subject of BOD/DO modelling. Only recently have trace metals and sediments been recognized as problem parameters and very little work has been directed to modelling their behavior, primarily due to the complexity of mass transport models. Few rivers in British Columbia are so severely taxed by waste discharge and withdrawals that the more obvious BOD/DO problem warrants study and model development. There may therefore be a tendency to ignore the less obvious problem of metals and sediment behavior because it does not appear to be worth the effort yet. The analytical framework developed here, while it does not give detailed answers to metal migration queries, does provide an idea of their behavior simply and inexpensively and with relatively few demands for data.

Water resource management in British Columbia has focused on data collection for point source pollution abatement and streamflow planning. As the demands for both beneficial and detrimental use of a limited water resource increase, so will the need for systematic water quality planning. MATBAL can assist in the transition from simple data collection and storage to complex systems modelling because the river-quality assessment framework quantifies the difference between what is known and what is not known but can be observed. Thus, the ultimate goal in the use of the framework would be to reduce this quantified margin of uncertainty through monitoring and research thereby resulting in a system which is understood and predictable. In its present form and with existing data its best use is as a tool to guide these investigations. With reduced errors and better understanding the planning aspects of the framework, estimation of available capacity and impact prediction, will take on greater meaning and use.

CHAPTER 4 - CONCLUSIONS AND RECOMMENDATIONS

The stream-quality assessment and planning framework presented in this thesis is in a developmental stage and is only a tool to aid in the development of water quality plans. There are many improvements to be made in both technical analytical abilities and the institutional environment which governs its use.

1. Technical/Methodological Conclusions

#1 EXPAND THE FRAMEWORK'S APPLICABILITY

As developed, the framework is only applicable to regional assessment of flowing surface waters and a select parameter list. To be generally applicable the framework should contain provisions for site specific lateral dispersion assessment and inclusion of reactive parameters. Both aspects require stream length distance data. With such data, the framework could be given two-dimensional character from the input point to the point of complete dispersion through the use of several one-dimensional frameworks linked in parallel. Inputs could then be diluted in stages across the river to simulate plume mixing. Reactive parameters could have segment specific decay constants to simulate their loss over time. The framework remains the basic structure which may be made more complex as the situation warrants and data permits.

#2 KEY EQUIS DATA FOR SYSTEM SURVEILLANCE

It has been shown that the abatement oriented design of EQUIS can lead to difficulty in data assembly for planning purposes. An EQUIS site designation delineating select sites as part of a new provincial water quality surveillance network would assist. As has been mentioned, each site should also be accompanied by a measure of the distance from the mouth of the water system.

Data retrieval would also be much simpler if the sites and associated data collected for water licenses by the Water Rights Branch and stream gauging by the Water Survey of Canada were included in the EQUIS data base. Ultimately it would be useful to include the location of valuable beneficial use sites, such as spawning habitat reaches, which have not been located for the purpose of regulation in a systematic form.

#3 LINK MATBAL TO EQUIS

The MATBAL framework should be viewed as a tool for data interpretation which must be linked to a data storage system. If the revisions to EQUIS mentioned in #2 above were made, all the data requirements of MATBAL could be satisfied. EQUIS already possesses a retrieval form, mean values by year and month, which assembles all data for a given month and site along with the associated standard deviation. This EQUIS output could be a direct MATBAL input. With modifications the framework could be a data manipulation option of EQUIS that would allow a water quality manager to view relevant information, discern data gaps and explore allocation alternatives.

#4 DEVELOP OTHER MODELS

The framework is a simple tool for estimating in-stream processes. Better understanding of these net effects would result if each process were modelled. For example, the materials balance approach could be extended to bed sediment transport and composition. Surface runoff models based on sub-basin water and chemical budgets could be developed to cope with problem parameters and watersheds.

To provide more comprehensive planning information for areas of high development pressure or ecological importance, treatment cost functions could be developed for waste dischargers. This information coupled with mean available capacity output, could be structured into a location optimization model based on quality effects and ability to pay. Demand models could be developed for beneficial use types based on preference sampling, resource availability and population projections. The demand models could also be incorporated in an optimization model and would assist program planning.

2. Institutional/Policy-Related Conclusions

#5 ACCEPT THE ECOSYSTEM APPROACH

The ecosystem approach is the basis of integrated resource management. In the words of the Honourable W.R. Bennett, Premier of the province of British Columbia (Bennett, 1978):

> "While we seek to protect our environment and provide for the well-being of the people of British Columbia, we have to be careful not to destroy the initiative of firms and individuals who develop our resource base in our mutual interests."

> "We will achieve the benefits of integrated resource management through responsible government which articulates its policies clearly, lays out the ground rules, and supports these through legislation and programs. We will apply the best technical knowledge and analytical techniques to identify and weigh the choices before us - and where value judgements must be made, we will consult with interested groups and individuals."

This desire to maximize social utility must be translated into programs for water quality assessment and control. The principles of the ecosystem approach must be accepted and instituted in the data collection and manipulation procedures of all those charged with allocation of the water resource. This means that criteria for all beneficial uses should be developed and adopted by the province, the assimilative capacity of the resource should be identified and monitored through regional surveillance of flow in conjunction with quality, methods must be developed to allow comparison of the conflicting values of resource use, and the information must be put in a form which will be understood by concerned groups and individuals.

Acceptance of this approach will not occur spontaneously. There must be a precise program for its implementation to co-ordinate with existing abatement activities. The starting point should be a policy that all highly stressed or ecologically important watersheds develop a water resource plan. As the Municipal Act presently requires that regional districts, settlement areas and communities develop land use plans, it may be necessary to wait until the land-based plans are formed before proceeding with water-based plans so that the demand factors of the land could be incorporated. In addition, the experience in funding, public input and level of professionalism gained in the land-based plans could then be used to guide the similar water-based program. Ideally, water and land-based plans should be developed concurrently.

Due to the technical nature of water quality data, the responsibility for data collection and interpretation to suit the information needs of water quality planning must lie with the governments. Consultants would not have the time to establish the necessary data base and it is essential that allocation decisions be based on a consistent approach to analysis. Parameters for study should be selected on their potential to cause impact now or in the future. It is also essential that water quality criteria already be accepted as the basis for the analysis.

#6 CO-ORDINATE FEDERAL AND PROVINCIAL ACTIVITIES

There is a limited pool of agency resources available for the study and control of water quality. The most efficient utilization of these resources requires co-ordination of their activities. It has been shown that diverse agency objectives and methods lead to difficulty in the comprehensive task of planning. Some responsibilities may be missed if there is no overview of what is being done and findings of one agency which might be useful to another may never be known or if they are known they may be in a form not useful to the other. These are problems in communication and may be rectified through contact and standardization.

From a system perspective the largest difficulty in data interpretation originates from the constantly changing sample collection times, locations, and analysis parameters both within each agency and between agencies. Times, sites and parameters should be standardized for each watershed based on its flow and quality characteristics, influence structure and demands for use. By this it is meant that each watershed should have a monitoring plan agreed upon by all agencies to ensure broadest use of the data generated. Sampling sites for system surveillance and abatement surveillance should be delineated and fixed. There will be some opportunity for identification of sites suited to both purposes.

Collection times should also be determined and fixed. For example all data should be collected within the same month quarterly. This would not hinder use of the data for abatement and would establish some system consistency. Watersheds might be staggered in time to reduce peak loads on field and laboratory personnel. Consultants would welcome the economies of scale. Random spot checks should also occur to ensure permittees do not abuse the fixed schedule.

Finally, a common parameter list, including flow and quality parameters important to the watershed, should be developed and adhered to for every sample taken. The only time a parameter should be dropped would be if it has been determined over time that it does not exist in the system or that it is not a significant impact parameter. The recent purchase by the Environmental Laboratory of an inductively coupled plasma spectrometer allows simultaneous determination of over fifty elements. Once the sample has been gathered, there is very little extra cost in the determination of thirty elements as compared to, say, three. Other analyses are more expensive because they are manual, however automation is bringing about economies of scale. Another aspect of parameter standization is the need for identical federal and provincial analysis methods. An example is the federal affinity for extractable metals versus the provincial reliance on total metals. Each uses a different acid in sample digestion, and although the two have been used interchangeably in this study, most scientists would argue that they cannot be compared. This is clearly a hindrance to common data use and should be eliminated in the interests of efficiency.

The above problems are not new to those working in the field. Yet, the only instances where co-ordination has occurred are in the joint studies performed under the Canada Water Act. Even in these instances, though historical data did exist, the lack of early co-ordination prior to study onset meant that new data had to be collected because historical data was suspect. The only significant step toward co-ordination in the long term was the decision to pool federal and provincial data in EQUIS. However, without accompanying changes in field and laboratory procedures, the common data base only promotes efficiency in data retrieval and not data interpretation.

The solution seems to be a long term movement toward standardization in field and laboratory procedures through continuing dialogue. Such dialogue should not be specific to a particular study and should be established as an entity with purpose, budget and the authority to bring about change. It is suggested that the entity be a joint federal/provincial committee established under the Canada Water Act with representatives from the Pollution Control Branch, Water Investigations Branch, Water Rights Branch, and the Environmental Laboratory of the Ministry of Environment, the Water Quality Branch and Water Survey of Canada Branch of the Inland Waters Directorate, the Water Pollution Control Directorate, and their laboratories. The committee should first examine present water resource management activities to identify gaps in abatement and prevention activities and opportunities for co-ordinated action. Other responsibilities should include agreement upon common monitoring sites and times, determination of the number of replicates required for statistically valid data, the determination of watershed plan development priorities and agreement upon a master parameter list which could be modified to suit particular watersheds. Criteria and standards might also be developed in this forum. The recommendations of the committee should be subject to public review and revision. It will also be necessary to have a link with land use planning agencies to obtain information regarding development plans and priorities so that planning effort and surveillance coverage can be shifted and focussed.

#7 ESTABLISH QUALITY CONTROL IN THE FIELD

Whether agencies decide to co-ordinate their activities or not, it is essential that data collection programs in the future ensure that measurements are representative of the water system. A great deal of effort is spent in the laboratory upon quality control. Equipment is standardized, duplicate sub-samples are analyzed and compared, calculations are checked by several people, and often an anion-cation balance check is performed with anomalies subject to reanalysis. This effort may be wasted if the sample was not representative of the water for which information is needed.

As has been discussed, the solution to this problem is a statistically based surveillance program. The work of the Water Quality Branch in this area should continue and should be incorporated by other agencies. Further it has been shown that MATBAL can act as a rough check of accurate quality representation for conservative parameter sampling much in the way that an anion-cation balance is used in the laboratory. With information on bed sediment movement the check could be applied to non-reactive sediment associated materials as well. Thus, MATBAL could become a tool for quality control checks of field sampling and a data base would be developed which would lend confidence to a materials balance analysis.

#8 INTEGRATE REGIONAL AND PROVINCIAL LEVEL MANAGEMENT ACTIVITIES

The British Columbia Ministry of Environment is decentralizing some decision-making abilities to the regional office of each of the eight resource management regions in the province. In each centre will be a Regional Manager of Water Management, Waste Management, and Fish and Wildlife under a Regional Director. It is not yet clear what the responsibilities of the regional offices will be but it seems likely that they will handle applications for waste discharge permits and water licenses, participate in Regional Resource Management Committees, and prepare regional resource management plans with local public input. Given a well designed surveillance network, complete land use plans for the region, responsibility to incorporate public values and a technical procedure for estimating the water system's assimilative capacity based on quality criteria, it should be possible to evolve a planning process leading to a water resource management plan for watersheds within the region. The main interaction with the provincial level will be in standardization of procedures and information flow. Criteria for surveillance network design and data interpretation should be developed in Victoria to ensure that the analytical base for plan development is consistent. Remote terminals should be installed in each regional centre and personnel should be instructed in their use for data access and manipulation.

For water systems that cross the boundaries of the management regions, such as the Fraser River which crosses four, a mechanism for co-ordination will have to be established to allocate assimilative capacity between regions. Similarily, location decisions between regions are not within the scope of the Regional Managers. These decisions are best made at the provincial level with regional input as to socio-economic conditions and demand factors. Options could be developed analytically but decisions of equity are often political decisions. This suggests that a body such as ELUC through a new water resource assessment component of ELUCS, could be an effective mechanism for the resolution of these inter-regional questions.

#9 START PLANNING

Throughout this discussion it has been assumed that the senior level o of government acknowledges planning is needed and that recent institutional changes have been made so that planning and integrated resource management can occur through some structured process. The basis of an information system is in place, resource management regions have been defined, regional management staff are being recruited, a new mandate for planning has been established at a policy level, land use plans are being developed, and inter-agency communication is improving. Much work remains to be done in improving surveillance network design, developing procedures for interpreting water quality data, establishing water quality criteria, defining assimilative capacity, exploring public input mechanisms and defining a planning process.

The best way to identify the problems to be overcome is to select a pilot study, preferably one watershed in each management region so that common problems can be defined and all staff will gain some experience, and start planning. The process could begin with problem identification and the design of a surveillance network. Data will have to be collected for several years and in this time other required procedures could be developed. The lessons learned would improve the process for future investigations.

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APPENDIX I - The MATBAL Program

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C          ***************************************************
C          *                                                 *
C          *      ********** THE MATBAL PROGRAM *********    *
C          *                                                 *
C          *  WRITTEN BY JACK M. NICKEL ON SEPT. 18, 1979 AT *
C          *  THE SCHOOL OF COMMUNITY AND REGIONAL PLANNING  *
C          *  UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, BC  *
C          *  THE PROGRAM PERFORMS A MATERIALS BALANCE OF    *
C          *  AQUEOUS POLLUTANTS THROUGH A DILUTION MODEL.   *
C          *  USE OF THIS SOFTWARE REQUIRES ACKNOWLEDGEMENT  *
C          *           AND THE AUTHOR'S PERMISSION.          *
C          *                                                 *
C          ***************************************************
C
C     VARIABLE DEFINITIONS & DATA FORMAT
C         I= CARD COUNTER (VALUES CREATED AS CARDS ARE READ)
C         J= SEGMENT NUMBER INDICATOR
C         L= INFLUENCE COUNTER
C
C     NOTE: (1)FIRST CARD WILL SUPRESS DETAILED PRINTOUT IF COL 1 = 1
C              THE FOLLOWING CARD ORDER IS REPEATED FOR EACH DATA
C              SUBSET (MONTH).
C           (2)SECOND CARD IS DATA DATE (COL 1-16), DATE(4)
C           (3)THIRD CARD CONTAINS PARAMETER CRITERIA (9X 6COL FIELDS)
C           (4)FOURTH CARD HAS SEGMENT LENGTHS (10 X 6COL FIELDS)
C           (5)THE REMAINDER OF THE CARDS ARE THE BULK OF THE DATA
C              SUBSET AND CONTAIN THE SPECIFIC SITE PARAMETER DATA
C              AS FOLLOWS:
C                SEG(200)= SEGMENT NUMBER FILE (COL 1-2)
C                INFL(200)= INFLUENCE TYPE (1=CHECK STATION,
C                           2=TRIBUTARY, 3=EFFLUENT, AND
C                           4=WITHDRAWAL) (COL3)
C                TYPE(200)= INFLUENCE TYPE SUBCLASS (COL 4)
C                SITE(200,5)= SITE NAME FILE (COL 5-24)
C                PARA(200,9)= WATER DATA (9 X 6COLUMN FIELDS
C                                  IN COLUMNS 25 TO 78)
C           (6)THE FINAL CARD IN EACH DATA SUBSET MUST HAVE -1 IN
C              COLUMNS 1 AND 2.
C
C
      INTEGER SEG(200), SITE(200,5), I, J, L, INFL(200), TYPE(200),
     1        DATE(4), P, Q, M, S, T, X, Y, SUPRES
      REAL PARA(200,9), FLOW(3), PH(3), CONC(3,9), DIF(9), FIN(10,9),
     1     CRIT(9), LOAD(3,9), PERC(9,2), CAP(9), NDIF(10,9),
     2     INIT(10,200,9), PRED(10,9), DIFF(10,9), STOR(10,9),
     3     OBS(10,9), DIST(10), CALC(10,200,9), INIL(10,200,9),
     4     CALI(10,9)
      CALL FTNCMD('SET MINUSZERO=ON;')
      READ (5,10) SUPRES
10    FORMAT (I1)
20    CONTINUE
      I = 1
C******BEGIN READING DATA SUBSET
      READ (5,30,END=1300) (DATE(N),N=1,4)
30    FORMAT (4A4)
      WRITE (6,40)
40    FORMAT ('1', T40, 'FRASER RIVER MATERIALS BALANCE')
      WRITE (6,50) (DATE(N),N=1,4)
```

```
50     FORMAT ('0', T40, 'DATE OF DATA - ', T55, 4A4)
       WRITE (6,60)
60     FORMAT ('0')
       WRITE (6,70)
70     FORMAT ('0', T32, 'FLOW', T42, ' PH ', T50, 'TEMP(C)', T60,
      1        'SP COND', T70, 'DISS NA', T79, 'NF RESIDUE', T90,
      2        'TOT FE', T100, 'TOT MN', T110, 'TOT CU')
       WRITE (6,80)
80     FORMAT (' ', T29, 'X1000M3/D', T40, '(UNITS)', T58, '(UMHOS/CM)',
      1        T70, '(MG/L)', T80, '(MG/L)', T90, '(MG/L)', T100,
      2        '(MG/L)', T110, '(MG/L)')
       READ (5,90) (CRIT(N),N=1,9)
9C     FCRMAT (9F6.0)
       READ (5,100) (DIST(N),N=1,10)
100    FCRMAT (10F6.0)
       WRITE (6,110) (CRIT(N),N=5,9)
110    FORMAT ('0', T6, 'PARAMETER CRITERIA', T31, '----', T42, '----',
      1        T51, '----', T61, '----', T70, F6.2, T80, F6.3, T90, F6.3,
      2        T100, F6.3, T110, F6.3)
12C    CONTINUE
C******READ PARAMETER DATA
       READ (5,130) SEG(I), INFL(I), TYPE(I), (SITE(I,N),N=1,5),
      1(PARA(I,N),N=1,9)
130    FORMAT (I2, I1, I1, 5A4, F6.0, 8F6.3)
C******CHECK FOR END OF DATA SUBSET
       IF (SEG(I) .LT. 0) GO TO 240
       IF (INFL(I) .NE. 1) GO TO 150
       WRITE (6,140) SEG(I)
140    FORMAT ('0', T2, 'SEGMENT', T10, I2)
C
C******CONVERT FLCW UNITS FROM CFS OR M3/DAY TO X1000M3/DAY
C
150    CCNTINUE
       IF (INFL(I) .EQ. 3) GO TO 160
       IF (INFL(I) .EQ. 4) GO TO 160
       PARA(I,1) = PARA(I,1) * 2.45
160    CONTINUE
       IF (INFL(I) .NE. 3) GO TO 170
       PARA(I,1) = PARA(I,1) * 0.001
170    CONTINUE
       DO 180 N = 2, 9
         IF (IBLANK(PARA(I,N)) .EQ. - 1) PARA(I,N) = 1000000000.
180    CONTINUE
       IF (PARA(I,1) .LT. 0) GO TO 200
       WRITE (6,190) I, (SITE(I,N),N=1,5), (PARA(I,N),N=1,9)
190    FORMAT (' ', T2, I3, T6, 5A4, T28, F10.3, T41, F5.2, T50, F6.2,
      1        T60, F6.0, T70, F6.2, T78, F8.1, T90, F6.3, T100, F6.3,
      2        T110, F6.3)
       GO TO 220
2CC    WRITE (6,210) I, (SITE(I,N),N=1,5), PARA(I,1)
210    FORMAT (' ', T2, I3, T6, 5A4, T28, F10.3)
220    CCNTINUE
       IF (PARA(I,2) .GT. 100.) PARA(I,2) = 7.0
       DC 23C N = 3, 9
         IF (PARA(I,N) .GT. 100000000.) PARA(I,N) = 0.
230    CONTINUE
       I = I + 1
       GO TO 120
```

```
240    CONTINUE
       WRITE (6,250)
250    FORMAT ('0', T20,'***** NO DATA OR ESTIMATE AVAILABLE, ASSUME',
     1         T64, 'THE VALUE IS ZERO (7.0 FOR PH)')
C******DATA SUBSET STORED; BEGIN DATA MANIPULATIONS
       DO 270 I = 1, 10
         DO 260 J = 1, 9
           STOR(I,J) = 0.
260      CONTINUE
270    CONTINUE
       I = 0
       J = 0
280    CONTINUE
       I = I + 1
C******CHECK FOR END OF DATA SUBSET
       IF (SEG(I) .LT. 0) GO TO 1110
C******CHECK FOR NEW SEGMENT
       IF (SEG(I) .EQ. J) GO TO 690
C******BEGIN SEGMENT SUMMARY CALCULATIONS
       J = J + 1
       FLOW(1) = PARA(I,1)
       PH(1) = PARA(I,2)
       DO 290 N = 3, 9
         CONC(1,N) = PARA(I,N)
290    CONTINUE
C******CHECK FOR SYSTEM INITIALIZATION
       IF (I .EQ. 1) GO TO 660
       DIF(1) = FLOW(1) - FLOW(3)
       DIF(2) = PH(1) - PH(3)
       K = J - 1
       FIN(K,1) = DIF(1)
       FIN(K,2) = DIF(2)
       DO 300 N = 3, 9
         DIF(N) = CONC(1,N) - CONC(3,N)
         FIN(K,N) = DIF(N)
300    CONTINUE
       T = 0
       X = 0
       P = I - L - 1
       Q = I - 1
       DO 340 S = P, Q
         T = T + 1
         DO 310 N = 1, 9
           INIT(K,T,N) = PARA(S,N)
310      CONTINUE
         DO 330 N = 5, 9
           IF (PARA(S,1) .LT. 0) GO TO 320
           INIL(K,T,N) = PARA(S,N) * PARA(S,1) / 1000
           GO TO 330
320        Y = T + (-1)
           INIL(K,T,N) = CALC(K,Y,N) * PARA(S,1) / 1000
330      CONTINUE
340    CONTINUE
       T = 1
       DO 350 N = 5, 9
         PRED(K,N) = LOAD(3,N)
350    CONTINUE
       DO 360 N = 5, 9
```

```
        OBS(K,N) = PARA(I,N) * PARA(I,1) / 1000
360   CONTINUE
      DO 37C N = 5, 9
        DIFF(K,N) = OBS(K,N) - PRED(K,N)
370   CONTINUE
      DO 380 N = 5, 9
        STOR(K,N) = STOR(K,N) / M - DIFF(K,N)
380   CONTINUE
      CALI(K,1) = DIF(1)
      CALI(K,2) = (-1) * ALOG10(ABS((10**((-1)*PARA(I,2))*PARA(I,1) - 10
     1 **((-1)*CALC(K,L,2))*CALC(K,L,1))/DIF(1)))
      DO 390 N = 3, 9
        CALI(K,N) = (PARA(I,N)*PARA(I,1) - CALC(K,L,1)*CALC(K,L,N)) /
     1  DIF(1)
390   CONTINUE
C
C******END OF SEGMENT SUMMARY CALCULATIONS
C
      WRITE (6,400) K, (DATE(N),N=1,4)
400   FORMAT ('1',T28,'SEGMENT ',I2,' - CONCENTRATION SUMMARY ',4A4)
      WRITE (6,410)
410   FORMAT ('0'/'0', T32, 'FLOW', T43, 'PH', T50, 'TEMP', T58,
     1        'SP COND', T69, 'DISS NA', T79, 'NF RESIDUE', T90,
     2        'TOT FE', T100, 'TOT MN', T110, 'TOT CU')
      WRITE (6,420)
420   FORMAT (' ', T29, 'X1000M3/D', T40, '(UNITS)', T50, '(C)', T56,
     1        '(UMHOS/CM)', T70, 'MG/L', T81, 'MG/L', T91, 'MG/L', T101,
     2        'MG/L', T111, 'MG/L')
      WRITE (6,430) (SITE(P,N),N=1,5)
430   FORMAT ('0', 'INITIAL VALUE'/' ', 4X, 5A4)
      WRITE (6,440) (INIT(K,1,N),N=1,9)
440   FORMAT ('+', T28, F10.3, T42, F4.1, T49, F5.1, T59, F5.0, T67,
     1        F9.2, T80, F7.1, T90, F7.3, T100, F7.3, T110, F7.3)
      WRITE (6,450)
450   FORMAT ('0', 'INFLUENCE INPUT VALUES')
      P = P + 1
      DO 490 S = P, Q
        T = T + 1
        X = X + 1
        WRITE (6,460) X, (SITE(S,N),N=1,5)
460     FORMAT (' ', I2, 2X, 5A4)
        IF (INIT(K,T,1) .LT. 0) GO TO 470
        WRITE (6,440) (INIT(K,T,N),N=1,9)
        GO TO 490
470     WRITE (6,480) INIT(K,T,1)
480     FORMAT ('+', T28, F10.3)
490   CONTINUE
      WRITE (6,500)
500   FORMAT ('0', 'PREDICTED DOWNSTREAM VALUES')
      X = 0
      DO 510 S = P, Q
        X = X + 1
        WRITE (6,460) X, (SITE(S,N),N=1,5)
        WRITE (6,440) (CALC(K,X,N),N=1,9)
510   CONTINUE
      WRITE (6,520) (SITE(I,N),N=1,5)
520   FORMAT ('0', 'OBSERVED END VALUE'/' ', 4X, 5A4)
      WRITE (6,440) (PARA(I,N),N=1,9)
```

```
      WRITE (6,530)
530   FORMAT ('0', 'DIFFERENCE (OBS-CALC)*')
      WRITE (6,440) (FIN(K,N),N=1,9)
      WRITE (6,540)
540   FORMAT ('0'/'0', 4X, '* A NEGATIVE VALUE INDICATES DEPOSITION',
     1       T46, 'OR LOSS & A POSITIVE INDICATES UNACCOUNTED INPUT')
      WRITE (6,550) K, (DATE(N),N=1,4)
550   FORMAT ('1',T25,'SEGMENT ',I2,' - LOAD SUMMARY FOR ', 4A4)
      WRITE (6,560)
560   FORMAT ('0'/'0', T32, 'FLOW', T42, 'DISS NA', T53, 'NF RESIDUE',
     1       T66, 'TOT FE', T78, 'TOT MN', T90, 'TOT CU')
      WRITE (6,570)
570   FORMAT (' ', T29, 'X1000M3/D', T41, 'TONS(M)/D', T53, 'TONS(M)/D',
     1       T65, 'TONS(M)/D', T77, 'TONS(M)/D', T89, 'TONS(M)/D')
      P = P - 1
      WRITE (6,580) (SITE(P,N),N=1,5)
580   FORMAT ('0', 'INITIAL FLOW & LOAD'/' ', 4X, 5A4)
      WRITE (6,590) INIT(K,1,1), (INIL(K,1,N),N=5,9)
590   FORMAT ('+', T28, F7.0, T39, F9.1, T51, F9.1, T64, F9.2, T77,
     1       F8.2, T89, F9.3)
      WRITE (6,600)
600   FORMAT ('0', 'INPUT LOADS')
      T = 1
      P = P + 1
      X = 0
      DO 620 S = P, Q
        T = T + 1
        X = X + 1
        WRITE (6,460) X, (SITE(S,N),N=1,5)
        WRITE (6,610) INIT(K,T,1), (INIL(K,T,N),N=5,9)
610     FORMAT ('+', T28, F10.3, T40, F10.3, T52, F10.3, T64, F10.3,
     1         T77, F9.3, T89, F9.3)
620   CONTINUE
      WRITE (6,630)
630   FORMAT ('0'/'0', 'PREDICTED END VALUE')
      WRITE (6,590) FLOW(3), (PRED(K,N),N=5,9)
      WRITE (6,520) (SITE(I,N),N=1,5)
      WRITE (6,590) PARA(I,1), (OBS(K,N),N=5,9)
      WRITE (6,530)
      WRITE (6,590) DIF(1), (DIFF(K,N),N=5,9)
      WRITE (6,640) (STOR(K,N),N=5,9)
640   FORMAT ('0', 'MEAN AVAILABLE CAPACITY+'/' ', '(AV.CALC.CAP - LOAD
     1DIFF)', T29, '------', T39, F9.1, T51, F9.1, T64, F9.2, T77, F8.2,
     2       T89, F9.3)
      WRITE (6,540)
      WRITE (6,650)
650   FORMAT (' ', 4X, '+ A NEGATIVE VALUE INDICATES LOAD', T40,
     1       'IN EXCESS OF CRITERIA')
660   CONTINUE
      IF(SUPRES.EQ.1) GO TO 1310
      WRITE (6,670) SEG(I), (SITE(I,N),N=1,5)
670   FORMAT ('1', 'SEGMENT', 2X, I2, 2X, 'BEGINNING WITH ', 2X, 5A4)
      WRITE (6,680)
680   FORMAT ('+', '____________________________________________________')
1310  CONTINUE
      L = 0
      M = 0
      GO TO 280
```

```
C******BEGIN INFLUENCE CALCULATIONS
650   CONTINUE
      L = L + 1
      IF (SUFRES .EQ. 1) GO TO 720
      WRITE (6,700)
700   FORMAT ('0')
      WRITE (6,710) (SITE(I,N),N=1,5)
710   FORMAT ('0'/'0',25X,'*******  INFLUENCE OF  ',5A4,'  *******')
720   CONTINUE
      FLOW(2) = PARA(I,1)
      FLOW(3) = FLOW(1) + FLOW(2)
      CALC(J,L,1) = FLOW(3)
      IF (FLOW(2) .LT. 0) GO TO 980
      M = M + 1
      PH(2) = PARA(I,2)
      PH(3) = (-1) * ALOG10((10**((-1)*PH(1))*FLOW(1) + 10**((-1)*PH(2))
     1*FLOW(2))/FLOW(3))
      CALC(J,L,2) = PH(3)
      DO 730 N = 3, 9
        CONC(2,N) = PARA(I,N)
        CONC(3,N) = (CONC(2,N)*FLOW(2) + CONC(1,N)*FLOW(1)) / FLOW(3)
        CALC(J,L,N) = CONC(3,N)
730   CONTINUE
C
C******CALCULATE LOADS
C
      DO 740 N = 5, 9
        LOAD(1,N) = CONC(1,N) * FLOW(1) / 1000
        LOAD(2,N) = CONC(2,N) * FLOW(2) / 1000
        LOAD(3,N) = CONC(3,N) * FLOW(3) / 1000
740   CONTINUE
      IF (SUPRES .EQ. 1) GO TO 780
C
C******CALCULATE PERCENTAGE CHANGE
C
      PERC(1,1) = FLOW(2) / FLOW(1) * 100
      DO 760 N = 3, 9
        IF (CONC(1,N) .EQ. 0) GO TO 750
        PERC(N,1) = (CONC(3,N) - CONC(1,N)) / CONC(1,N) * 100
        IF (PERC(N,1) .GT. 999) PERC(N,1) = 999.
        GO TO 760
750     PERC(N,1) = 100
760   CONTINUE
      DO 780 N = 5, 9
        IF (LOAD(1,N) .EQ. 0) GO TO 770
        PERC(N,2) = (LOAD(3,N) - LOAD(1,N)) / LOAD(1,N) * 100
        IF (PERC(N,2) .GT. 999) PERC(N,2) = 999.
        GO TO 780
770     PERC(N,2) = 100
780   CONTINUE
C******CALCULATE AVAILABLE LOAD CAPACITY FROM CALCULATED FLOW AND
C******DIFFERENCE BETWEEN CRITERIA AND CALCULATED CONCENTRATION
      DO 790 N = 5, 9
        CAP(N) = (CRIT(N) - CONC(3,N)) * FLOW(3) / 1000
        STOR(J,N) = STOR(J,N) + CAP(N)
790   CONTINUE
      IF (SUPRES .EQ. 1) GO TO 960
      WRITE (6,800)
```

```
800   FORMAT ('C', T31, 'UPSTREAM', T50, 'INPUT', T62, 'DOWNSTREAM',
     1        T80, 'PERCENT')
      WRITE (6,810)
810   FORMAT (' ', T32, 'VALUE', T50, 'VALUE', T61, 'VALUE (CALC)', T80,
     1        'CHANGE')
      WRITE (6,820) FLOW(1), FLOW(2), FLOW(3), PERC(1,1)
820   FORMAT ('0', 'FLOW (X1000M3/DAY)', T31, F7.0, T47, F10.3, T62,
     1        F7.0, T80, F6.2)
      WRITE (6,830) PH(1), PH(2), PH(3)
830   FORMAT (' ', 'PH (UNITS)', T35, F4.1, T51, F4.1, T66, F4.1, T81,
     1        '----')
      WRITE (6,840) CONC(1,3), CONC(2,3), CONC(3,3), PERC(3,1)
840   FORMAT (' ', 'TEMPERATURE (C)', T35, F4.1, T49, F6.1, T66, F4.1,
     1        T79, F7.2)
      WRITE (6,850) CONC(1,4), CONC(2,4), CONC(3,4), PERC(4,1)
850   FORMAT (' ', 'SP CONDUCTANCE (UMHOS/CM)', T33, F5.0, T49, F5.0,
     1        T64, F5.0, T80, F6.2)
      WRITE (6,860)
860   FORMAT ('0')
      WRITE (6,870)
870   FORMAT ('0', T31, 'UPSTREAM', T50, 'INPUT', T62, 'DOWNSTREAM',
     1        T80, 'PERCENT', T92, 'AVAILABLE')
      WRITE (6,880)
880   FORMAT (' ', T32, 'VALUE', T50, 'VALUE', T61, 'VALUE (CALC)', T80,
     1        'CHANGE', T92, 'CAPACITY*')
      WRITE (6,890)
890   FORMAT ('0', T28, 'MG/L', T33, 'TONS(M)/D', T45, 'MG/L', T51,
     1        'TONS(M)/D', T62, 'MG/L', T67, 'TONS(M)/D', T78, 'CONC',
     2        T85, 'LOAD', T92, 'TONS(M)/D')
      WRITE (6,900) CONC(1,5), LOAD(1,5), CONC(2,5), LOAD(2,5),
     1CONC(3,5), LOAD(3,5), PERC(5,1), PERC(5,2), CAP(5)
900   FORMAT ('0', 'DISSOLVED SODIUM', T26, F6.2, T33, F7.1, T44, F6.2,
     1        T51, F9.3, T60, F6.2, T67, F7.1, T77, F6.2, T84, F6.2, T91,
     2        F11.3)
      WRITE (6,910) CONC(1,6), LOAD(1,6), CONC(2,6), LOAD(2,6),
     1CONC(3,6), LOAD(3,6), PERC(6,1), PERC(6,2), CAP(6)
910   FORMAT (' ', 'SUSPENDED SOLIDS', T26, F6.2, T33, F7.1, T42, F8.2,
     1        T51, F9.3, T60, F6.2, T67, F7.1, T77, F6.2, T84, F6.2, T91,
     2        F11.3)
      WRITE (6,920) CONC(1,7), LOAD(1,7), CONC(2,7), LOAD(2,7),
     1CONC(3,7), LOAD(3,7), PERC(7,1), PERC(7,2), CAP(7)
920   FORMAT (' ', 'TOTAL IRON', T27, F6.3, T33, F9.3, T45, F6.3, T51,
     1        F9.3, T61, F6.3, T67, F9.3, T77, F6.2, T84, F6.2, T91,
     2        F11.3)
      WRITE (6,930) CONC(1,8), LOAD(1,8), CONC(2,8), LOAD(2,8),
     1CONC(3,8), LOAD(3,8), PERC(8,1), PERC(8,2), CAP(8)
930   FORMAT (' ', 'TOTAL MANGANESE', T27, F6.3, T33, F9.3, T45, F6.3,
     1        T51, F9.3, T61, F6.3, T67, F9.3, T77, F6.2, T84, F6.2, T91,
     2        F11.3)
      WRITE (6,940) CONC(1,9), LOAD(1,9), CONC(2,9), LOAD(2,9),
     1CONC(3,9), LOAD(3,9), PERC(9,1), PERC(9,2), CAP(9)
940   FORMAT (' ', 'TOTAL COPPER', T27, F6.3, T33, F9.3, T45, F6.3, T51,
     1        F9.3, T61, F6.3, T67, F9.3, T77, F6.2, T84, F6.2, T91,
     2        F11.3)
      WRITE (6,950)
950   FORMAT ('0', T15, '* BASED ON INPUT CRITERIA')
960   CONTINUE
C
```

```
C******END OF INFLUENCE LOAD CALCULATIONS
C
      PH(1) = PH(3)
      DO 970 N = 3, 9
        CONC(1,N) = CONC(3,N)
970   CONTINUE
      GO TO 1100
C
C******PRINT WITHDRAWAL VALUES
C
980   CONTINUE
      CALC(J,L,2) = PH(1)
      DO 990 N = 3, 9
        CALC(J,L,N) = CONC(1,N)
990   CONTINUE
      IF (SUPRES .EQ. 1) GO TO 1100
      WRITE (6,1000)
1000  FORMAT ('0'/'0','CALCULATED WITHDRAWAL PARAMETER VALUES:')
      WRITE (6,1010) FLOW(2)
      WRITE (6,1020) PH(1)
      WRITE (6,1030) CONC(1,3)
      WRITE (6,1040) CONC(1,4)
      WRITE (6,1050) CONC(1,5)
      WRITE (6,1060) CONC(1,6)
      WRITE (6,1070) CONC(1,7)
      WRITE (6,1080) CONC(1,8)
      WRITE (6,1090) CONC(1,9)
1010  FORMAT ('0', 'FLOW(X1000M3/DAY) = ', F10.3)
1C20  FORMAT ('0', 'PH (UNITS) = ', F6.2)
1030  FORMAT ('0', 'TEMPERATURE (C) = ', F6.2)
1040  FORMAT ('0', 'CONDUCTIVITY (UMHOS/CM) = ', F6.1)
1050  FORMAT ('0', 'DISSOLVED SODIUM (MG/L) = ', F6.2)
1060  FORMAT ('0', 'SUSPENDED SOLIDS (MG/L) = ', F6.1)
1070  FORMAT ('0', 'TOTAL IRON (MG/L) = ', F6.3)
1080  FORMAT ('0', 'TOTAL MANGANESE (MG/L) = ', F6.3)
1090  FORMAT ('0', 'TOTAL COPPER (MG/L) = ', F6.3)
1100  CONTINUE
      FLOW(1) = FLOW(3)
      GO TO 280
1110  CONTINUE
      WRITE (6,1120)
1120  FORMAT ('0'/'0', T30, '****** END OF RIVER DATA ******')
      WRITE (6,1130) (DATE(N),N=1,4)
1130  FORMAT ('1'/'0', T35, 'RIVER SYSTEM SUMMARY - ', 4A4/'0', T2,
     1       '1. CONCENTRATION DIFFERENCES (OBS-CALC)')
      WRITE (6,1140)
1140  FORMAT ('0', T20, 'FLOW', T33, 'PH', T40, 'TEMP(C)', T50,
     1.       'SP COND', T60, 'DISS NA', T70, 'NF RES.', T80, 'TOT FE',
     2       T90, 'TOT MN', T100, 'TOT CU')
      WRITE (6,1150)
1150  FORMAT (' ', T18, 'X1000M3/D', T32, 'UNITS', T50, 'UMHOS/CM', T61,
     1       'MG/L', T71, 'MG/L', T81, 'MG/L', T91, 'MG/L', T101,
     2       'MG/L')
      DO 117C I = 1, K
        WRITE (6,1160) I, (FIN(I,N),N=1,9)
1160    FORMAT ('0', T2, 'SEGMENT', 2X, I2, T18, F7.0, T30, F6.2, T40,
     1             F6.2, T50, F6.1, T59, F8.2, T69, F8.1, T78, F8.3, T90,
     2             F6.3, T100, F6.3)
```

```
1170  CONTINUE
      WRITE (6,1180) (DATE(N),N=1,4)
1180  FORMAT ('0'/'0', '2. LOAD DIFFERENCES* FOR ',4A4)
      WRITE (6,1190)
1190  FORMAT ('0', T39, 'DISS NA', T49, 'NF RESIDUE', T60, 'TOT FE',
     1        T70, 'TOT MN', T80, 'TOT CU')
      WRITE (6,1200)
1200  FORMAT (' ', T38, 'TONS(M)/D', T49, 'TONS(M)/D', T59, 'TONS(M)/D',
     1        T69, 'TONS(M)/D', T79, 'TONS(M)/D')
      DO 1230 I = 1, K
        WRITE (6,1210) I, (DIFF(I,N),N=5,9)
1210    FORMAT ('0', T19, 'SEGMENT', 2X, I2, T37, F10.3, T49, F9.1, T60,
     1          F8.2, T70, F7.3, T80, F7.3)
        DO 1220 N = 5, 9
          NDIF(I,N) = DIFF(I,N) / DIST(N)
1220    CONTINUE
1230  CONTINUE
      WRITE (6,540)
      WRITE (6,1240) (DATE(N),N=1,4)
1240  FORMAT ('1'/'0', '3. NORMALIZED LOAD DIFFERENCES* (PER KILOMETER)
     1FOR ',4A4)
      WRITE (6,1190)
      WRITE (6,1200)
      DO 1250 I = 1, K
        WRITE (6,1210) I, (NDIF(I,N),N=5,9)
1250  CONTINUE
      WRITE (6,540)
      WRITE (6,1260) (DATE(N),N=1,4)
1260  FORMAT ('0'/'0', '4. MEAN AVAILABLE CAPACITIES* FOR ',4A4)
      WRITE (6,1190)
      WRITE (6,1200)
      DO 1270 I = 1, K
        WRITE (6,1210) I, (STOR(I,N),N=5,9)
1270  CONTINUE
      WRITE (6,950)
      WRITE (6,1280) (DATE(N),N=1,4)
1280  FORMAT ('1', '5. SYSTEM CALIBRATION VALUES FOR ', 4A4)
      WRITE (6,1140)
      WRITE (6,1150)
      DO 1290 I = 1, K
        WRITE (6,1160) I, (CALI(I,N),N=1,9)
1290  CONTINUE
      GO TO 20
1300  CONTINUE
      RETURN
      END
```

APPENDIX II

CONVERSION FACTORS

ENGLISH UNIT	MULTIPLIER	S.I. UNIT
acre	4,046	m^2
acre	0.405	ha
acre-ft	1,234	m^3
cu ft	0.028	m^3
cu in	16.39	cm^3
cfm	0.02832	m^3/min
cfs	1.70	m^3/min
ft	0.3048	m
^oF	0.5555 (^oF - 32)	^oC
gal (Imp)	0.004546	m^3
gpm (Imp)	0.2728	m^3/hr
in	2.54	cm
lb (mass)	0.4546	kg
lb/cu ft	16.02	kg/m^3
lb/day/acre	0.112	g/day/m^2
lb/day/acre - ft	3.68	g/day/m^3
lb/day/cu ft	16.02	kg/day/m^3
lb/day/sq ft	4.880	g/day/m^2
lb/ton	0.5	kg/t
mgd (Imp)	4546	m^3/day
sq ft	0.09290	m^2
ton	9072	kg
ton	0.9072	t