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Government of Canada
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Dartmouth, Nova Scotia
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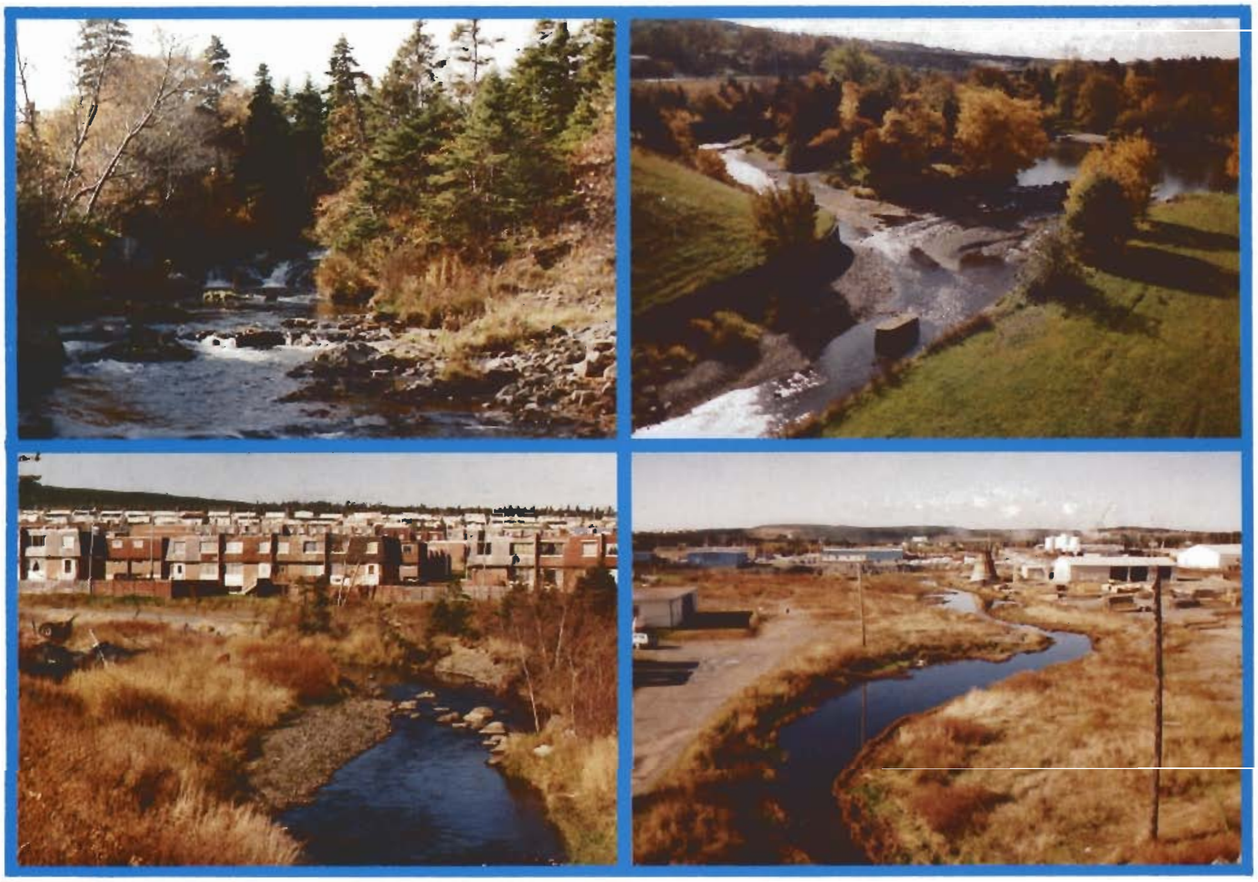
SURFACE WATER QUALITY STUDY



Urban Hydrology Study of the Waterford River Basin

TECHNICAL REPORT No.
UHS-WRB 1.4

SURFACE WATER QUALITY STUDY

IN THE WATERFORD RIVER BASIN

by

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Dear Dr. Ullah:

I am pleased to enclose a copy of the final report of the Water Quality Sub-Committee entitled "Surface Water Quality in the Waterford River Basin" as our contribution to the Waterford River Basin Urban Hydrology Study.

Yours truly,

T.L. Pollock, Ph.D.
Chairman
Water Quality Sub-Committee

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ABSTRACT

This report summarizes surface water quality observed in the Waterford River Basin during the period 1980-1984. This water quality study was carried out as part of the Waterford River Basin Urban Hydrology Study. The report presents data summary statistics for stations situated in (i) wooded, (ii) agricultural, (iii) light industrial, (iv) residential, and (v) urban areas. Surface water quality differences and variations observed in these various regions, both within and between rain events, are interpreted. The adequacy of the sampling and analytical scheme adopted is discussed in relationship to future studies in Newfoundland.

RÉSUMÉ

Le présent rapport résume l'état de la qualité des eaux de surface du bassin de la rivière Waterford observé durant la période 1980-1984. Cette étude sur la qualité des eaux a été accomplie dans le cadre de l'étude sur l'hydrologie urbaine du bassin de la rivière Waterford. Sont présentées dans ce rapport les données sommaires de la qualité des eaux recueillies aux stations d'échantillonnage situées dans des régions boisées (i), agricoles (ii), légèrement industrielles (iii), résidentielles (iv), et urbaines (v). Les différences et variations de qualité des eaux de surface observées dans ces différentes régions, pendant et entre les événements pluviaux, sont interprétées. Le programme d'échantillonnage et d'analyse adopté lors de cette étude est discuté en fonction des besoins de futures études qui seront effectuées à Terre-Neuve.

PREFACE

The Waterford River Basin Urban Hydrology Study, developed as a co-operative effort between the Governments of Canada and the Province of Newfoundland, was proposed by the Newfoundland Department of Environment in response to watershed management problems that had resulted from urbanization of the Waterford River Basin. Among such problems, negative effects of urbanization on both water quality and quantity were found so serious that the Newfoundland Department of Environment identified the Waterford River Basin as a high priority area.

The five-year study began in 1980 and most tasks were completed in March, 1985. Primary objectives of the study were to develop environmentally acceptable criteria for urban development in Newfoundland and to utilize the study results directly in the urban planning process in the Province. The specific objectives of the study, as outlined in the report "Waterford River Basin - Urban Hydrology Study Plan", were as follows:

(1) To examine the processes leading to changes in the hydrologic regime of the Waterford River watershed. This should include evaluation and monitoring of major hydrologic changes caused by urbanization, the study of precipitation-runoff processes, and the study of various forms of pollution originating in the urban areas of the watershed.

(2) To provide a hierarchy of mathematical models describing hydrologic processes in the watershed. Such models should deal with both water quantity and quality, and should be capable of simulating the impact of urbanization on the water resources in the studied basin.

(3) To recommend solutions to specific water management problems in the studied basin and to develop guidelines for implementation of similar solutions elsewhere in Newfoundland. Furthermore, planning and management criteria should be developed for those aspects of the urban development which relate to the environmental protection of the affected water resources.

The complexity of the study called for a comprehensive approach which included hydrometric surveys, hydrological modelling, groundwater studies, biological surveys, water quality assessment, investigations of flooding, and land use and socio-economic analyses.

The study was administered by a Steering Committee appointed by the governments of Newfoundland and Canada. To implement the study plan, a Technical Committee consisting of two representatives of each government was established. Subsequently the Technical Committee appointed sub-committees and working groups to prepare and carry out work plans for the various components of the study. The report that follows deals with one such component - surface water quality.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of the laboratory staff of the Environmental Protection Service, St. John's, the Newfoundland and Labrador Public Health Laboratories, St. John's and the Inland Waters Directorate, Water Quality Branch Laboratory, Moncton for the analyses of all the water samples. The staff of Water Resources Branch, IWD St. John's kept the CAE automatic water sampler working under adverse conditions and Mr. Ken Rollings, Newfoundland Department of the Environment kept the water samples coming as the project wound down.

We here acknowledge the skill and patience of Louise Boulter who typed this manuscript in all its various forms.

We also extend our appreciation to Geoffery Howell for his input, to Ron Howatt and Hal Bailey for drafting the maps, and to Lawrence Wong and Dick Bingham for their computer data management assistance.

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1.0 INTRODUCTION

The Water Quality Branch (WQB), Atlantic Region, was given the task of investigating the surface water quality in the Waterford River basin. The goal was to quantitatively evaluate the extent to which several existing and proposed agricultural, urban (developing and developed) and industrial activities could be affecting surface water resources throughout the basin. During the period of December 1980 to July 1984 a rigorous monitoring program was established to assess the influence of urbanization, seasonal/annual variations and individual storm events on receiving surface water quality. Physical, chemical and bacteriological water quality parameters were analyzed, the data are presented, discussed and interpreted in this report. Data from the groundwater and storm runoff studies, which were performed in the Waterford River basin during the same period of time as the surface water study, were used in this report to complement the surface water data interpretation.

2.0 WATER QUALITY MONITORING

2.1 Urban Development and Water Quality

The process of urbanization creates different types and degree of impacts on water quality depending on the stage of development. The developing and fully developed areas create dissimilar effects on receiving waters in terms of physical, chemical and biological quality changes. The difference in impacts are briefly outlined in the following sub-sections.

2.1.1 Urbanizing areas

The major water quality problems associated with developing urban areas can result from till exposure and soil disturbance, vegetation removal, excavation within, and exposure of bedrocks and draining of bogs. Specifically, the impacts resulting from these activities include the following:

1. Till exposure and soil disturbance tend to increase erosion and siltation processes which in in turn increase the levels of suspended and total solids, turbidity and colour of the receiving waters. This can result in loss of recreational facilities, fish habitat, deteriorated water quality for beneficial uses and reduced level of productivity (primary/secondary/tertiary) and benthic populations in the aquatic environment.

2. Removal of vegetation can increase nitrification rates which produce high levels of nitrate and dissolved cations in both surface and groundwaters. The potential effects of this process on receiving waters include:

   (a) high nitrate levels in potable water which constitutes a direct health hazard;

(b) high nitrate levels in surface water which can lead to eutrophication (algal blooms, smells, etc.).

3. Excavation within an exposure of certain bedrock units (sandstone, shale and coal) can result in acid mine drainage. The principal source of acid mine drainage is sulphide minerals (pyrite and/or marcasite) contained within the host rock. Upon exposure to air and water, the sulphide minerals oxidize to form sulphates which hydrolyze to produce both sulphuric acid and ferric hydroxide compounds. Receiving waters into which acid mine drainage is discharged are typically acidic (pH 2-4), highly coloured, and contain, because of increased leaching potential, high concentrations of aluminum, sulphate, iron, manganese and heavy metals which are normally present at trace or undetectable levels. Excavation of foundations and discharge of turbid water have potential to create serious siltation of receiving waters.

4. Bog and wetland drainage operations can result in a number of undesirable receiving water quality impacts because bog waters are typically highly coloured and acidic. Bog drainage practices can therefore produce high levels of iron, manganese, colour (organic acids such as humic and fulvic acids) and an acidic condition within receiving waters.

2.1.2 Urbanized areas

Fully or partially urbanized areas have been found to exert a significant influence on receiving surface water and groundwater quality. Surface and stormwater runoff from urban centres contain a number of dissolved substances (cations, metals, nutrients) and suspended particulate matter. The sources of pollutants originating from urban centres include: street litter and debris, leaf throughfall, use of deicing and/or dust control agents, dustfall and bird droppings from roofs, animal waste, nutrients from fertilizing lawns and gardens, metals from parking lots and streets, nutrients from decaying vegetation and septic tanks, and erosion of material around site excavations and open areas.

Results from other studies have demonstrated that surface and storm water runoff from urban centres can contain contaminants in excess of levels measured in sanitary sewers. The quality of stormwater from a developed area varies significantly from runoff associated with a developing urban area because developing areas produce storm water which is relatively higher in suspended solids and lower in TDS and nutrients. Alternatively, urban stormwater runoff from a developed area is suspected to be higher in TDS, nutrients, BOD, metals and somewhat lower in solids. Storm water runoff from fully developed urban areas can accelerate the eutrophication process within aquatic environments, contaminate water supplies, emplace high levels of metals into surface and groundwaters and increase the levels of sodium, chloride, TDS and conductivity in surface and groundwaters because of road salting activities.

2.1.3 Agricultural runoff

Agricultural runoff causes a number of water resources impacts in surface waters including sediment build-up, nutrient enrichment and bacteria increases within lakes and rivers. Sediment losses from agricultural land has been estimated to be approximately 18-23 metric tons/ha per year. The combined effects of fertilization, drainage and microbial activities has been estimated to yield 4 to 5 times more phosphorous and 40 to 50 times more nitrate in storm runoff from agricultural as compared to forested watersheds. Nutrient loadings can accelerate the eutrophication processes within aquatic systems. Storm runoff from livestock wastes can constitute a significant source of fecal (particularly fecal streptococcus) bacteria in river, lake and possibly groundwater systems.

2.1.4 Hydrologic influences on water quality

Prior to evaluating the water quality impacts resulting from cultural activities, it is imperative to define seasonal/annual variations in water quality as influenced by streamflow characteristics. It is well known that major ion chemistry (amount and distribution) can be significantly altered on a seasonal basis in response to variations in flows. It is, therefore, essential to determine parameter loadings based on streamflow volumes for comparison purposes.

Contaminants/pollutants associated with urban activities are typically "washed-off" the land surface during rain events. It is therefore necessary to collect a series of event samples during heavy rains to determine "first flush phenomena" and impacts on receiving waters.

2.2 Water Quality Program Objectives

The objectives of the water quality program were:

1) to characterize background surface and groundwater quality conditions throughout the basin while considering seasonal variations in water quality corresponding to major hydrologic events.

2) to assess the influence of cultural activities (agriculture, urban, industrial) on receiving surface and groundwater quality; and

3) to provide quantitative water quality information required to calibrate and verify models designed to predict urban runoff/receiving water effects.

2.3 Sampling Program

2.3.1 Sampling Network

As part of the water quality program, eight surface and 14 groundwater stations were regularly monitored to determine and characterize water quality conditions throughout the basin. The Newfoundland Department of Environment had established surface water stations and had monitored them on a regular basis for two years prior to initiating this program. The existing surface water sites are located in a manner which should permit the identification of impacts of alternative land use activities on receiving waters. The location and description of these sites are given in Section 3. The site description of the groundwater monitoring sites is contained in a separate report on groundwater.

As part of water quality monitoring, one automatic water sampler (CAE type) was installed at the hydrometric station in Kilbride and one Sirco sampler was installed at the outlet of the storm runoff study area. The samplers have the capacity to sequentially obtain 40 and 24 samples respectively during a rain event. This permitted the identification of the variation in water quality within the event.

2.3.2 Sampling frequency and water quality parameters

Table 1 is a list of water quality parameters which were analyzed in surface and groundwater samples collected from the study sites. Single grab samples were obtained on a monthly basis from the selected surface water sampling stations throughout the basin. In order to quantitatively assess the influence of hydrologic variability on water quality, grab samples were also collected following every rainfall event exceeding 15 mm.

Water samples for bacteriological analysis were collected once a month and also during an event sampling from each of the surface water stations and the stormwater outfall.

The CAE type automatic sampler was installed at the hydrometric station, Kilbride, by the Water Survey of Canada in November 1981. In the initial period of its installation, a number of operational problems and difficulties associated with water quality sampling were encountered. These were gradually resolved. The sampler started functioning satisfactorily in September 1982. Since then, the sampler has functioned well without any serious problems except for the period

TABLE 1. Listing of studied parameters

Parameters	Abbreviations used in Data Tables*	Units	NAQUADAT Numbers
Color apparent	Col. App.	Rel. Units	02011L
Specific conductance	Sp. Cond.	uS/cm	02041L;02051L;02051S
Water temperature	Water Temp.	^{o}C	02061L;02061S
Turbidity	Turb.	J.T.U.	02073L
Total organic carbon	T.O.C.	mg/L	06001P;06001L
Dissolved organic carbon	D.O.C.	mg/L	06107L
Nitrite-nitrate	NO2-NO3	mg/L as N	07110P;07110L
Nitrogen total	NTot	mg/L	07601L;07601P
Oxygen dissolved	Diss.Oxygen	mg/L	08101F;08102F
Alkalinity total	Alk. Tot.	mg/L as $CaCO_3$	10101L;10101F
Alkalinity Gran	Alk. Gran	mg/L as $CaCO_3$	10110L
pH			10301F;10301L;10301S
Residue nonfilterable	Res. N.F.	mg/L	10401L;10401F
Sodium dissolved	Na Diss.	mg/L	11103L
Magnesium dissolved	Mg Diss.	mg/L	12107L;12102L
Silica reactive	SiO_2	mg/L	14102L
Phosphorus total	P Tot.	mg/L	15413P;15413L
Sulfate dissolved	SO_4 Diss.	mg/L	16304L;16309L
Chloride dissolved	Cl Diss.	mg/L	17205L
Potassium dissolved	K Diss.	mg/L	19102L
Calcium dissolved	Ca Diss.	mg/L	20110L;20103L
Manganese extractable	Mn Extract.	mg/L	25304P
Iron extractable	Fe Extract.	mg/L	26304P
Copper extractable	Cu Extract.	mg/L	29305P;29306P
Zinc extractable	Zn Extract.	mg/L	30304P
Lead extractable	Pb Extract.	mg/L	82301P;82302P
Instantaneous discharge		m^3/s	97160F;97160S

* see pages 23 to 26.

January to March 1984.

The sampler was programmed to fill a sample bottle every half hour when the river stage exceeded 1.8 m. During the months of June to August, the stage was set at 1.7 m. because of relatively low flow conditions. The sampler could collect a maximum of 40 samples in one pint glass bottles. A system of sequencing of bottles on a rotating basis from event to event was developed and followed for submission of sample bottles. They were forwarded to Water Survey of Canada for sediment analysis, and to laboratories in Moncton and St. John's for chemical and physical analyses respectively. The system was designed to ensure that each laboratory would get representative samples for all stages of flow as characterized by the hydrograph.

The Sirco sampler located at the stormwater outfall station in Mount Pearl became operational in 1983. Samples collected from this sampler were sent to the respective laboratories for analysis similar to other surface water samples. Further details of this sampling program and the results of the analyses are presented in a separate report on the Urban Runoff Study.

The collection of groundwater samples from seven deep and seven shallow observation wells was initiated in mid 1981. These samples were analysed for physical, chemical, and bacteriological quality by the laboratories in Moncton and St. John's. The initial problem of high turbidity in samples was remedied by the use of a peristaltic pump for sample collection. Details of the sampling program and the results of the analyses are presented in a separate report on groundwater.

2.3.3 Sampling methodology/preservation

The methods for surface water sampling and preservation are outlined in "Sampling for Water Quality" (WQB, 1983). The methods used for groundwater sampling for both shallow and bedrock observation wells have been described in detail in the report on groundwater. Water sampling and preservation of samples was performed by field personnel from the Newfoundland Department of Environment. As a field quality control measure, field blanks were prepared whenever samples were preserved. Water samples were shipped to Moncton in coolers by air express.

Water samples for bacteriological analyses were also collected from all surface water monitoring sites in sterilized glass bottles on a monthly and event basis. These samples were submitted to the Public Health Laboratories in St. John's within 24 hours of sampling. The samples were always stored at less than 10°C.

2.3.4 Sample analyses

Standard WQB laboratory analytical methodologies were followed, as described in the Analytical Methods Manual (WQB, 1979) and are listed in Table 1. The Environmental Protection Service (EPS) laboratory in St. John's carried out the analysis of physical parameters such as conductivity, TDS, TSS, turbidity and colour. The WQB laboratory in Moncton was responsible for the analysis of the remaining chemical parameters.

The membrane filtration technique was used throughout the bacteriological investigation by the Newfoundland Public Health Laboratory. This technique is considered to be highly reproducible and was carried out according to methods described in the Standard Methods for the Examination of Water and Waste Water (15th ed., 1980).

2.3.5 River stages/flow rates

River stages and flow rates for the water quality stations at Kilbride, Mt. Pearl, and Donovans were obtained from the water level recorder charts for the respective hydrometric stations. For stations at the CDA farm, South Brook at Old Bay Bulls Road and South Brook at Ruby Line, river stages were read on the staff gauges. The stage heights were then converted to discharge values using approximate stage-discharge relationships developed by the Water Survey of Canada. During the period of this study, flow rates for each sampling from all water quality stations were provided by the Project Engineer in consultation with the WSC staff. Flow rates at the remaining two sites were estimated based on measured values of other stations.

3.0 STUDY AREA AND MONITORING STATIONS

3.1 Study Area

3.1.1 Physical features

The Waterford River Basin covers an area of approximately 61 km^2 and is located on the western outskirts of the City of St. John's (Figure 1). The Waterford River stretches 13 km from Bremigans Pond at an elevation of about 170 m in the west to St. John's Harbour in the east. The major tributary of the Waterford River is South Brook which extends 11 km from the marshy headwaters, where flow is intermittent, to the confluence with the main river at Bowring Park. There are other smaller tributaries which drain into either the Waterford River or the South Brook.

The portion of the Waterford River basin (53 km^2) which comprises the study area extends up to the hydrometric station at Kilbride. The remaining portion of the basin downstream of the hydrometric station is fully developed and in a number of places the drainage system has been modified. Also, there are several unidentified cross connections of sanitary and storm sewers and domestic sewage outfalls. This part of the basin was therefore not included in the study area.

3.1.2 Geology and soils

The bedrocks of the area consist largely of Precambrian materials, mostly sedimentary in origin but with some volcanic deposits. The principal rock types are hydryrian siltstone, arkose, conglomerate, slate and acidic to intermediate volcanic rocks. The most significant features influencing groundwater movement in the basin are major plunging folds and fracture zones in low porosity rocks which generally slope toward the Waterford River and South Brook. Secondary growths of pyrite and pyrolusite are commonly altered to iron and manganese

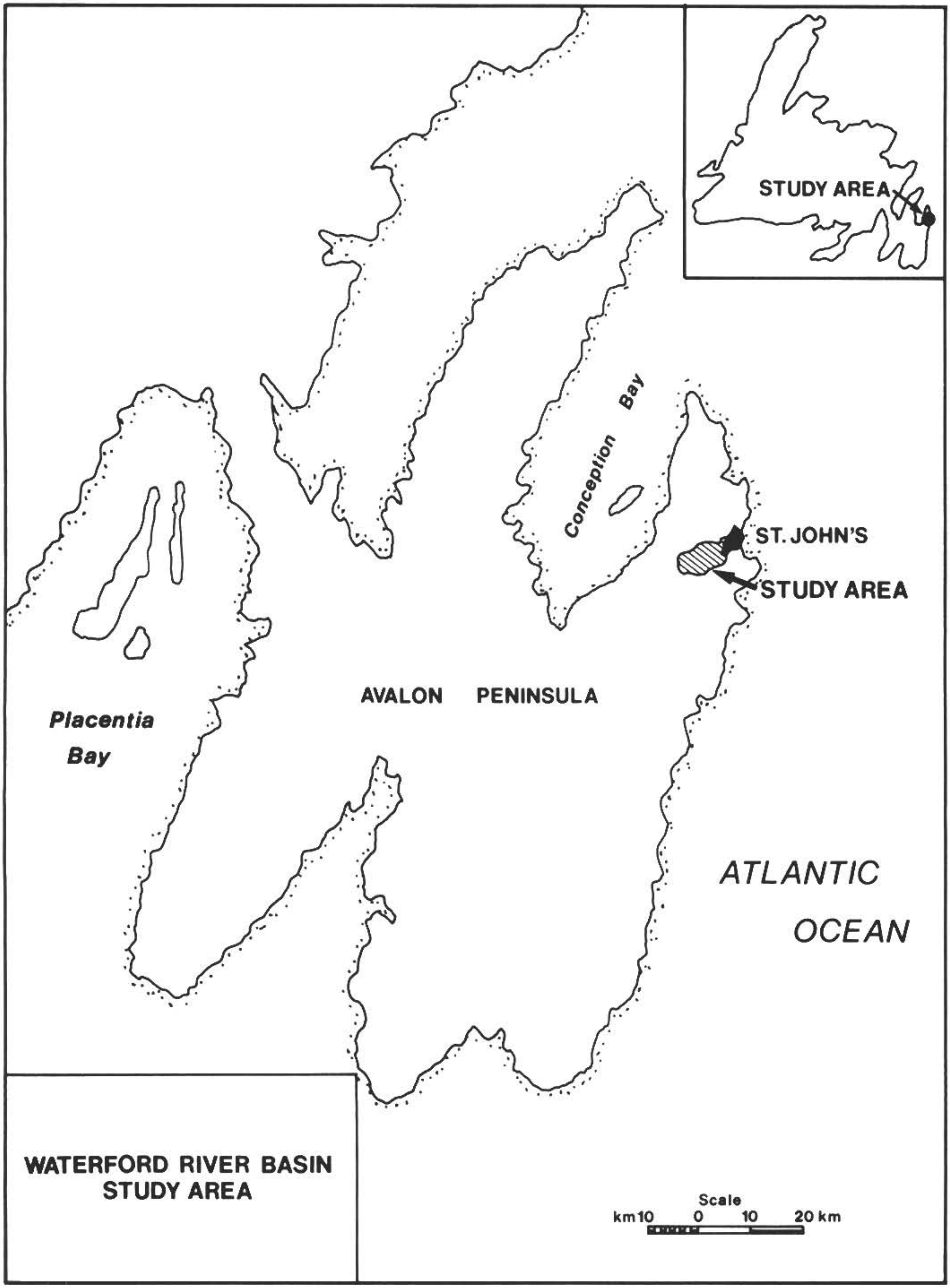

STUDY AREA
Conception Bay
ST. JOHN'S
STUDY AREA
Placentia Bay
AVALON PENINSULA
ATLANTIC OCEAN
WATERFORD RIVER BASIN
STUDY AREA
Scale
km 10 0 10 20 km

Figure 1

precipitates along fractures in some formations including thinly bedded sandstones which adversely affect water quality (King, 1984).

Most of the study area is covered by materials of glacial origin which range in depth from zero to 5 m. The overburden is composed of a very compact, poorly sorted lodgement till with high silt-clay content overlain by a till deposit that is looser, coarser and more permeable. The soils were formed largely by the action of weather and glacial deposits. The soils are coarse textured and contain stones, gravel, and boulders. Water movement is largely determined by the overburden mantle (Batterson 1984). Soil capability for agriculture and forestry in the area is low because of unfavourable topography, stoniness and shallow depths of the soil.

3.1.3 Climate

The climate of the Avalon Peninsula is somewhat more temperate than the remainder of the Island, being modified by its proximity to the sea. The mean annual temperature is 4.0°C, mean relative humidity is 86%, average annual precipitation is 1600 mm, and estimated annual evaporation is 380 mm. The distribution of precipitation is fairly uniform throughout the year except June and July which receive relatively less rainfall. Snowfall accounts for about one third of the total annual precipitation.

The snow accumulation is usually not excessive because of frequent thawing periods during winter months.

3.1.4 Land use and land use changes

The Working Group on Land Use, appointed by the Technical Committee for the assessment of land use changes during the period of this study, prepared land use maps based on aerial photographs of the study area taken in 1973, 1981 and 1984. The extent of various land uses in the study area based on the 1981 and 1984 maps is presented in Table 1A.

TABLE 1A

LAND USE CHANGE DURING 1981-84

Land Use Category	1981		1984		
	Area km^2	% of Basin Area	Area km^2	% Basin Area	Change %
Residential	6.6	12.5	7.3	13.2	+ 1.3
Commercial/ Industrial	2.5	4.7	2.9	5.5	+ 0.8
Agriculture	6.2	11.7	5.9	11.2	- 0.5
Forest	19.7	34.3	17.2	32.6	- 4.7
Unproductive Lands	13.2	25.0	15.3	29.0	+ 4.0
Other, (Recreation, Ponds, Lakes, etc.)	4.6	8.7	4.8	8.1	- 0.6

TABLE 2

SURFACE WATER STATIONS

STATION NO.	NAQUADAT STATION NO.	DESCRIPTION	DRAINAGE AREA (KM)	LAND USE
6	OONF02ZM0001	SOUTH BROOK AT CULVERT ON RUBY LINE ROAD	5.41	FOREST
1	OONF02ZM0003	WATERFORD RIVER AT DONOVANS (PAST THE INDUSTRIAL PARK)	11.4	LIGHT INDUSTRIES
2	OONF02ZM0004	WATERFORD RIVER AT COMMONWEALTH AVENUE BRIDGE	16.6	RESIDENTIAL/ COMMERCIAL
4	OONF02ZM0006	BROOK AT AGRICULTURE CANADA FARM	3.16	RESIDENTIAL/ AGRICULTURAL
7	OONF02ZM0007	SOUTH BROOK AT HEAVY TREE ROAD	7.40	FOREST
8	OONF02ZM0008	TRIBUTARY OF SOUTH BROOK DRAINING DEADMANS POND. STATION AT BRIDGE NEXT TO 95 OLD BAY BULLS ROAD	6.01	SUB-URBAN/ AGRICULTURE
5	OONF02ZM0009	WATERFORD RIVER AT KILBRIDE	52.7	ALL USES
3	OONF02ZM0012	WATERFORD RIVER AT BRIDGE ON DUNNS ROAD	21.1	RESIDENTIAL/ COMMERCIAL

The study area has not experienced any significant change in land uses during the period under study as was initially anticipated. There was only a small increase (2.1%) in the urban land use. There has been sustained decrease in agricultural and forest uses. This decline contributed mostly to unproductive sectors (cleared and open areas) which generally is a transitionary stage between forest and developed land use category. These changes were generally observed uniformly in all sub-basins. There was no evidence of any substantial change in any of the sub-basins monitored for water quality. The extent of urbanized area in any of the sub-basins did not exceed 20-25%.

3.2 Monitoring Stations

The selection of the water quality stations was primarily based on land use consideration, geographical distribution and representativeness. Eight water quality stations were selected in representative industrial, urban, agricultural and forested parts of the basin. This was done to obtain information on the effects of the various land uses on the surface water quality in the study area. The locations of these stations are shown in Figure 2. A listing of the stations and their descriptions are given in Table 2.

The most upstream station (#1) was located just below Donovans industrial park, which is mainly occupied by warehouses and some light industries. The second site (#2) is about 2 km downstream at the Commonwealth Avenue bridge. During its run to this site the river leaves the industrial park and enters the Town of Mount Pearl. A further 2 km downstream is the Dunns Road station (#3). Before reaching this site at the eastern extremity of Mount Pearl, the river follows an irregular sinuous pattern. These three stations, as will be discussed later, were characterized by very similar water chemistry. All three were located near a major road system and in a relatively more developed (industrial and urban) area. The most downstream station on the Waterford River was situated at the Kilbride hydrometric station (#5), and integrated the effects from all of the tributaries. A fifth station (#4) was located on a tributary to the Waterford River at the Agriculture Canada

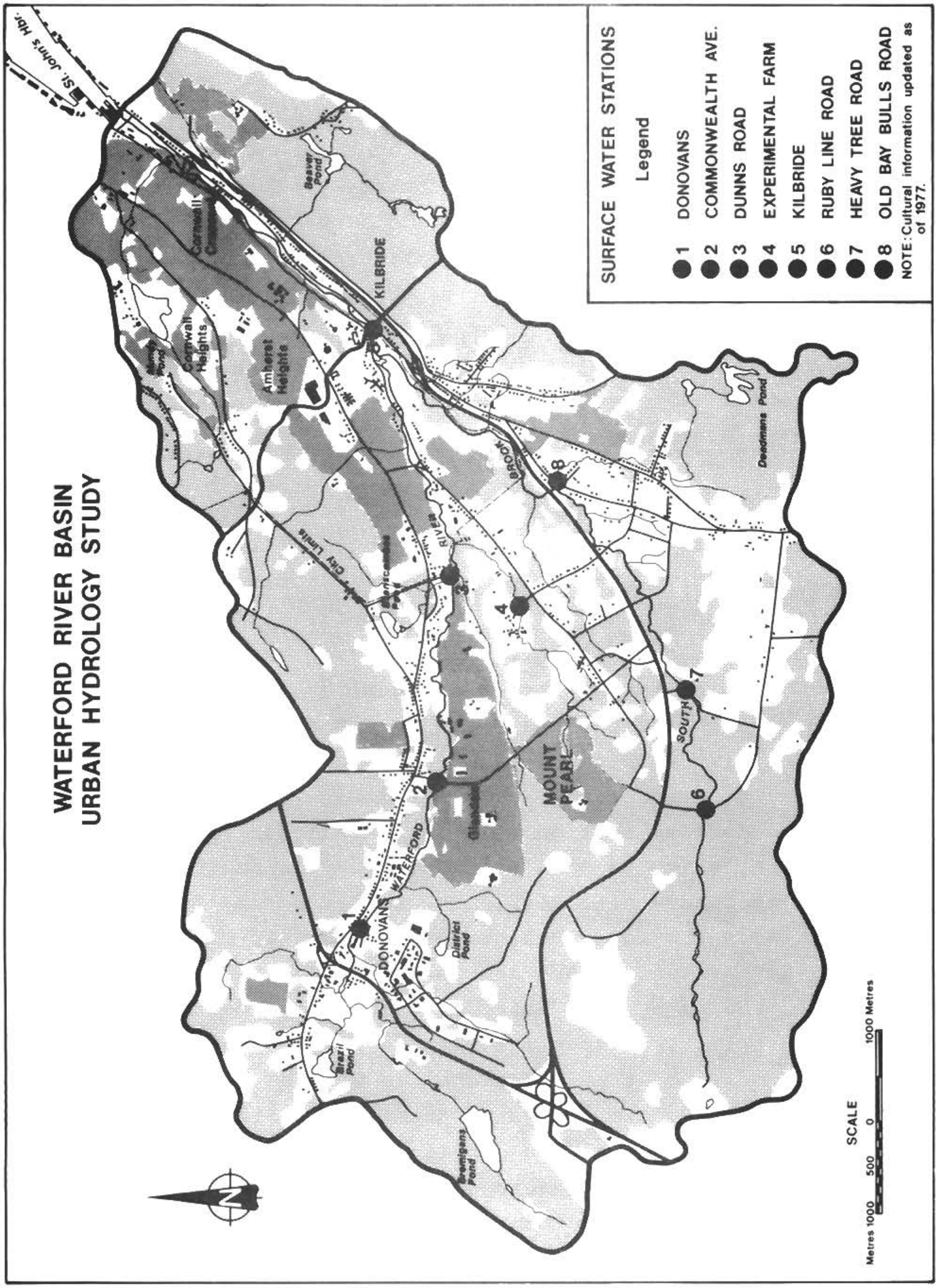

WATERFORD RIVER BASIN
URBAN HYDROLOGY STUDY
SURFACE WATER STATIONS
Legend
1 DONOVANS
2 COMMONWEALTH AVE.
3 DUNNS ROAD
4 EXPERIMENTAL FARM
5 KILBRIDE
6 RUBY LINE ROAD
7 HEAVY TREE ROAD
8 OLD BAY BULLS ROAD
NOTE: Cultural information updated as of 1977.
St. John's Hbr.
KILBRIDE
Amherst Heights
Cornwall Heights
WATERFORD
RIVER
MOUNT PEARL
DONOVANS
SOUTH
BROOK
District Pond
Beaver Pond
Deadmans Pond
City Limits
SCALE
Metres 1000 500 0 1000 Metres

Figure 2

Experimental Farm. This tributary originates in a suburban area in the southern part of the Town of Mount Pearl. It subsequently drains some sheep pastures before reaching the sampling site, after which it meets the mainstem of the Waterford River just downstream of the Dunns Road station.

There were two stations on South Brook and one station on a tributary to South Brook. The most upstream station was located at Ruby Line (#6) and was indicative of "background" conditions. The samples were taken about 10 m upstream of the intake of the 2 m culvert which goes under Ruby Line. The whole area surrounding this site was forested with conifers. The second station on South Brook was located at the intersection with Heavy Tree Road (#7), about 2 km downstream of the Ruby Line station. The land was mainly forested between these two stations with black spruce (Picea mariana), white spruce (Picea glauca), white pine (Pinus strobus) and balsam fir (Abies balsamea) being the dominant species. These two stations were located in the most undeveloped region on the basin.

There was also a station located on a tributary of South Brook which drains Deadman's Pond, just upstream of the bridge next to Old Bay Bulls Road (#8). There are farms and homes in this area of the basin, but no industrial development.

A number of stormwater outfalls and ditches are located along the reaches of the Waterford River and its major tributaries. These were generally the source of some turbidity in the river water.

4.0 SURFACE WATER CHARACTERISTICS

4.1 Physical Parameters

4.1.1 Water colour

Colour is attributable to organic and inorganic matter dissolved in water and is affected by turbidity. Common organic sources include natural products from decaying vegetation, leachates from soils and agricultural runoff.

There were no major differences observed in apparent water colour between the sampling sites located on the Waterford River Basin. The range for all stations, except Donovans, varied between 5 and 70 Hazen units. At Donovans, the maximum observed value was 50 H.U.. The two stations on South Brook generally had higher apparent water colour and higher dissolved organic carbon concentrations than the stations on the mainstem. This was possibly due to influences of the marshy headwaters. The Old Bay Bulls Road station also frequently had relatively high colour values (over 50 H.U.). Concomitantly, this South Brook tributary frequently showed the highest organic carbon and total nitrogen content, and the fecal coliform counts were generally high compared to the other study sites. There were some coloured and turbid waters flowing from a ditch located directly on the left side of this sampling site, which probably contributed to these observations. In addition, upstream from this site, there are pasture lands. These could be sources of allochthonous inputs of coloured organic matters carried to the river by runoff. Figure 3 presents the frequency distribution of apparent water colour values observed at the Donovans, Ruby Line and Old Bay Bulls stations. From this figure, it is obvious that these three representative stations have a high frequency of apparent water colour values of 20 H.U., and that Ruby Line had the highest values in the range 60 to 70 H.U.

There seemed to be seasonal variations in apparent water colour

FIG. 3 FREQUENCY OF APPARENT WATER COLOUR VALUES AT THREE STATIONS

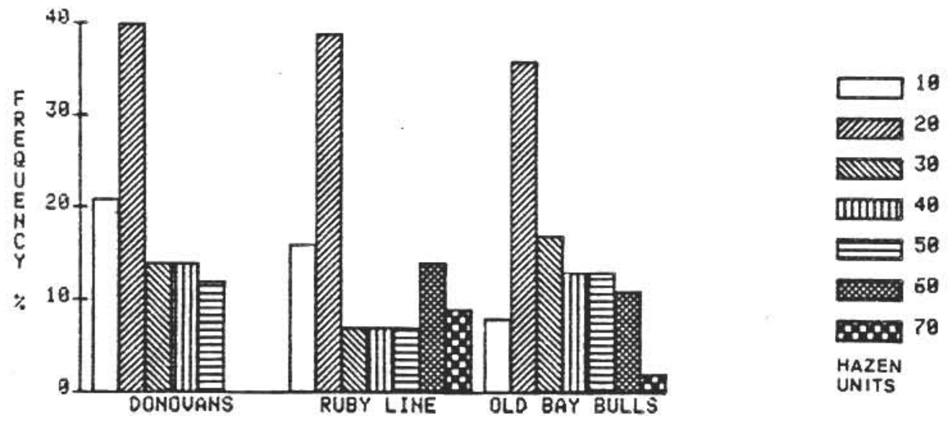


FIG. 4 VARIATION OF APPARENT WATER COLOUR AT DONOVANS

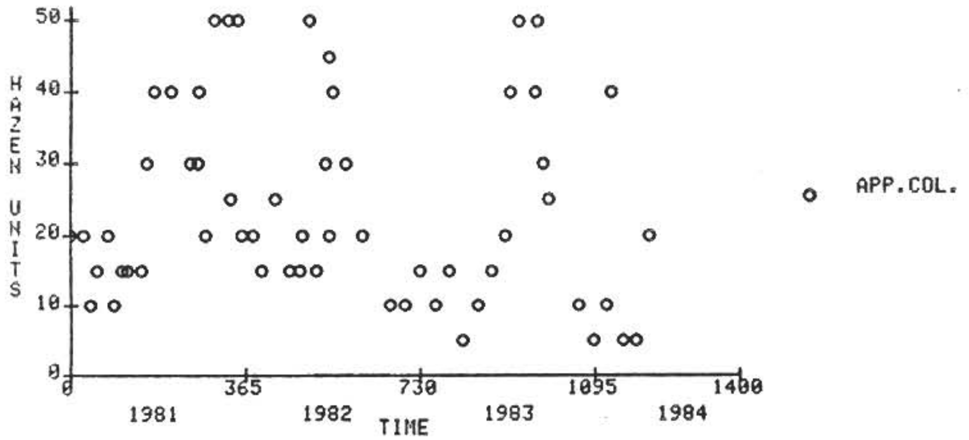
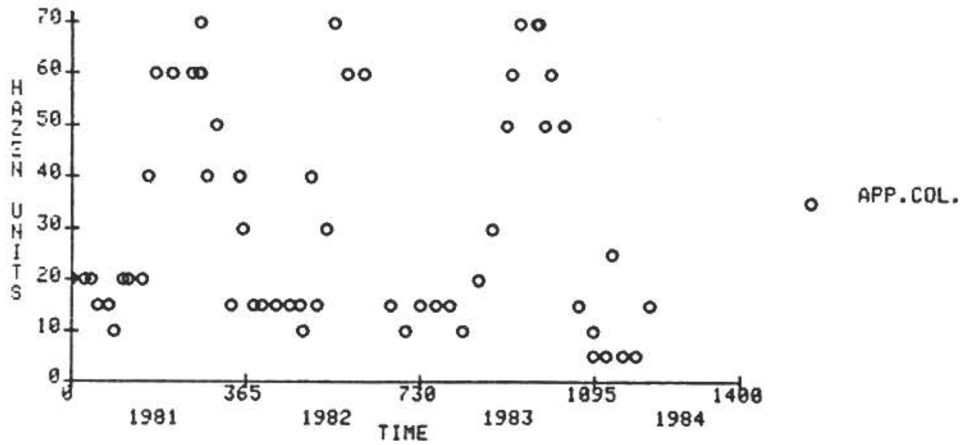


FIG. 5 VARIATION OF APPARENT WATER COLOUR AT RUBY LINE



as shown in Fig. 4-5. Lower values were generally observed in winter and in spring. This could be explained by the retention of coloured matter (soluble or particulate) by the snow and the ice in winter and early spring, and by the dilution effects caused by the spring melts and rain. Further there is a decrease in the activity of bacteriological decomposers during low temperatures causing the detritus to remain intact and insoluble. The higher values observed in summer and fall were not unexpected considering that colour is a measure of organics in the water.

4.1.2 Water temperature

The temperature of surface water is a function of season, latitude, elevation, time of day, rate of flow, depth and other factors. Water temperature at all stations fluctuated rapidly with changing air temperature. The range of water temperature observed during this study was from 0.0°C in winter to about 22°C in summer. The highest value recorded by field personnel, 21.6°C, was on the morning of July 8, 1983 at the Old Bay Bulls Road station. As for the three previous days, air temperature during that late morning was 27°C. All other stations had water temperatures varying between 18 and 20°C on that day.

4.1.3 Dissolved oxygen and oxygen saturation

The amount of dissolved oxygen in natural waters varies with temperature, salinity, turbulence (mixing) of the water, and atmospheric pressure. The concentration of dissolved oxygen is subject to diurnal and seasonal variations that are partly related to variation in temperature, photosynthetic activity and river discharge. It has been shown that a concentration of less than 4 mg/L results in detrimental effects on most aquatic organisms (McNeely, et al., 1979).

Dissolved oxygen generally ranged from 8 to 15 mg/L, with percent saturation usually over 90. Supersaturation was occasionally observed at every station. However, at the Donovans station, which is just downstream of an animal feed factory, some lower dissolved oxygen values at 6.8 mg/L and 7.5 mg/L (percent saturation of 68 and 76) were observed during the summer of 1983.

The observed values reflect the quality of the river water as it tumbles over a series of small falls and supports resident population of brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta Linnaeus).

4.1.4 pH

The range of pH values observed in the Waterford mainstem was indicative of slightly acidic to neutral (5.5 to 7.7) conditions, well within observed values for insular Newfoundland (Environment Canada, 1982). The lowest median value (6.3) on the mainstem was observed at the Donovans station and the highest value (6.8) at the Kilbride station. Kilbride generally had higher pH values than the three upstream stations on the mainstem. It also had higher alkalinity values.

The South Brook background station at Ruby Line always had the lowest pH values, ranging from 4.8 to 6.5 with a median of 5.6. This was a reflection of the marshy "acidic" headwater influence. At the downstream station, at Heavy Tree Road, pH was still low but higher than Ruby Line. It is suggested that this increase is related to both geological influences (groundwater contribution) and basin development. The Old Bay Bulls Road station had higher pH values than those observed at the two South Brook stations, indicating that the water from this site was more alkaline.

The higher pH values at any given station were generally associated with the lower flows, when groundwater may have been making its largest contribution to the flow. The pH values indicate a carbonic acid-bicarbonate buffering system. Figure 6 illustrates the range and median value observed at all surface water stations during the study period.

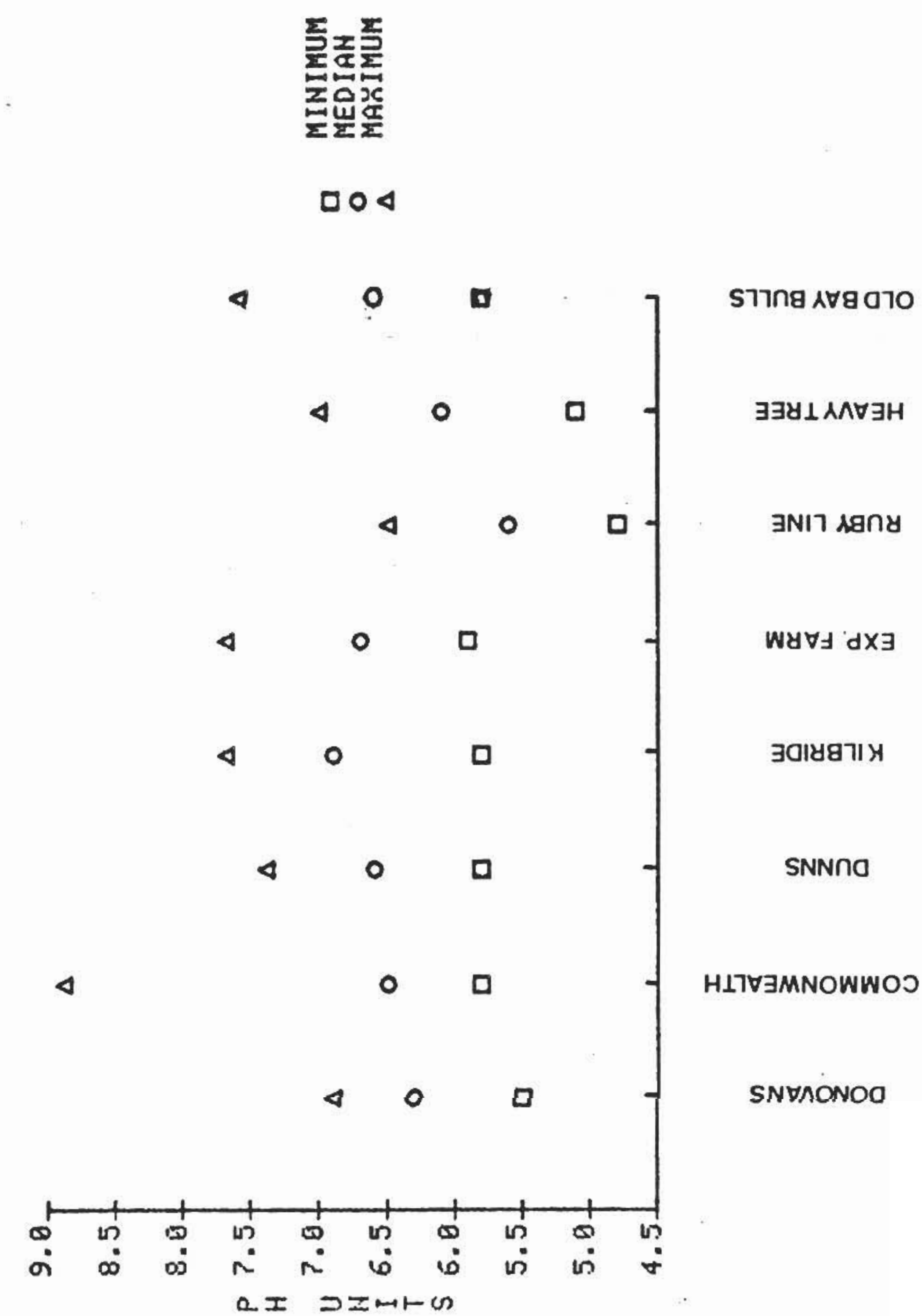


FIG.6 PH RANGE AND MEDIAN VALUE AT ALL STATIONS

TABLE 3
DATA SUMMARY : DONOVANS STATION (00NF02ZM0003)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	63	55	50	6	56	57	50	57	55	36	59	60
MINIMUM	5.5	4.5	0.6	-1.3	6.0	7.0	0.52	0.4	1.9	73	5	0.8
MAXIMUM	6.9	10.0	10.8	7.2	58.0	100.0	1.90	2.3	7.8	360	50	280.0
MEAN	-	6.5	5.6	4.0	21.9	37.3	1.20	0.8	4.7	155	24	14.7
MEDIAN	6.3	6.4	5.8	3.8	19.5	35.0	1.20	0.7	4.8	139	20	4.7

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 T.O.C.	17 NO2-NO3	18 N TOT.	19 P TOT.	20 FE EXTRACT.	21 MN EXTRACT.	22 CU EXTRACT.
COUNT	61	57	33	32	61	63	66	51	51	51
MINIMUM	0.0	1.7	1.4	3.5	0.01	0.17	0.008	0.18	0.01	0.002
MAXIMUM	400.0	6.1	9.3	31.5	0.76	1.80	0.470	2.80	0.80	0.008
MEAN	21.1	3.9	3.6	9.2	0.26	0.54	0.068	0.86	0.36	0.003
MEDIAN	6.8	4.0	3.3	6.5	0.22	0.46	0.048	0.68	0.37	0.002

	23 PB EXTRACT.	24 ZN EXTRACT.	25 WATER TEMP.	26 DISS. OXYGEN	27 COLIFORMS TOTAL	28 COLIFORMS FECAL
COUNT	50	35	60	30	37	37
MINIMUM	0.002	0.01	0.0	6.81	520	30
MAXIMUM	0.019	0.07	18.0	14.40	560000	22000
MEAN	0.003	0.03	6.8	10.80	24865	1791
MEDIAN	0.002	0.02	6.9	11.00	5300	700

TABLE 4
DATA SUMMARY : COMMONWEALTH AVE STATION (00NF02ZM0004)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	63	55	50	6	56	57	50	57	55	36	59	60
MINIMUM	5.8	4.5	1.6	2.1	5.3	6.4	0.2	0.4	1.9	59	5	0.6
MAXIMUM	8.9	14.5	10.1	6.9	102.0	170.0	1.8	1.1	9.4	600	70	520.0
MEAN	-	6.7	5.3	3.7	22.8	39.1	1.2	0.8	4.6	164	24	33.0
MEDIAN	6.5	6.6	5.2	3.2	19.0	32.5	1.2	0.7	4.6	140	20	4.8

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 T.O.C.	17 NO2-NO3	18 N TOT.	19 P TOT.	20 FE EXTRACT.	21 MN EXTRACT.	22 CU EXTRACT.
COUNT	61	57	33	32	61	63	66	51	51	51
MINIMUM	0	0.1	1.4	2.5	0.01	0.21	0.006	0.18	0.11	0.002
MAXIMUM	744	6.2	7.1	65.0	0.59	1.00	1.700	3.80	1.50	0.008
MEAN	55	3.8	3.2	11.5	0.27	0.50	0.120	0.85	0.38	0.003
MEDIAN	9	3.9	2.7	6.5	0.24	0.45	0.040	0.54	0.31	0.002

	23 PB EXTRACT.	24 ZN EXTRACT.	25 WATER TEMP.	26 DISS. OXYGEN	27 COLIFORMS TOTAL	28 COLIFORMS FECAL
COUNT	50	35	60	30	37	37
MINIMUM	0.002	0.01	0.0	8.8	1300	100
MAXIMUM	0.020	0.07	18.5	14.8	32000	5000
MEAN	0.004	0.03	7.1	11.5	6183	1273
MEDIAN	0.002	0.02	7.0	11.1	4200	700

TABLE 5

DATA SUMMARY : DUNNS ROAD BRIDGE STATION (00NF02ZM0012)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	61	54	50	6	55	56	48	55	55	35	57	60
MINIMUM	5.8	4.8	2.0	2.2	6.1	7.8	0.65	0.5	2.1	63	5	0.6
MAXIMUM	7.4	11.2	11.3	6.9	130.0	178.0	1.90	1.2	7.5	630	70	400.0
MEAN	-	6.8	6.0	3.4	25.8	42.8	1.20	0.8	4.9	179	20	27.5
MEDIAN	6.6	6.7	5.6	2.6	21.0	37.5	1.20	0.7	5.0	144	15	4.6

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 T.O.C.	17 NO2-NO3	18 N TOT.	19 P TOT.	20 FE EXTRACT.	21 MN EXTRACT.	22 CU EXTRACT.
COUNT	62	56	33	31	61	62	63	49	48	49
MINIMUM	0.0	0.1	1.2	3.0	0.01	0.20	0.007	0.17	0.10	0.002
MAXIMUM	490.0	6.0	6.6	49.0	0.73	0.95	0.850	6.70	1.10	0.011
MEAN	40.1	3.6	3.1	10.1	0.28	0.53	0.077	0.79	0.36	0.002
MEDIAN	7.0	3.8	3.0	6.5	0.27	0.48	0.034	0.52	0.33	0.002

	23 PB EXTRACT.	24 ZN EXTRACT.	25 WATER TEMP.	26 DISS. OXYGEN	27 COLIFORMS TOTAL	28 COLIFORMS FECAL
COUNT	47	33	61	30	36	36
MINIMUM	0.002	0.01	0.0	8.8	200	50
MAXIMUM	0.038	0.10	18.5	15.6	60000	10000
MEAN	0.005	0.03	7.0	11.5	7728	1276
MEDIAN	0.002	0.03	6.7	11.0	3000	600

TABLE 6

DATA SUMMARY : EXPERIMENTAL FARM STATION (00NF02ZM0006)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	57	51	49	3	51	52	45	51	50	33	54	56
MINIMUM	5.9	5.4	2.7	4.8	4.8	6.2	0.3	0.4	2.1	79	5	0.4
MAXIMUM	7.7	11.8	17.0	10.3	76.0	130.0	2.7	1.4	11.0	380	70	285.0
MEAN	-	7.9	9.5	6.8	23.2	40.5	1.5	0.8	6.6	175	20	16.9
MEDIAN	6.7	7.8	8.8	5.4	18.9	32.5	1.5	0.8	7.0	163	15	4.4

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 T.O.C.	17 NO2-NO3	18 N TOT.	19 P TOT.	20 FE EXTRACT.	21 MN EXTRACT.	22 CU EXTRACT.
COUNT	59	52	30	31	58	60	60	46	46	46
MINIMUM	0.0	0.1	1.1	2.5	0.01	0.29	0.003	0.12	0.06	0.002
MAXIMUM	328.0	6.9	5.6	85.0	0.60	1.10	0.700	1.80	0.81	0.006
MEAN	20.4	4.2	2.9	9.3	0.38	0.58	0.051	0.44	0.30	0.002
MEDIAN	4.0	4.4	2.6	6.4	0.38	0.56	0.023	0.29	0.30	0.002

	23 PB EXTRACT.	24 ZN EXTRACT.	25 WATER TEMP.	26 DISS. OXYGEN	27 COLIFORMS TOTAL	28 COLIFORMS FECAL
COUNT	45	29	57	28	36	36
MINIMUM	0.002	0.01	0.0	8.7	200	10
MAXIMUM	0.014	0.08	19.1	14.8	8600	4400
MEAN	0.002	0.04	7.5	11.4	1698	713
MEDIAN	0.002	0.03	7.8	11.0	1200	325

TABLE 7

DATA SUMMARY : RUBY LINE STATION (00NF02ZM0001)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	61	51	29	12	54	55	47	54	54	34	57	59
MINIMUM	4.8	2.1	0.5	-0.1	2.2	4.4	0.2	0.1	0.42	27	5	0.3
MAXIMUM	6.5	5.0	15.1	2.4	10.7	27.0	2.1	2.5	6.35	104	70	6.0
MEAN	-	2.9	1.7	0.6	4.5	7.6	0.6	0.3	1.06	40	32	1.4
MEDIAN	5.6	2.8	0.7	0.4	4.4	7.0	0.6	0.3	0.90	36	20	1.0

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 T.O.C.	17 NO2-NO3	18 N TOT.	19 P TOT.	20 FE EXTRACT.	21 MN EXTRACT.	22 CU EXTRACT.
COUNT	61	55	32	32	61	62	65	48	48	48
MINIMUM	0	0.3	1.4	2.5	0.01	0.05	0.001	0.10	0.05	0.002
MAXIMUM	26	6.1	13.0	15.4	1.10	1.40	0.230	2.50	0.95	0.002
MEAN	4	3.1	4.8	7.7	0.08	0.25	0.015	0.47	0.14	0.002
MEDIAN	2	3.3	4.4	7.1	0.02	0.20	0.010	0.31	0.09	0.002

	23 PB EXTRACT.	24 ZN EXTRACT.	25 WATER TEMP.	26 DISS. OXYGEN	27 COLIFORMS TOTAL	28 COLIFORMS FECAL
COUNT	47	18	59	26	38	38
MINIMUM	0.002	0.001	0.0	8.3	0.2	0.1
MAXIMUM	0.005	0.010	19.3	14.7	5600.0	1100.0
MEAN	0.002	0.010	7.1	11.2	479.0	66.0
MEDIAN	0.002	0.010	7.5	10.8	120.0	10.0

TABLE 8

DATA SUMMARY : HEAVY TREE ROAD STATION (00NF02ZM0007)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	59	51	40	7	52	53	47	52	54	33	58	59
MINIMUM	5.1	2.2	0.5	0.4	3.5	4.8	0.39	0.1	0.72	32	5	0.3
MAXIMUM	7.0	5.2	9.4	2.2	15.0	33.0	2.10	1.2	6.60	194	70	32.0
MEAN	-	3.2	2.8	0.9	7.8	13.5	0.80	0.4	1.80	70	28	2.2
MEDIAN	6.1	3.2	2.4	0.6	7.2	11.8	0.80	0.4	1.80	58	20	1.3

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 T.O.C.	17 NO2-NO3	18 N TOT.	19 P TOT.	20 FE EXTRACT.	21 MN EXTRACT.	22 CU EXTRACT.
COUNT	61	54	32	32	61	63	61	48	47	48
MINIMUM	0.0	0.1	1.3	3.0	0.010	0.10	0.001	0.10	0.05	0.002
MAXIMUM	324.0	5.7	14.0	15.0	0.630	0.72	1.300	1.50	0.52	0.007
MEAN	9.7	3.3	4.2	7.1	0.068	0.22	0.035	0.39	0.16	0.002
MEDIAN	1.0	3.4	3.4	7.5	0.040	0.20	0.011	0.26	0.12	0.002

	23 PB EXTRACT.	24 ZN EXTRACT.	25 WATER TEMP.	26 DISS. OXYGEN	27 COLIFORMS TOTAL	28 COLIFORMS FECAL
COUNT	46	18	59	27	35	35
MINIMUM	0.002	0.007	0.0	8.6	0.2	0.1
MAXIMUM	0.003	0.030	20.0	14.6	8600.0	5200.0
MEAN	0.002	0.012	7.1	11.3	552.0	201.0
MEDIAN	0.002	0.010	7.2	11.0	60.0	10.0

TABLE 9

DATA SUMMARY : OLD BAY BULLS ROAD STATION (00NF02ZM0008)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	61	53	49	6	54	55	47	54	54	34	56	59
MINIMUM	5.8	2.8	0.5	2.4	3.9	5.6	0.4	0.4	1.7	56	10	0.6
MAXIMUM	7.6	13.1	16.5	7.5	120.0	170.0	2.0	1.7	7.7	345	70	50.0
MEAN	-	4.4	7.8	3.8	14.3	23.0	1.2	0.8	3.7	106	33	7.9
MEDIAN	6.6	4.0	7.3	3.2	10.0	17.0	1.2	0.8	3.5	82	30	4.0

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 T.O.C.	17 NO2-NO3	18 N TOT.	19 P TOT.	20 FE EXTRACT.	21 MN EXTRACT.	22 CU EXTRACT.
COUNT	61	55	32	32	61	63	63	49	49	49
MINIMUM	0	0.1	2.0	4.0	0.01	0.20	0.008	0.17	0.07	0.002
MAXIMUM	100	6.3	11.0	20.0	0.67	2.20	0.650	1.60	0.65	0.011
MEAN	15	3.0	4.9	9.7	0.26	0.66	0.096	0.55	0.20	0.002
MEDIAN	6	3.0	4.2	9.5	0.25	0.60	0.048	0.43	0.18	0.002

	23 PB EXTRACT.	24 ZN EXTRACT.	25 WATER TEMP.	26 DISS. OXYGEN	27 COLIFORMS TOTAL	28 COLIFORMS FECAL
COUNT	48	25	58	29	38	38
MINIMUM	0.002	0.009	0.0	8.6	80	60
MAXIMUM	0.015	0.040	21.6	15.6	72000	26000
MEAN	0.002	0.020	8.0	11.1	18668	5683
MEDIAN	0.002	0.020	8.2	10.6	12500	4150

TABLE 10

DATA SUMMARY : KILBRIDE STATION (00NF02ZM0009)

(REGULAR MONITORING DATA)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	61	53	51	3	53	54	47	53	53	32	63	65
MINIMUM	5.8	4.5	1.5	4.2	8.1	12.5	0.17	0.5	2.8	69	5	0.7
MAXIMUM	7.7	29.5	15.2	9.3	210.0	350.0	2.30	1.6	17.0	1100	70	128.0
MEAN	6.8	7.4	8.0	6.1	30.6	50.0	1.34	0.9	6.0	190	23	17.4
MEDIAN	6.8	6.7	7.4	4.7	20.0	36.0	1.36	0.9	5.8	147	20	10.0

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 T.O.C.	17 NO2-NO3	18 N TOT.	19 P TOT.	20 FE EXTRACT.	21 MN EXTRACT.	22 CU EXTRACT.
COUNT	67	54	31	31	60	61	59	48	48	48
MINIMUM	0.0	0.1	1.2	2.5	0.01	0.31	0.008	0.15	0.01	0.002
MAXIMUM	165.0	6.2	7.2	22.5	0.90	1.30	0.300	3.90	1.30	0.008
MEAN	25.1	3.7	3.3	8.3	0.39	0.66	0.084	0.74	0.24	0.003
MEDIAN	10.0	3.8	3.1	7.0	0.40	0.65	0.048	0.44	0.18	0.002

	23 PB EXTRACT.	24 ZN EXTRACT.	25 WATER TEMP.	26 DISS. OXYGEN	27 COLIFORMS TOTAL	28 COLIFORMS FECAL
COUNT	47	32	54	21	37	37
MINIMUM	0.002	0.01	0.0	8.8	1600	200
MAXIMUM	0.037	0.10	19.8	16.8	110000	48000
MEAN	0.006	0.04	7.6	11.4	17692	6282
MEDIAN	0.002	0.03	7.4	10.5	5800	2000

TABLE 10A

DATA SUMMARY : KILBRIDE STATION (00NF02ZM0009)

(RAIN EVENTS MONITORING DATA)

	1 PH	2 SO4 DISS.	3 ALK.TOT.	4 ALK.GRAN	5 NA DISS.	6 CL DISS.	7 MG DISS.	8 K DISS.	9 CA DISS.	10 SP.COND. LAB.	11 COL.APP.	12 TURB.
COUNT	253	212	217	34	224	219	192	224	210	185	161	187
MINIMUM	3.9	4.5	1.1	-8.7	5.3	7.0	0.7	0.6	2.0	61	5	3
MAXIMUM	7.8	18.2	16.9	9.0	114.0	180.0	1.9	3.2	9.0	657	70	150
MEAN	6.5	7.5	5.9	4.8	23.6	35.8	1.2	1.1	4.7	154	24	22
MEDIAN	6.4	7.3	5.2	6.0	18.3	31.0	1.1	1.0	4.6	120	20	15

	13 RES.N.F.	14 SIO2 REACT.	15 D.O.C.	16 NO2-NO3	17 N TOT.	18 P TOT.	19 FE EXTRACT.	20 MN EXTRACT.	21 PB EXTRACT.
COUNT	186	190	219	205	224	23	164	218	163
MINIMUM	1	2.0	1.2	0.1	0.03	0.02	0.22	0.01	0.002
MAXIMUM	444	6.1	9.8	1.7	1.80	1.65	8.40	2.00	0.300
MEAN	37	3.4	4.3	0.4	0.59	0.16	1.15	0.26	0.019
MEDIAN	22	3.3	3.6	0.4	0.52	0.06	0.84	0.22	0.015

4.1.5 Specific conductance

In the discussion herein, as for the data summaries presented in the table section, only the specific conductance values measured by the Moncton laboratory will be considered.

Specific conductance is a numerical expression of a water's ability to conduct an electrical current and thus is dependent on ionic concentrations and temperature. Values of 20-35 uS/cm are common for surface waters of Newfoundland and Labrador. Development easily perturbs such low values, as was evidenced by the increase in values between the station at Ruby Line and the one at Heavy Tree Road, and the differences in specific conductance values observed between the Waterford River and South Brook.

The specific conductance ranged from 60 to 1100 uS/cm on the mainstem during the study period. The Agriculture Canada farm station had values similar to these with the highest values measured in winter and spring when road salting was performed (a measurement of 1100 uS/cm was made in February 1983 at Kilbride). Typical values for these stations were in the order of 120-150 uS/cm.

The specific conductance values at the South Brook stations ranged from 27 to 190 uS/cm. A few higher values were also recorded in winter and spring, mainly at the Heavy Tree Road station which is located downstream and near the road. It seemed that road salting rarely affected the water at Ruby Line (this station is located 10 m upstream from the road). Typical values at Ruby Line and Heavy Tree Road were in the order of 25-40 uS/cm and 45-60 uS/cm respectively. The major differences in specific conductance between the two branches, observed even in summer and fall, reflect the dissimilarity in the ionic contents between the developed and undeveloped areas. Section 4.2 will deal with the major ions. The Old Bay Bulls Road station exhibited higher specific conductance values (median of 82 uS/cm) than those observed at the South Brook stations, but lower than those observed on the mainstem or at the Agriculture Canada farm station.

4.1.6 Turbidity and suspended solids

Turbidity is a measure of the suspended particles in water which are usually held in suspension by turbulent flow and Brownian movement.

Turbidity was observed to be higher in the Waterford River than in South Brook. These higher values can be related to human presence and activities in the Waterford River sub-basin, unlike the undeveloped and forested upper South Brook sub-basin. As previously stated, dust from roads and water flowing from ditches and stormsewer outfalls were major sources of turbidity (suspended particles inputs) along the mainstem. This was also observed at the Old Bay Bulls Road station. The South Brook generally had turbidity values lower than 2 JTU while at other stations turbidity varied anywhere between 1 and 500 JTU, depending on the flow conditions, seasons and development activities ongoing on the basin. A rain event will usually cause an increase in suspended solids in the river water (as reflected by turbidity measurements), by the washing and weathering effects of runoff and the turbulence produced by high flows. Similar effects are evident during the period of snowmelt runoff in spring. Figure 7 illustrates the typical hydrograph and turbidity variation at Kilbride during a rain event.

4.2 Major Ions

The Waterford River basin waters, as expected for a coastal basin, were observed to be dominated by sodium chloride (Fig. 8-9). However, major differences in concentration levels were observed between the developed and undeveloped parts of the basin (Fig. 10).

On the developed part of the basin, where the main Waterford River is situated, a number of sources were considered to be contributing to the high sodium and chloride concentrations observed in the river waters. These were the two known road salt depots, Donovans industrial park, major roads (road salting), urban and suburban development along the river and sea spray inputs (these will be discussed later in this text).

On the South Brook sub-basin, there was no known road salt depot or possible industrial sources, and the sodium chloride levels were observed to be as much as 5 times lower at Ruby Line than observed in the Waterford River sub-basins. The salinity at Ruby Line was typically 17 mg/L compared to 70 mg/L at Donovans. However, the salinity rose, as one moved down the South Brook. Salinity levels of 28 mg/L were observed at Heavy Tree Road (2 km downstream of Ruby Line). The water at the Old Bay Bulls Road station showed higher salinity at about 44 mg/L. This level however, was still lower than that of the Waterford River itself.

As previously stated, the basin surface waters were dominated by sodium chloride and its concentration was observed to be higher on the downstream course of the South Brook. This was observed throughout the year (not a seasonal trend), but some higher values were observed in winter and spring, obviously related to road salting. The two stations on the South Brook were affected by road salting to a much lower extent than the Old Bay Bulls Road station or the Waterford River stations. Figures 11 to 14 illustrate the variation of sodium concentrations during the period of January 1981 to December 1983, for the Ruby Line, Heavy Tree Road, Old Bay Bulls Road and Donovans stations.

It is known that the sea is a dominant source of atmospheric supply of sodium, chloride, magnesium and sulphate (Wetzel, 1975). It is believed that, on the South Brook sub-basin, the major sodium chloride contributor was dry fallout of sea spray, because no sodium chloride appeared to be available within the basin based on examination of available geologic mapping and further consideration of the observed quality of groundwater from the 7 shallow and 7 deep wells monitored as part of this study. In addition, on the undeveloped and mainly forested (coniferous) part of the basin, there were no potential urban nor industrial sources of salt, other than the houses and farms, located in the eastern part of this sub-basin.

The higher values observed, as one moves downstream on South Brook, could be explained by the shorter distance to the sea and the less dense forest, assuming that the coniferous cover could be acting as

FIG.7 Hydrograph and turbidity variation during the December 20-21/82 rain event

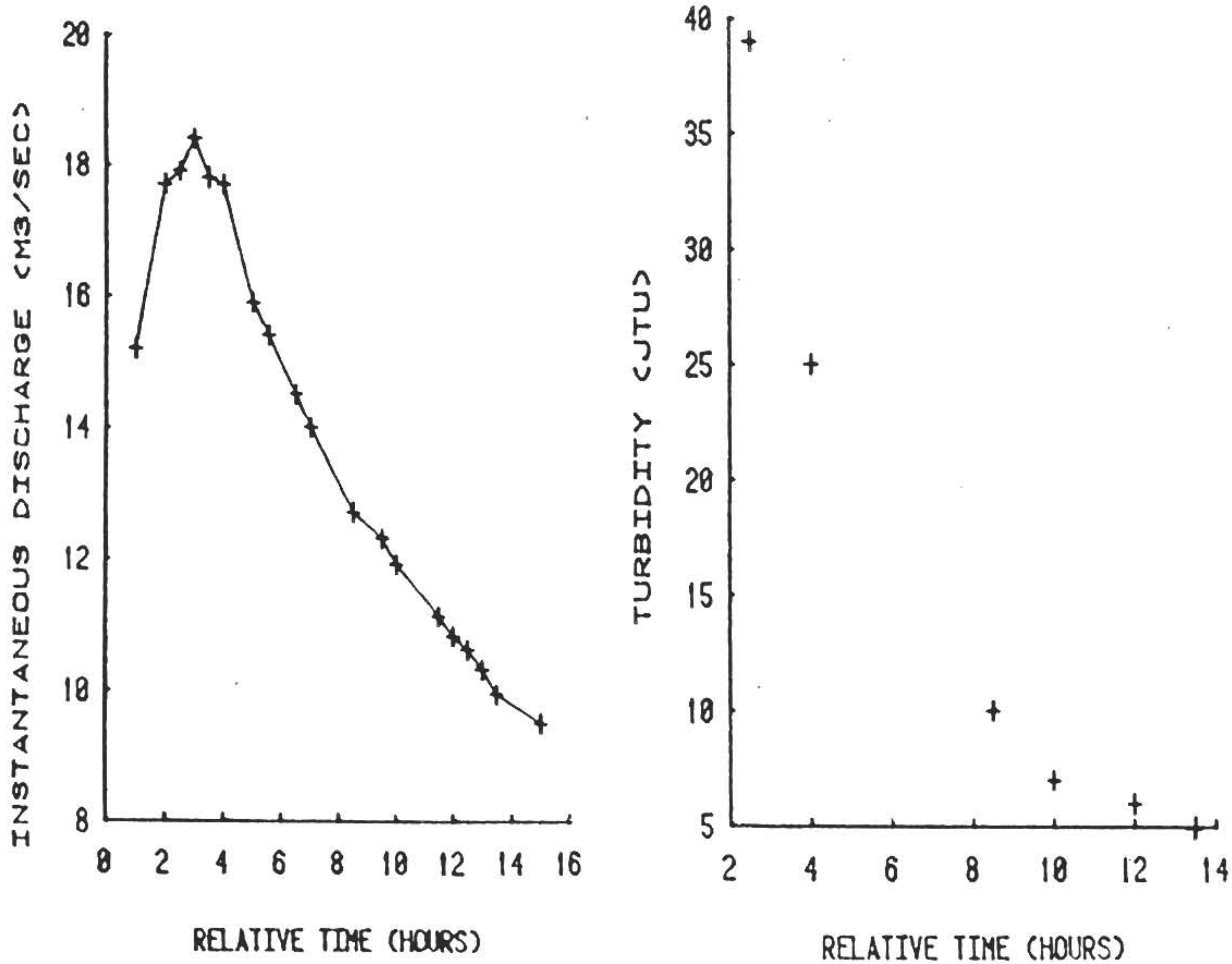
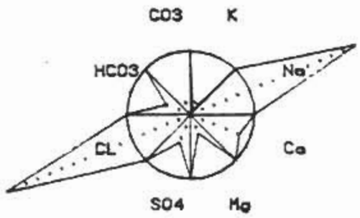
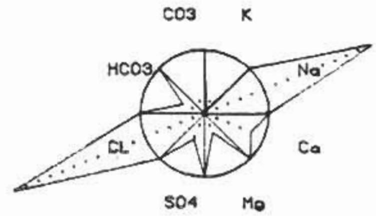


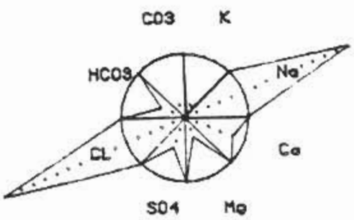
FIG.8 IONIC PROPORTIONS: MAINSTEM



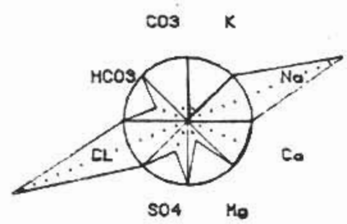
DONOVANS
00NF02ZM0003
Salinity = 2.33 meq/L (epm)



DUNNS
00NF02ZM0012
Salinity = 2.58 meq/L (epm)

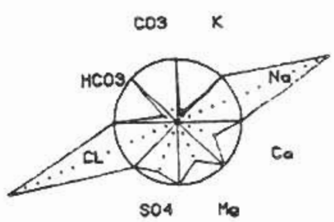


COMMONWEALTH
00NF02ZM0004
Salinity = 2.21 meq/L (epm)

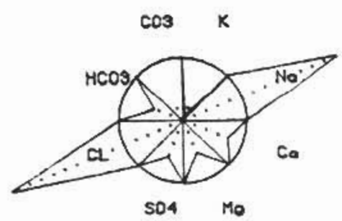


KILBRIDE
00NF02ZM0009
Salinity = 2.30 meq/L (epm)

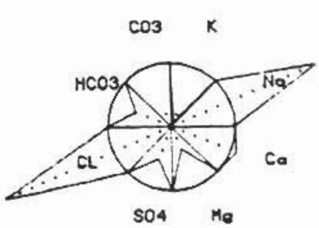
FIG.9 IONIC PROPORTIONS: TRIBUTARIES



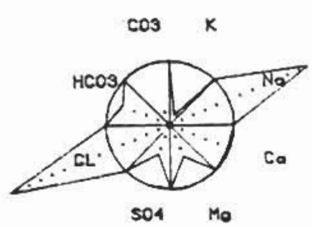
RUBY LINE
00NF02ZM0001
Salinity = 0.57 meq/L (epm)



HEAVY TREE
00NF02ZM0007
Salinity = 0.91 meq/L (epm)

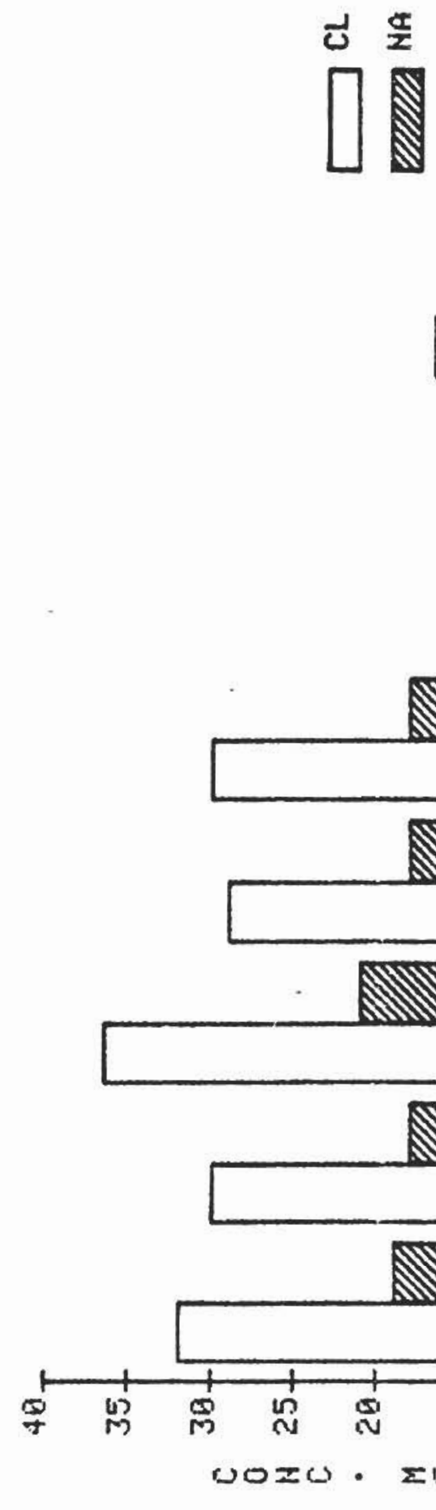


EXP. FARM
00NF02ZM0006
Salinity = 2.46 meq/L (epm)



OLD BAY BULLS
00NF02ZM0008
Salinity = 1.43 meq/L (epm)

FIG.10 MEDIAN CHLORIDE AND SODIUM CONCENTRATIONS AT ALL STATIONS



a "filter" of the sea air.

A pine, spruce and fir forest, like that found on the upper South Brook sub-basin, offers a large contact surface. The needles of these trees, which are good particle collectors (Belot and Gauthier, 1975) could be acting, throughout the year, as captors of airborne sea salt. The surface structure and geometry of receiving substrates and the size of the airborne particles are important factors controlling the rates and extent of deposition (Davidson et al., 1982). From this, it is believed that the various size particles present in the sea spray will not be "filtered" by the coniferous canopy to the same extent. The sea spray particles would accumulate on the vegetation and would then be washed down by rain into the lower South Brook and tributaries, and back to the sea. Deeper into the forest (farther from the sea), less sodium and chloride (and other ions) should be observed in the water because of the coming sea spray being more and more filtered, as it passes through the forest. This could well explain the lower but still dominant sodium chloride concentrations, observed at Ruby Line, the most distant station from the sea located in the forested area. Rainstorms coming from the direction of the sea could also account for part of the sodium chloride input in the basin surface waters, particularly at Ruby Line.

Deadmans Pond was sampled once in June 1984 for major ion analyses (Table 12) and indicated a low salinity (comparable to the water at Ruby Line). The water at the Old Bay Bulls Road station had a higher salinity and much higher sodium chloride concentrations. For this station, some ion ratios by weight compared well to sea water ion ratios (Table 11). The fact that other ratios were much higher than the sea water ion ratios indicated that some calcium, potassium and sulphate were available geologically and/or from human sources in the area. However, the major contribution to sodium, chloride and magnesium concentrations was assumed to be from sea spray (Na/Cl = 0.59 and Mg/Cl = 0.070). The lowest sodium (3.9 mg/L) and chloride (5.6 mg/L) concentrations observed at this site was on the 26 November 1981. The low values were due to the dilution effect of a major rainstorm that occurred on that date and affected in a similar manner all the other stations.

FIG.11 VARIATION OF SODIUM CONCENTRATION
AT RUBY LINE

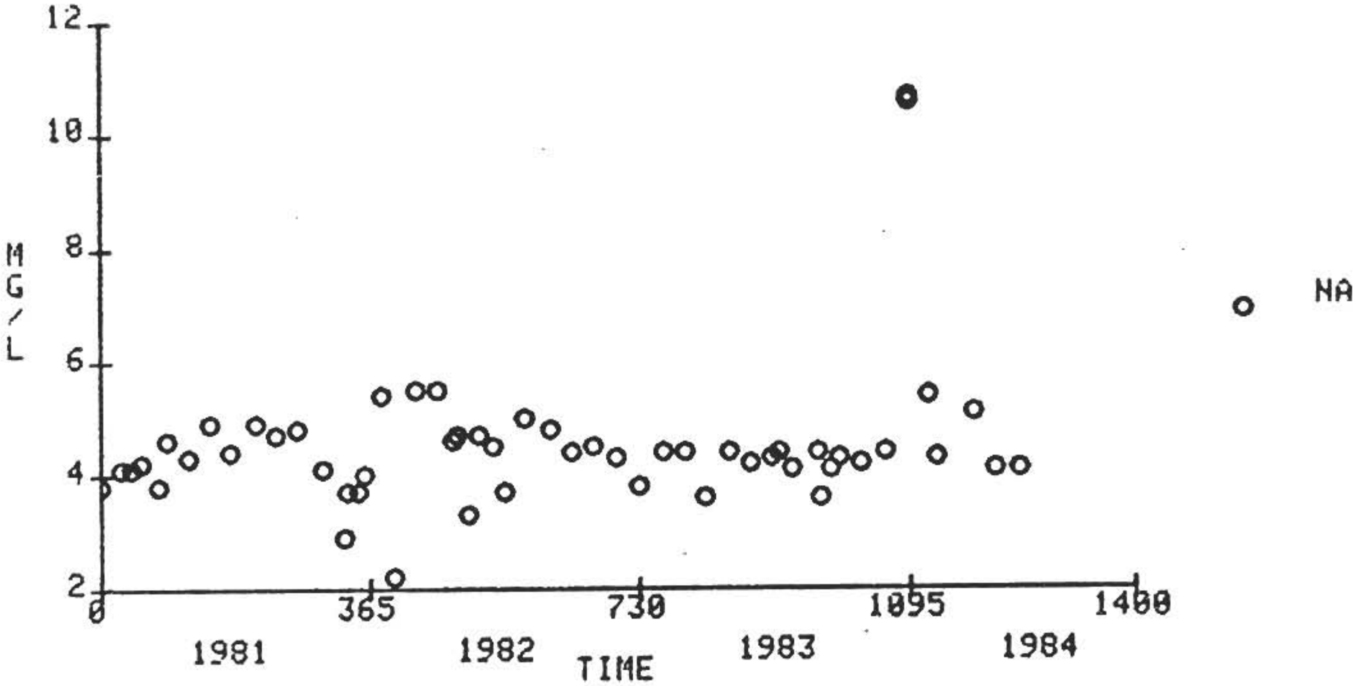


FIG.12 VARIATION OF SODIUM CONCENTRATION
AT DONOVANS

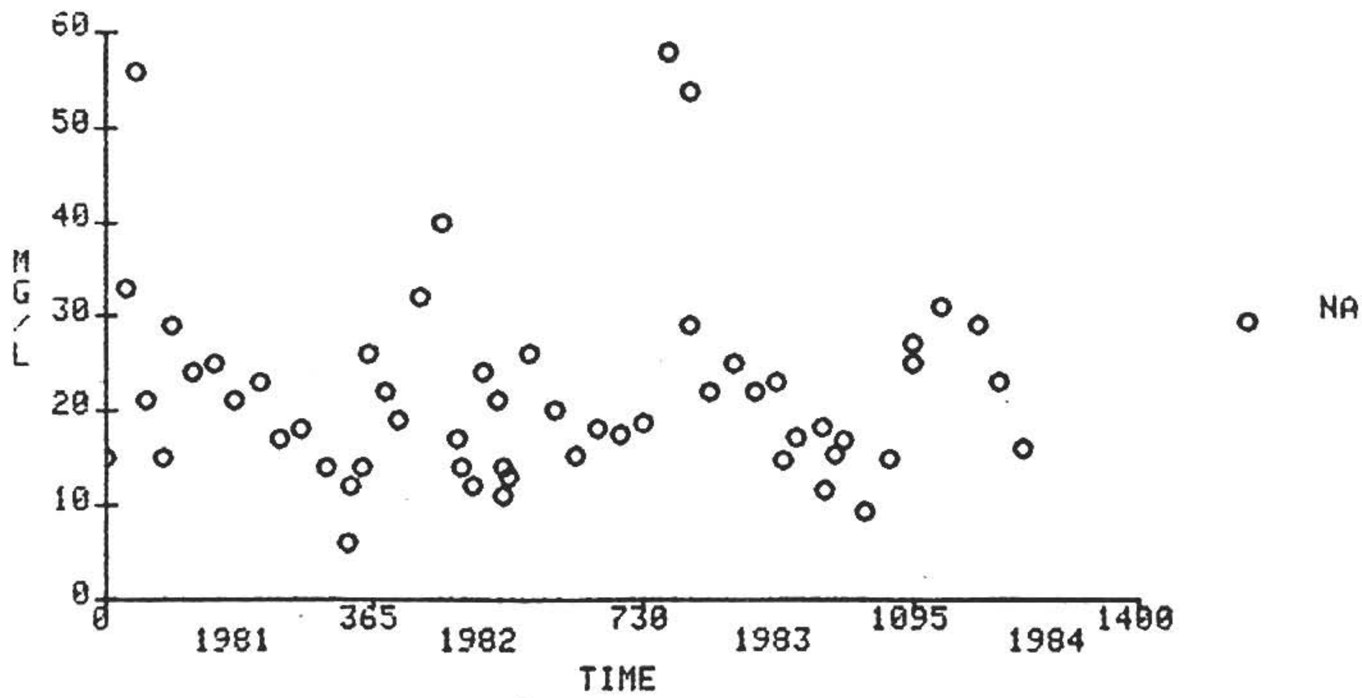


FIG.13 VARIATION OF SODIUM CONCENTRATION AT HEAVY TREE

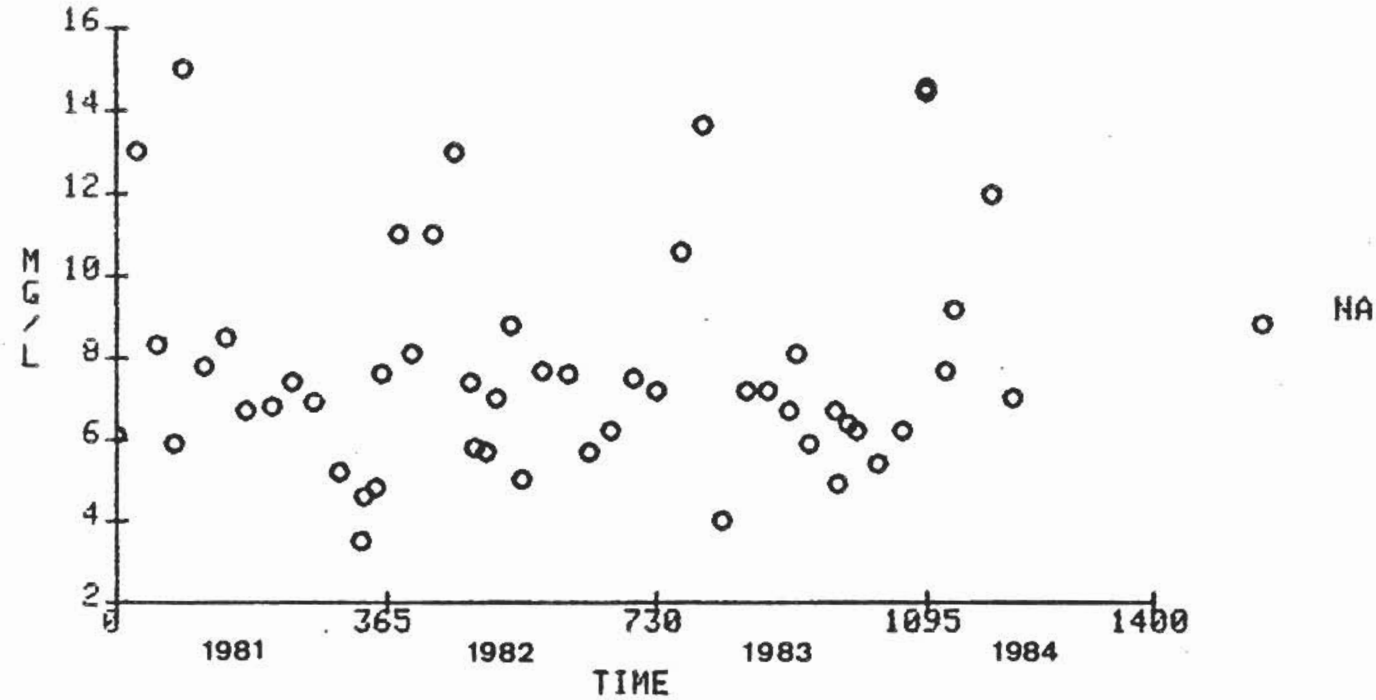
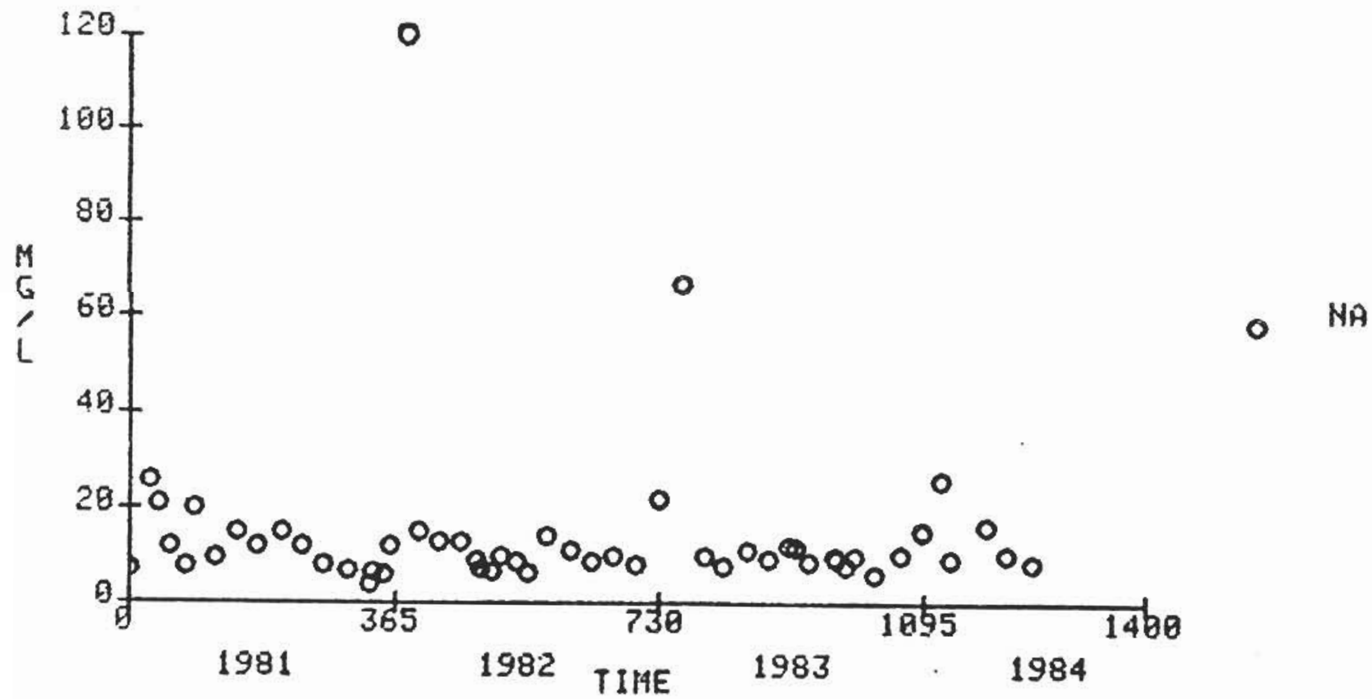


FIG.14 VARIATION OF SODIUM CONCENTRATION AT OLD BAY BULLS



In comparison to Old Bay Bulls station, the Waterford River at Donovans had concentrations of sodium chloride elevated by a factor of two, even though both sites are located in developed areas. Although the sodium chloride concentration was double at Donovans, the magnesium was the same as that observed at the Old Bay Bulls Road station, at 1.1 mg/L. This probably meant that on the Waterford River sub-basin, there were important sodium chloride sources low in magnesium content and the magnesium observed in the river water was originating mainly from sea spray, as was suggested for the Old Bay Bulls Road station.

The main Waterford River, located on the most developed part of the basin, was noticeably affected by urban and industrial activities. In winter and spring, road salting was a major source of sodium chloride.

In June 1984, the two Waterford River headwater ponds (Bremigens and Brazil) located upstream of the Donovans industrial park, were sampled for major ion analyses and had much lower sodium chloride concentrations than typically observed in the river waters. Brazil Pond had a higher sodium chloride concentration than Bremigens Pond, but this could be related to the major highway passing by its shore (Table 12).

There was a road salt depot located in Mount Pearl (on Park Avenue) that, throughout the study, was obviously affecting the salt level observed in the water from a shallow well located in its vicinity (Table 14), and the river surface water at the Dunns Road station. The latter usually had the highest sodium and chloride concentrations of all stations on the Waterford River (Fig. 10). In late 1982, the Mount Pearl salt depot was moved to the Donovans industrial park and since then, the studied shallow well located in the park consistently showed high sodium chloride concentrations (Table 13). The District Pond, located near to this depot was sampled once in June 1984 and had high sodium chloride levels (similar to that of the river), probably related to its presence. However, no changes in water characteristics have yet been observed in the river water or the two other shallow wells located near the river in the Donovans area.

TABLE 11

ION RATIOS USING MEDIAN VALUES FOR ALL SURFACE WATER STATIONS (AND STORMSEWER) COMPARED TO ION RATIOS FOR SEA WATER

STATION #	NA/CL	SO4/CL	K/CL	CA/CL	MG/CL
DONOVANS	0.56	0.18	0.020	0.14	0.034
COMMONWEALTH AVE	0.58	0.20	0.022	0.14	0.037
DUNNS ROAD BRIDGE	0.56	0.18	0.019	0.13	0.032
KILBRIDE	0.62	0.23	0.031	0.20	0.041
EXPERIMENTAL FARM	0.58	0.24	0.025	0.22	0.046
RUBY LINE	0.63	0.40	0.043	0.13	0.086
HEAVY TREE ROAD	0.61	0.27	0.034	0.15	0.068
OLD BAY BULLS ROAD	0.59	0.24	0.047	0.21	0.070
STORMSEWER*	0.61	0.35	0.032	0.26	0.063
SEA	0.556	0.139	0.020	0.021	0.067

*STORMSEWER:SUMMER+FALL DATA ONLY

TABLE 12

MAJOR IONS RESULTS FOR PONDS SAMPLED ON JUNE 18/84

STATION	NA DISS.	CL DISS.	CA DISS.	MG DISS.	SO4 DISS.	SPECIFIC CONDUCTANCE	PH
BREMIGENS POND	4.0	6.0	0.88	0.56	4.0	36	5.7
DISTRICT POND	12.1	24.0	3.90	0.98	5.0	105	6.3
BRANSCOMBE POND	9.7	18.0	2.00	0.81	2.5	76	6.1
BRAZIL POND	9.6	14.0	1.80	0.64	4.2	70	6.2
DEADMANS POND	4.2	6.1	0.55	0.52	2.9	33	5.4

TABLE 13

MAJOR IONS DATA FOR THE SHALLOW WELL LOCATED IN THE VICINITY OF THE ROAD SALT DEPOT IN THE DONOVANS INDUSTRIAL PARK

DATE	PH	SO4 DISS.	ALK.TOT.	NA DISS.	CL DISS.	MG DISS.	K DISS	CA DISS.	SP.COND. LAB.
810508	6.8	15.3	30.4	14.0	16.0	1.80	1.9	12.20	145
810807	7.0	6.9	50.2	13.0	9.8	1.83	1.0	10.25	-
820209	6.5	4.0	10.7	12.0	25.0	1.20	0.6	5.80	-
820517	7.0	3.0	21.5	13.0	19.0	0.96	0.4	5.60	-
821006	6.1	2.5	36.9	14.3	11.0	1.13	0.7	6.00	82
830524	7.1	9.8	40.4	115.0	170.0	-	1.6	8.80	530
830816	6.8	16.3	34.9	140.0	220.0	2.00	2.2	13.00	600
831109	6.1	4.2	33.1	43.0	55.0	0.84	0.5	-	-
840215	6.2	-	6.1	-	1360.0	-	-	-	4090
840508	6.3	27.0	15.4	480.0	810.0	5.70	3.0	35.00	2510

TABLE 14

MAJOR IONS DATA FOR THE SHALLOW WELL LOCATED NEAR THE ROAD SALT DEPOT IN MOUNT PEARL

DATE	PH	SO4 DISS.	ALK.TOT.	NA DISS.	CL DISS.	MG DISS.	K DISS.	CA DISS.	SP.COND. LAB.
820217	6.1	18.0	13.8	180	280	4.6	3.0	26.0	-
820518	6.5	17.5	8.3	140	250	4.6	4.7	25.0	-
821007	5.2	16.0	-	85	160	3.7	5.0	19.0	380
830524	5.8	19.5	-	62	96	-	2.7	9.0	330
831107	6.1	18.7	14.6	43	61	1.5	2.4	9.5	-
840215	6.4	-	9.8	-	250	-	-	-	840
840508	6.2	19.5	8.9	96	170	2.3	3.0	15.0	630

The depot was moved out of Mount Pearl in late 1982, but the accumulated salt in/on the ground in the vicinity of the depot was obviously still, at the end of the study, affecting the river and the well waters. Possibly many years will be needed to wash out the accumulated salt in the area.

Badly placed septic tanks were also a possible sodium chloride source, but to a lesser extent as no parallelling high nutrient concentrations were observed in the river water during the study. In most cases, when the nutrient concentrations peaked, during high runoff and subsequent high river discharge periods, the salinity was observed to be lower due to the dilution effects of rain (depending if road salt was used on the basin prior to a rain event).

From these facts, and accepting that part of the sodium chloride and most of the magnesium present in the Waterford River waters were originating from sea spray, the only logical conclusion is that there must be another major source of salt located in the Donovans industrial park which bypasses the two shallow wells and flows directly into the river (other than the shallow well contaminated by the road salt depot). This overwhelming source, assumed to be located in the Donovans industrial park, like the road salt from the depots (as shown by the groundwater analyses from the contaminated wells), must have been low in magnesium to explain the low Mg/Cl ratio by weight observed compared to sea water (Mg/Cl = 0.034 at the Donovans station compared to 0.067 in *sea water*).

The Mount Pearl stormwater had two times higher concentrations of calcium, magnesium, bicarbonate, sulphate and potassium, throughout the year, than those observed in the river water. However, the sodium and chloride concentrations were similar to those of the river. The fact that the magnesium concentration was double and that the chloride concentration stayed almost the same as in the river water resulted in a Mg/Cl ratio by weight (using summer and fall data) similar to that of sea water (all the other ion ratios were also much higher) (Table 11).

The basin surface waters were observed to be very soft as the computed hardness (Ca, Mg) was less than 30 mg/L as $CaCO_3$ (Table 16). The Agriculture Canada farm station presented the hardest surface waters (approx. 24 mg/L $CaCO_3$) and also the highest alkalinity of all studied sites. This could be explained partly by liming practices at this farm. Evidently, the water from this tributary, which joins the Waterford River below the Dunns Road station, affected the water at the Kilbride station. It had the highest water hardness of all stations on the mainstem while the two South Brook stations had the softest waters.

The highest sulphate concentrations measured in the basin surface waters were generally observed in winter and spring time. High calcium concentrations were also observed in winter and spring. These high sulphate and calcium values corresponded with the higher sodium chloride concentrations. It is possible that the road salt used contained some calcium sulphate. Figures 15 to 21 illustrate the variation of sulphate or calcium concentrations at selected surface water stations in the basin. In some isolated cases, magnesium was measured at abnormally high concentrations, in winter time but on those occasions, very high concentrations of sodium, chloride, sulphate and calcium were also measured. For example, a sample taken on December 30/1983 at Ruby Line presented abnormally high sodium (10.7 mg/L), chloride (27.0 mg/L), magnesium (2.0 mg/L), calcium (2.2 mg/L) and sulphate (5.0 mg/L) concentrations. The specific conductance was 105 uS/cm which is three times the typical values for this background station. The instantaneous discharge was higher than average on this date and time. Most of the other stations were also affected in the same way on this rainy day. The magnesium concentration variation over time at three surface water stations on the basin is presented in Figures 22 to 24.

Potassium concentrations were fairly constant throughout the year, although a few higher values were observed at higher flows and correspondingly high nutrients concentrations were also observed in those samples. The observed potassium concentration variation over time at two stations is illustrated in Figures 33 and 34 respectively.

TABLE 15

SUMMER-FALL DATA SUMMARY FOR STORMSEWER OUTFALL STATION

	PH	SO4 DISS.	ALK.TOT.	NA DISS.	CL DISS.	MG DISS.	K DISS.	CA DISS.
COUNT	18	16	16	16	16	10	16	16
MEDIAN	6.6	13.1	13.6	24.0	36.5	2.5	1.1	9.9
MEAN	6.5	13.1	13.4	23.5	37.6	2.3	1.2	9.8

TABLE 16

MEDIAN COMPUTED HARDNESS (CA,MG) FOR ALL SURFACE WATER QUALITY STATIONS

STATION	HARDNESS (CA,MG) MG/L AS CACO3
DONOVANS	16.9
COMMONWEALTH AVE	14.4
DUNNS ROAD	17.4
KILBRIDE	19.8
EXPERIMENTAL FARM	23.6
RUBY LINE	4.7
HEAVY TREE ROAD	7.8
OLD BAY BULLS ROAD	13.7

FIG.15 VARIATION OF SULPHATE CONCENTRATION AT RUBY LINE

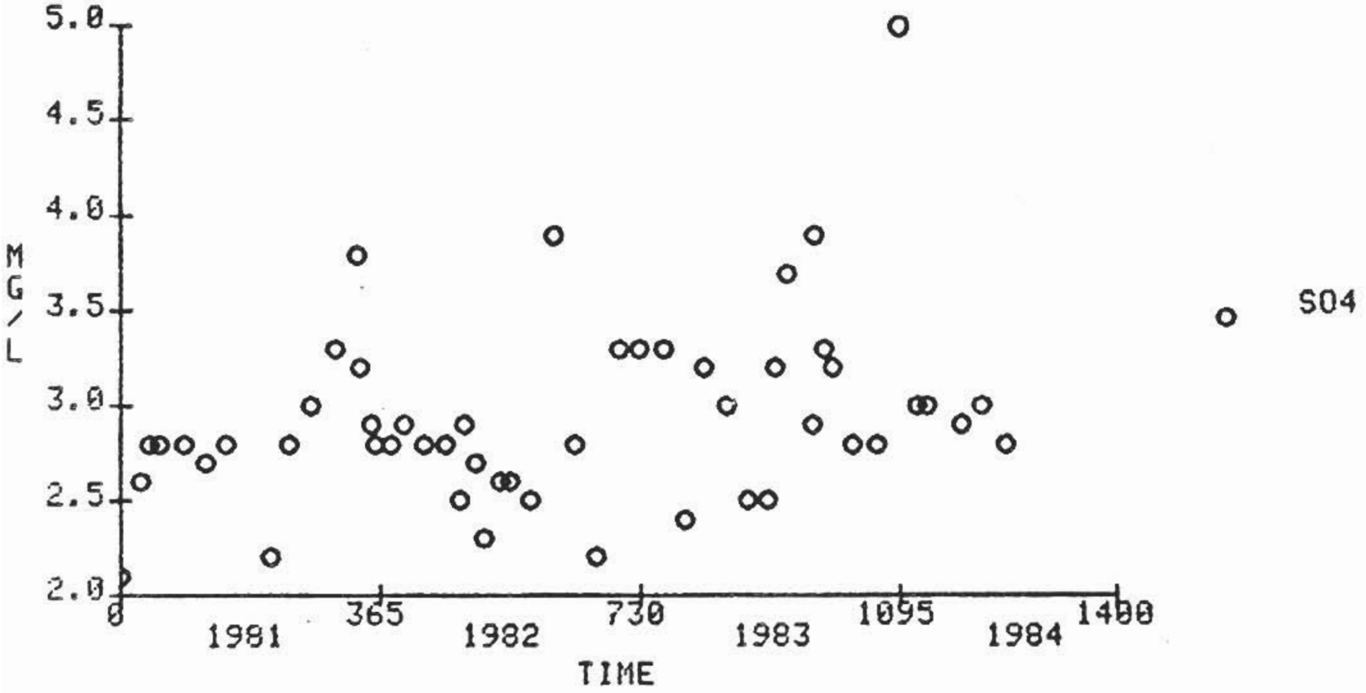


FIG.16 VARIATION OF SULPHATE CONCENTRATION AT DONOVANS

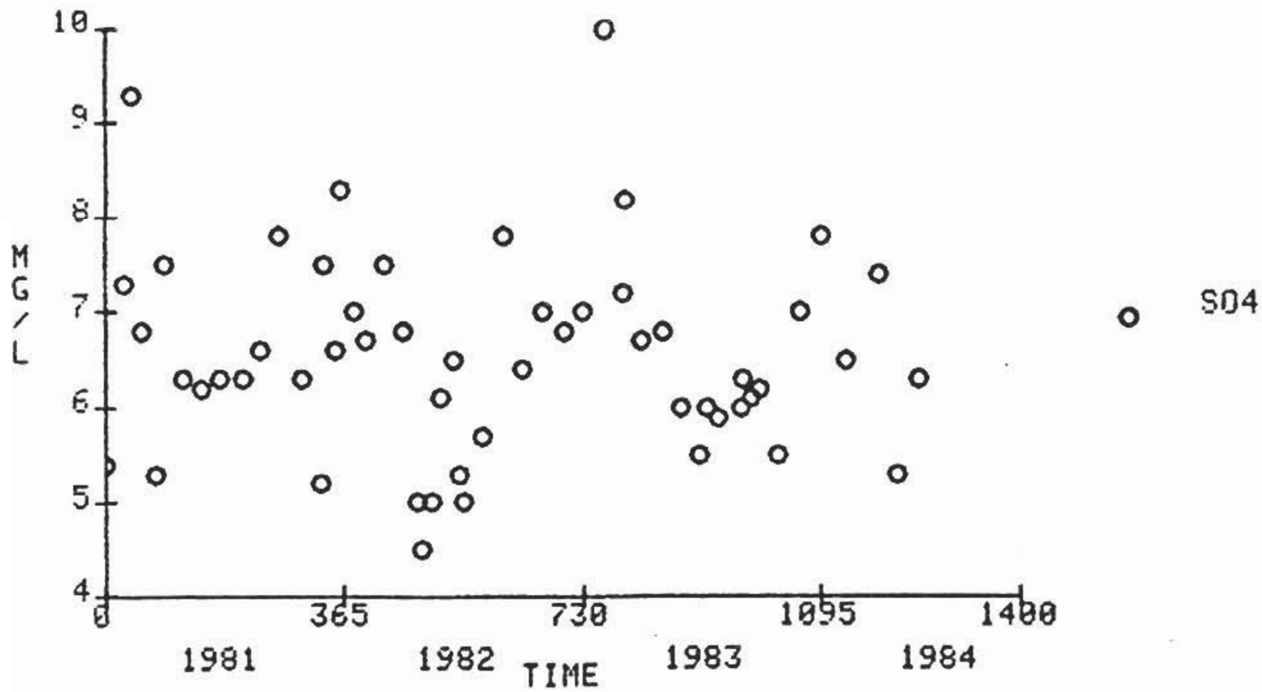


FIG.17 VARIATION OF SULPHATE CONCENTRATION AT OLD BAY BULLS

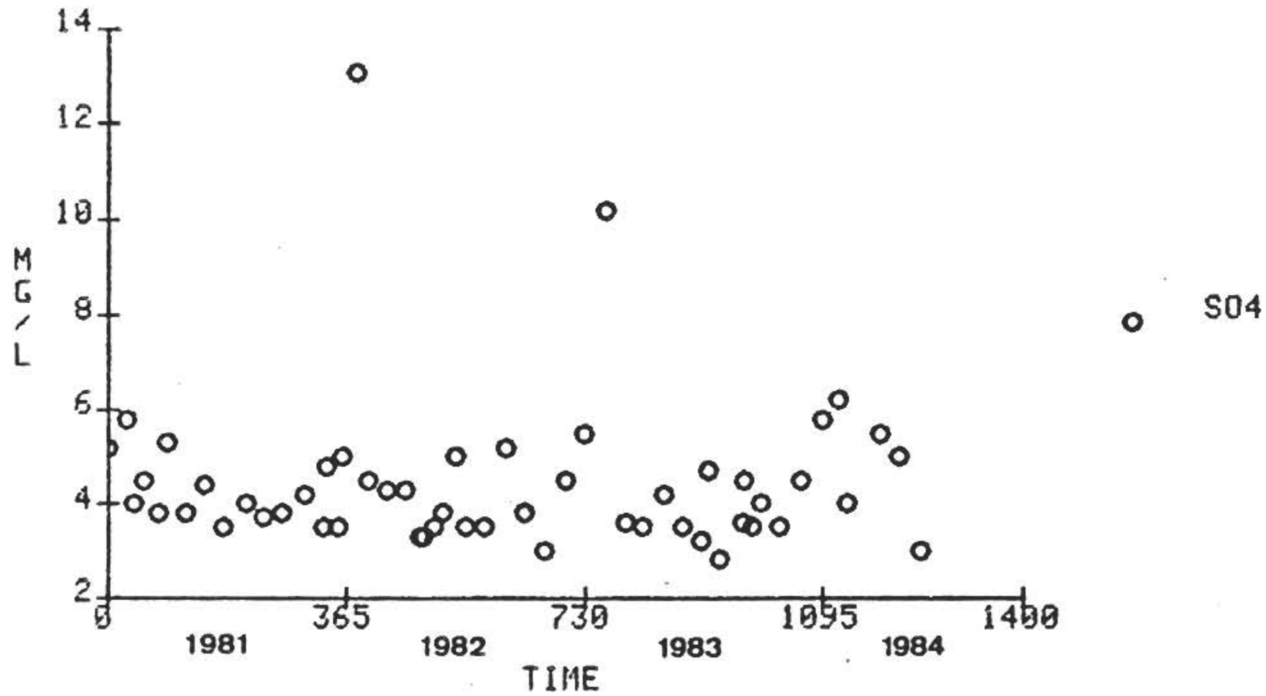


FIG.18 VARIATION OF SULPHATE CONCENTRATION AT DUNNS

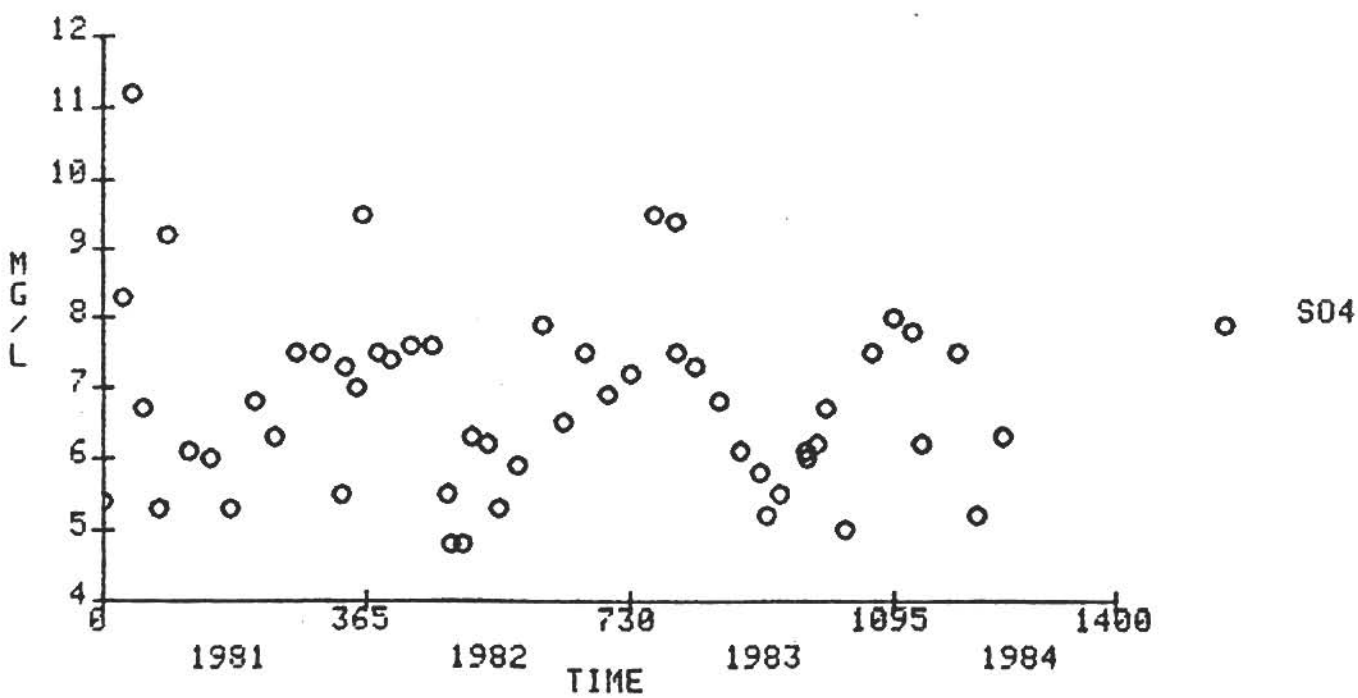


FIG.19 VARIATION OF CALCIUM CONCENTRATION
AT RUBY LINE

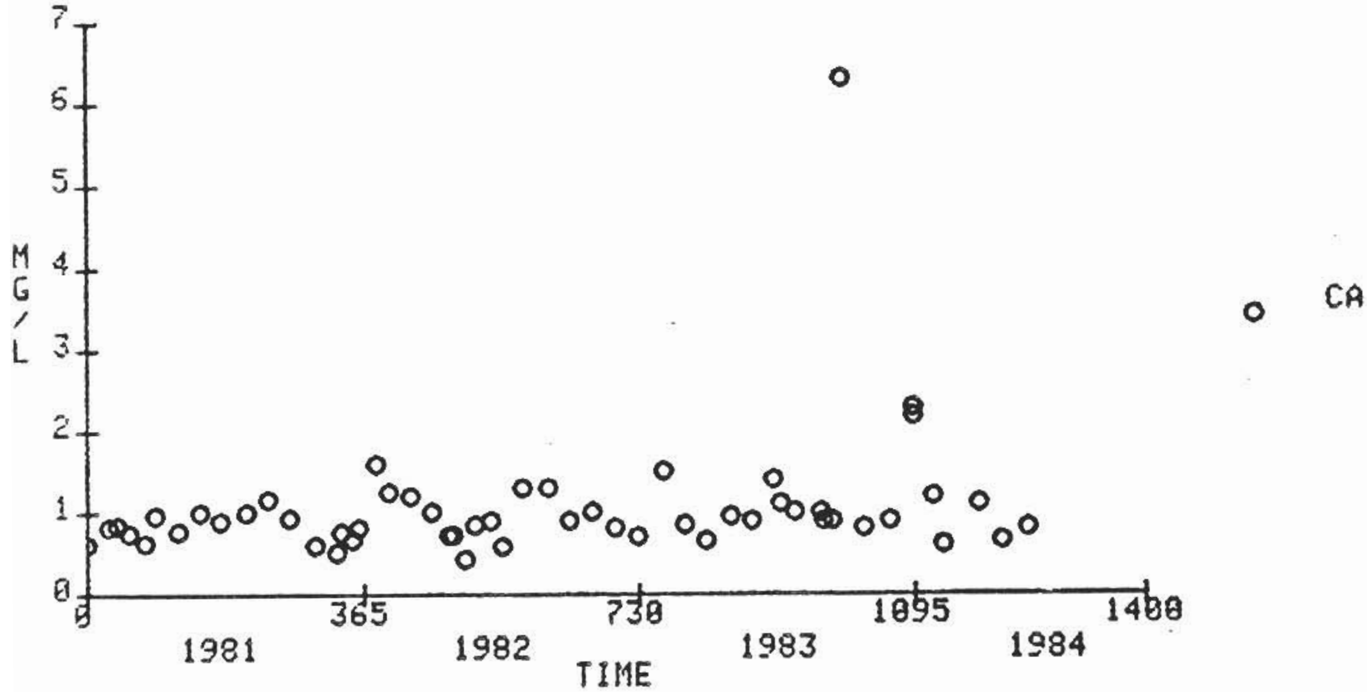


FIG.20 VARIATION OF CALCIUM CONCENTRATION
AT COMMONWEALTH

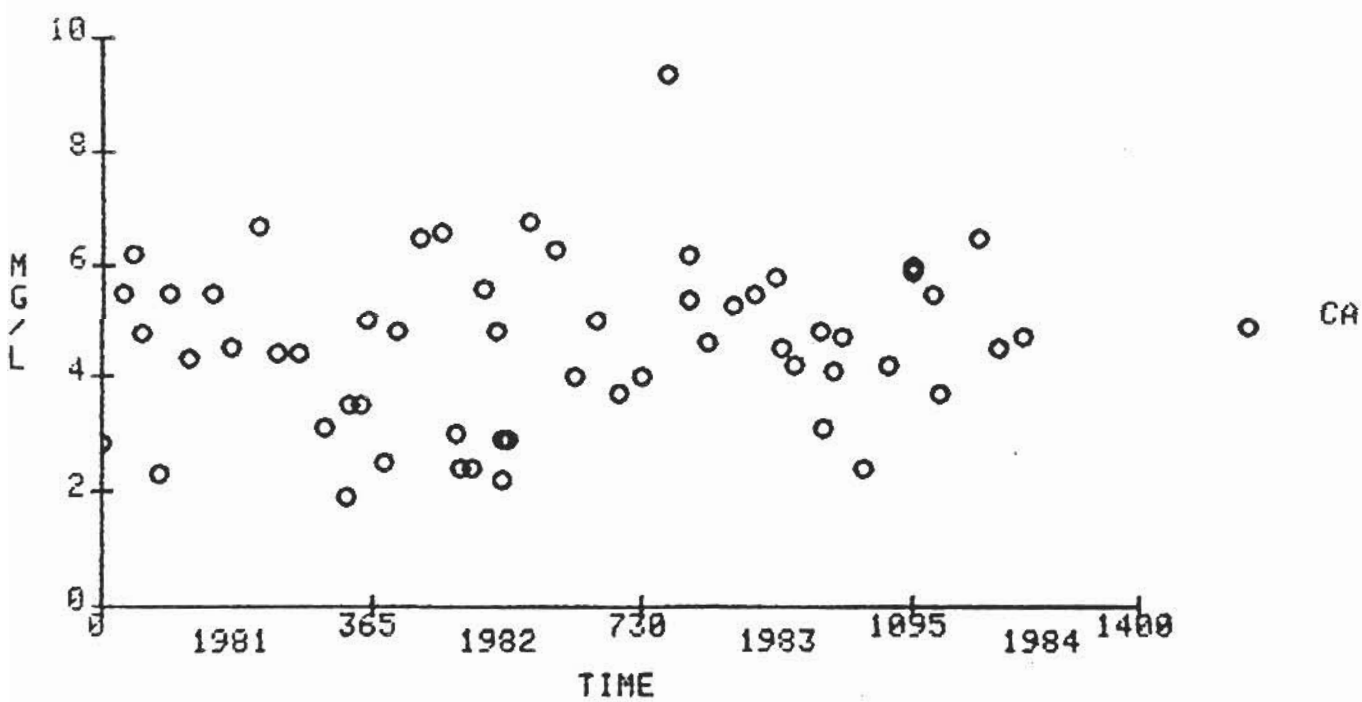


FIG.21 VARIATION OF CALCIUM CONCENTRATION
AT OLD BAY BULLS

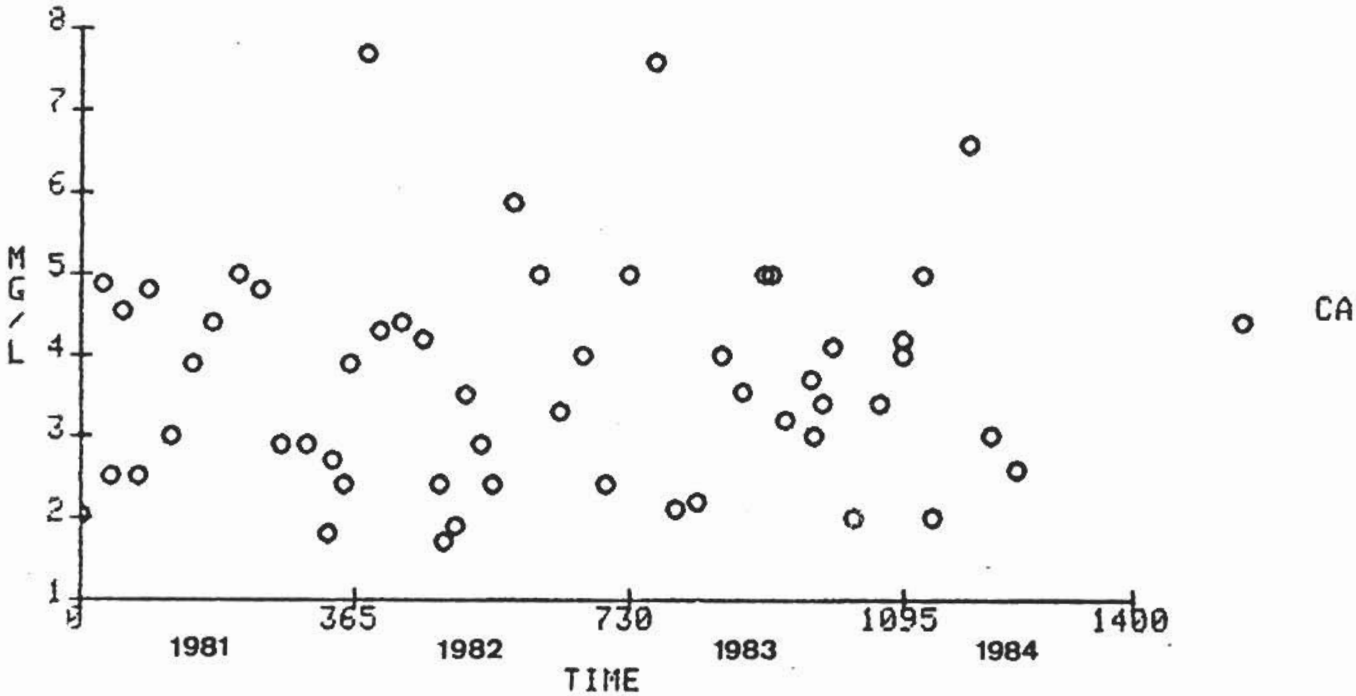
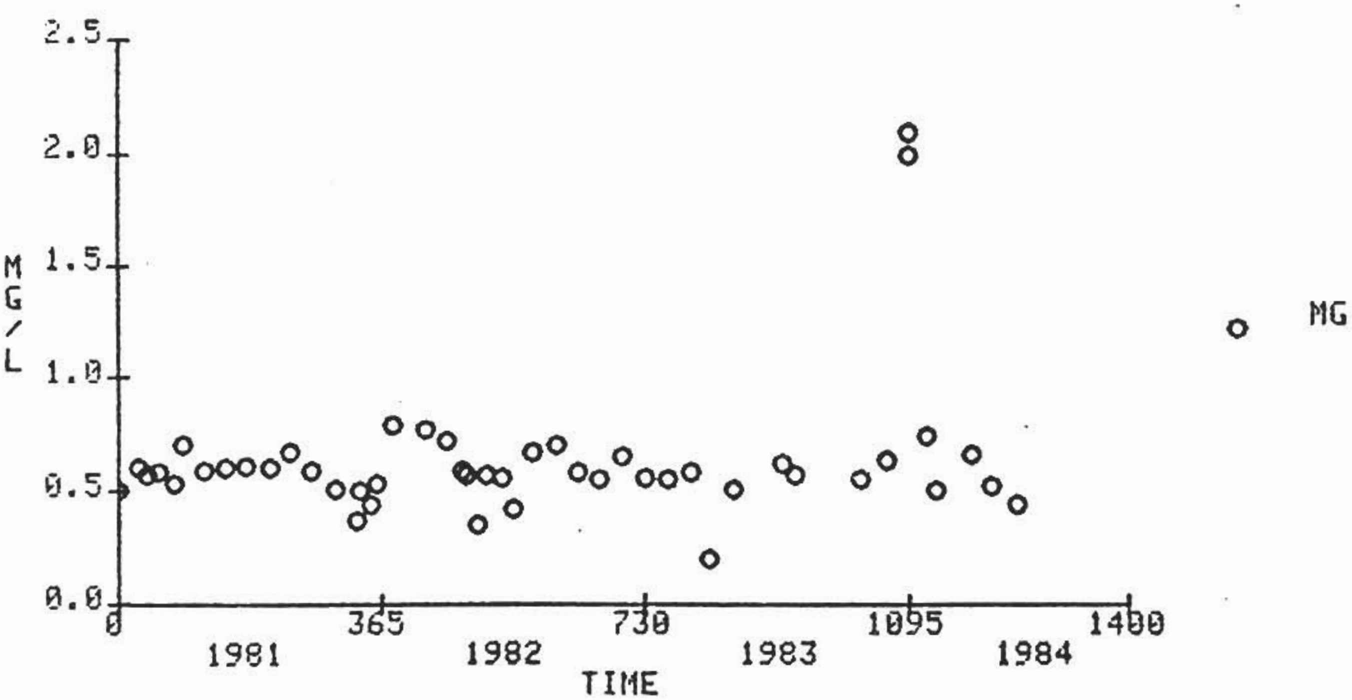


FIG.22 VARIATION OF MAGNESIUM CONCENTRATION
AT RUBY LINE



Alkalinity or bicarbonate concentration was a function of the season with the highest values measured during the summer months, generally under low flow conditions (Fig. 25-26). Concentrations increased towards the river mouth, suggesting that the levels were geochemically controlled. There seems to be a relationship between total alkalinity and the logarithm of the instantaneous discharge values. The same was observed for calcium. As river discharge increased, the total alkalinity and calcium concentrations were consistently lower, apparently the result of dilution. The best relationships between alkalinity or calcium and log of instantaneous discharge were observed for the Dunns Road station (Fig. 27-28). Weaker relationships were found for the South Brook stations and the Old Bay Bulls Road station. In the case of the South Brook, this could be related to the fact that these waters are less alkaline, with pH values often below 5.5. The Old Bay Bulls Road station had some samples with high calcium concentrations at high river discharges, although many of the samples followed the general relationship of dilution of calcium and alkalinity at higher discharge. These outliers caused weaker relationships (Fig. 29-30).

Silica (SiO_2) generally occurs in moderate abundance in fresh waters and is relatively unreactive chemically, although it does assume a major role in diatom algae cycles. Large quantities of silica are assimilated by diatoms for the synthesis of their frustule cell structure (Wetzel, 1975). Although silica is being discussed in this section, it could be considered as a nutrient as the availability of silica can have an important influence on planktonic succession and productivity. Degradation of alumino-silicates minerals is the major source of silica. At the pH values exhibited by the river, silica was present in the acid form and made a negligible contribution to the ion balance calculation.

The silica content of river waters tend to be remarkably uniform and does not show as large a response to change in discharge rates as other major constituents of river water (Wetzel, 1975). However, the Waterford River basin surface waters showed extreme variations (as low as 0.1 mg/L and as high as 6.9 mg/L). Very low silica concentrations

FIG.23 VARIATION OF MAGNESIUM CONCENTRATION AT COMMONWEALTH

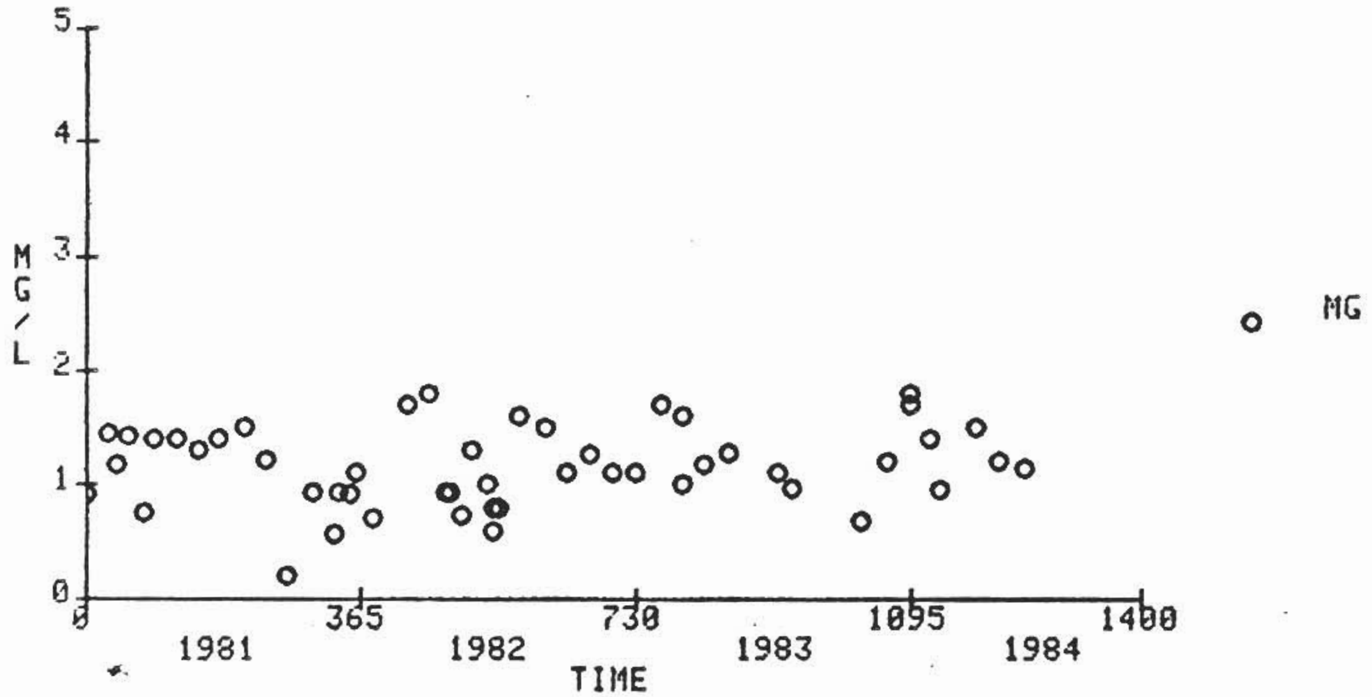


FIG.24 VARIATION OF MAGNESIUM CONCENTRATION AT DUNNS

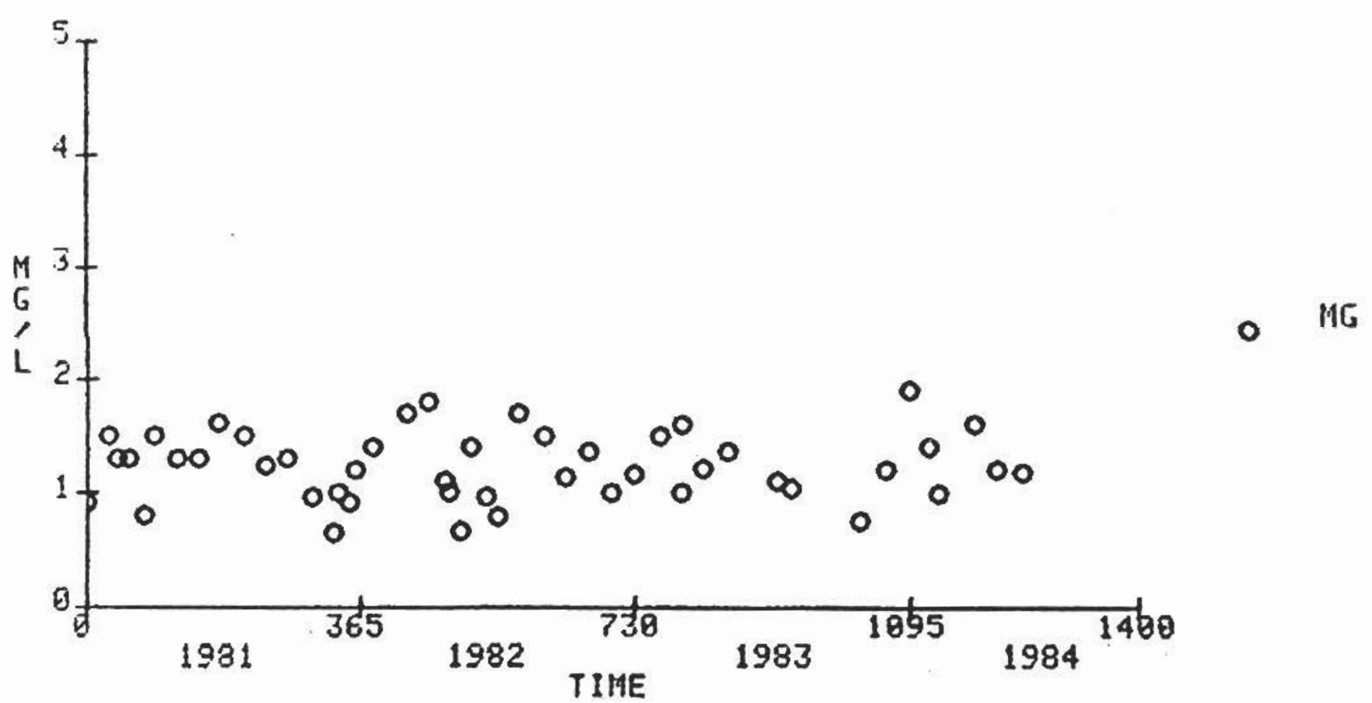


FIG.25 VARIATION OF TOTAL ALKALINITY CONCENTRATION AT DONOVANS

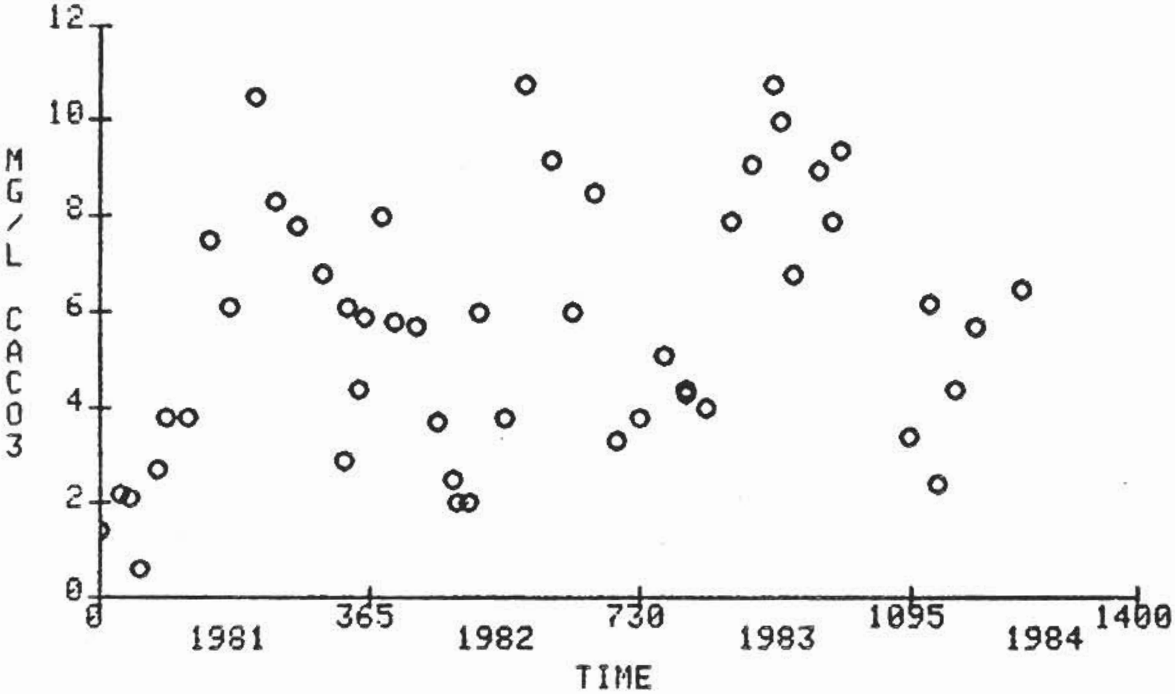


FIG.26 VARIATION OF TOTAL ALKALINITY CONCENTRATION AT OLD BAY BULLS

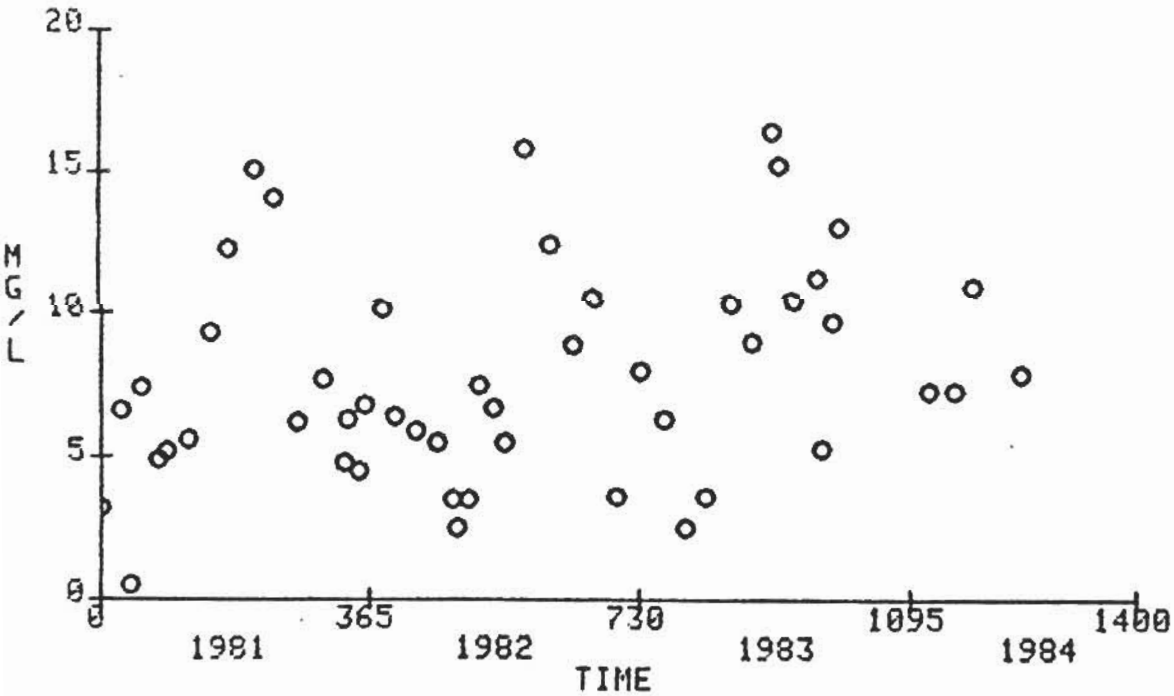


FIG.27 LOG(INST.DISCHARGE) VS TOTAL ALKALINITY FOR DUNNS ROAD STATION

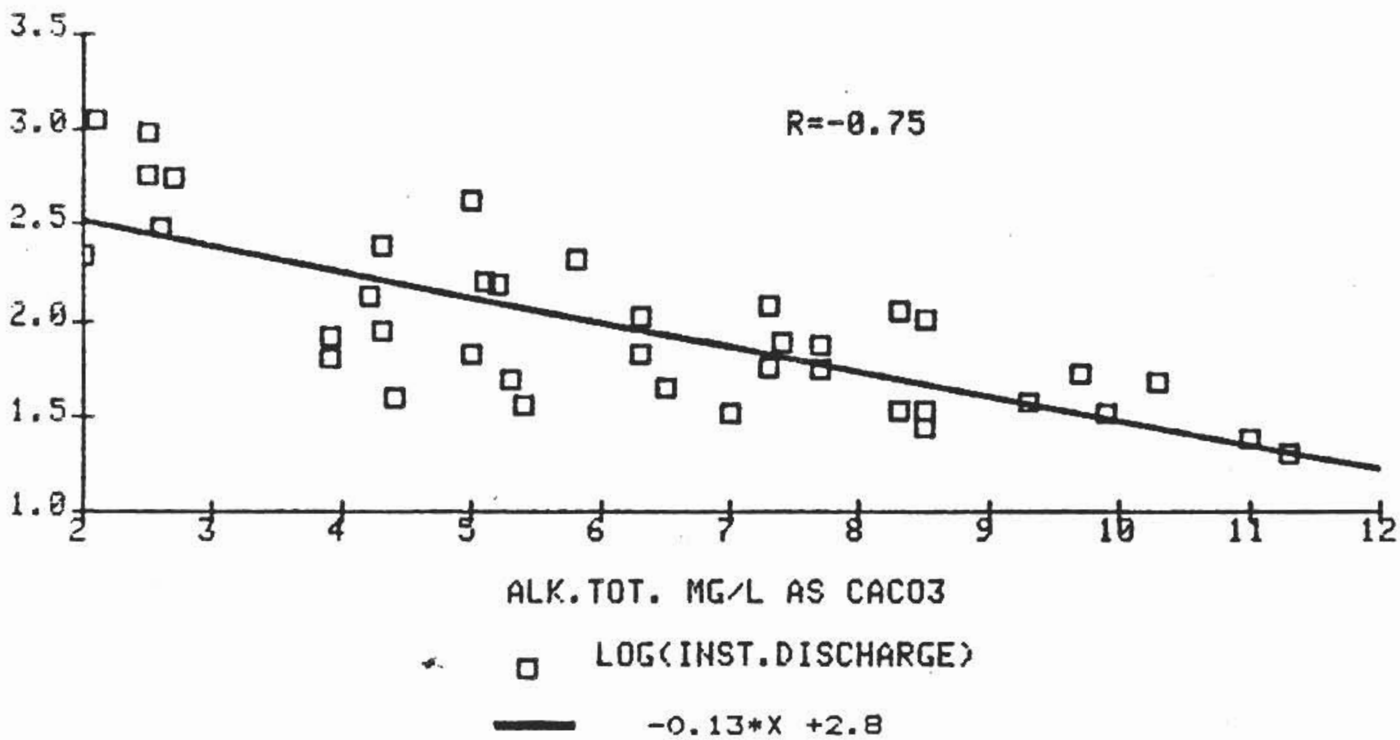


FIG.28 LOG(INST.DISCHARGE) VS CALCIUM DISSOLVED FOR DUNNS ROAD STATION

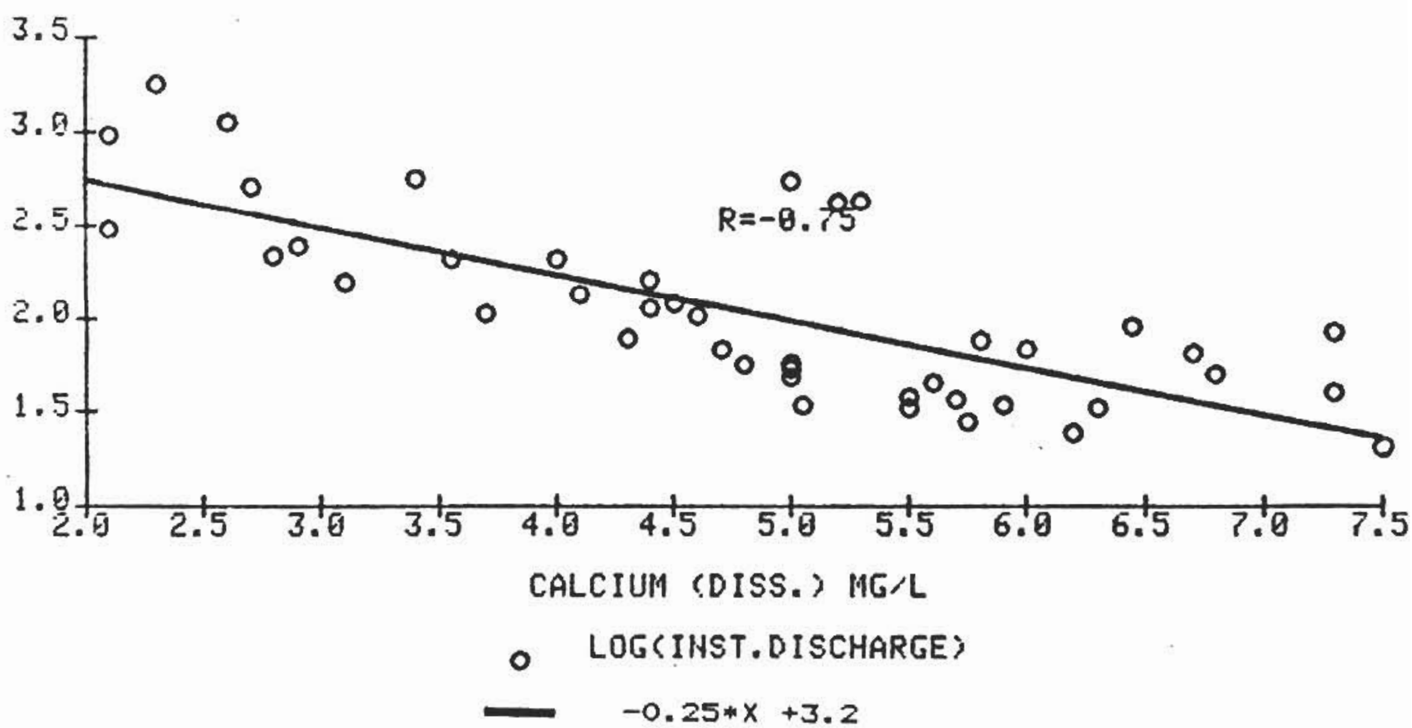


FIG.29 LOG(INST.DISCHARGE) VS TOTAL ALKALINITY
FOR OLD BAY BULLS ROAD STATION

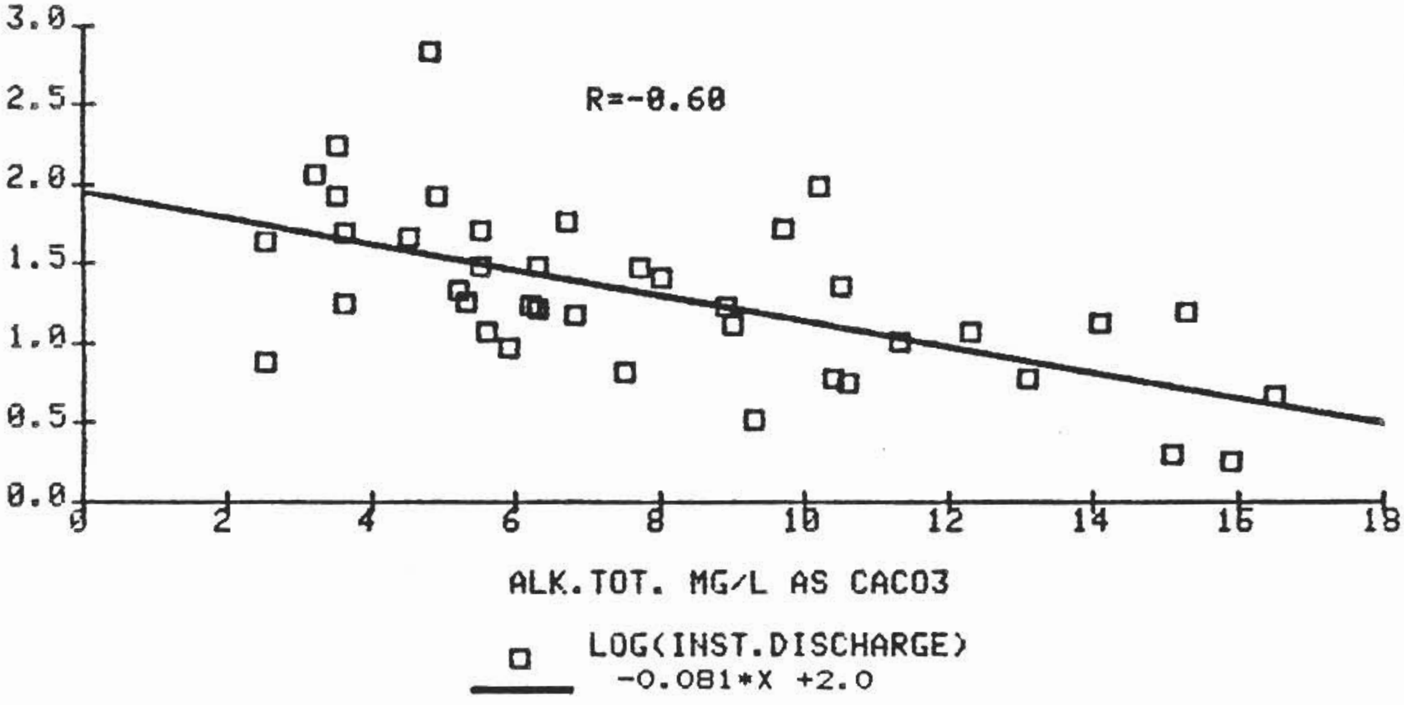
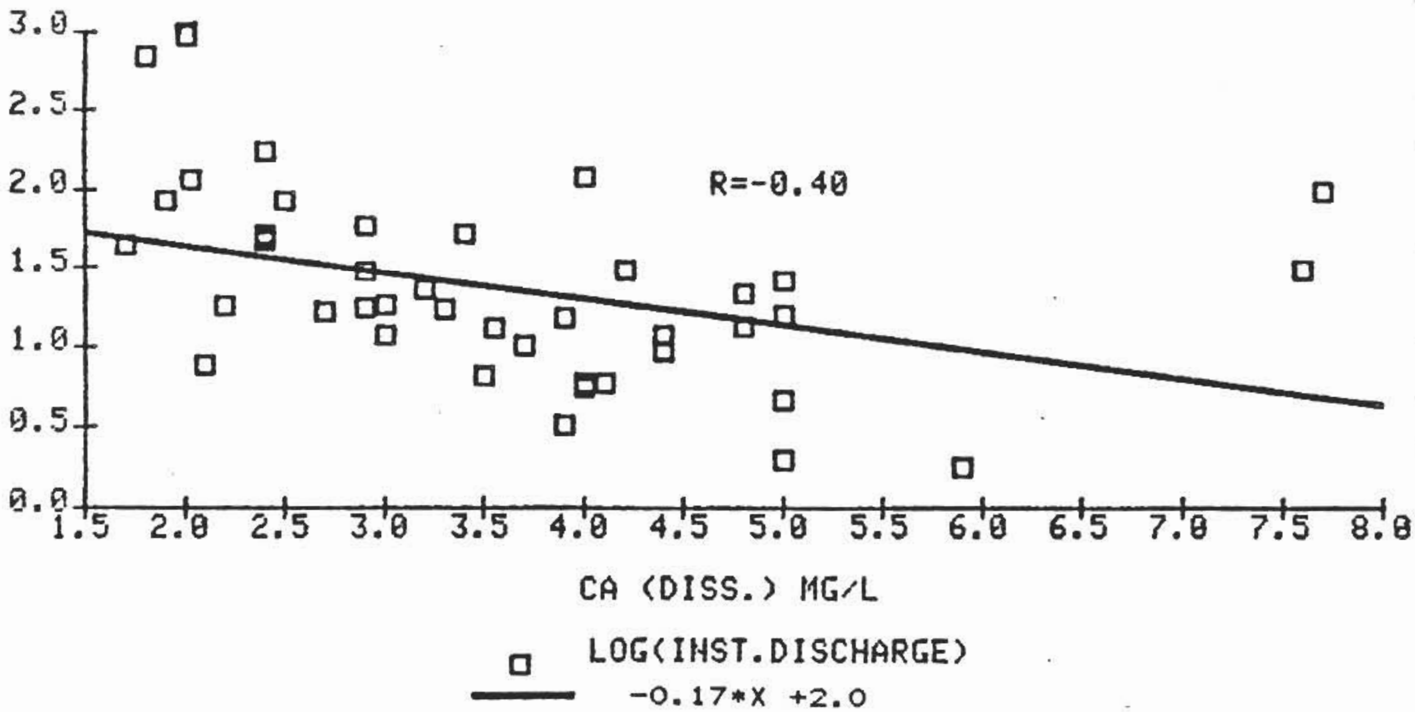


FIG.30 LOG(INST.DISCHARGE) VS CALCIUM DISSOLVED
FOR OLD BAY BULLS ROAD STATION



were observed in summer and very high concentrations were observed in fall and early winter. The general trend was lower concentrations during high flows, but high concentrations were observed in some cases during high flows. All stations had a series of lower silica concentrations during May and June 1982. Scrutiny of the discharge database revealed that during this period, the total discharge was more than twice that observed in May and June of 1981 or 1983. Consequently, dilution of silica did occur during that period. Typical Canadian surface water exhibits a silica concentration of 3 to 4 mg/L. Overall, this was observed in the Waterford River basin surface waters. The silica concentration variation over time at two selected surface water stations is shown in Figure 31 and 32.

4.3 Metals: Iron, Manganese, Copper, Lead and Zinc

Concentrations of iron and manganese in aerated surface waters are usually less than 0.5 mg/L and 0.2 mg/L respectively, but can be substantially greater in groundwater (McNeely et al., 1979).

The collection, preservation and analysis procedure for extractable metals calls for the addition of 2 mL of concentrated nitric acid to a litre of sample (extractable metals are those present in the supernatent of an acidified sample). This guarantees that metal ions will not be adsorbed onto the walls of the container. However, it also desorbs metal ions from the surface of particulate matter present in the water. During a rain event, the turbidity was generally higher in the river water due to the flushing of particulate matter by the runoff. This was observed to affect the levels of iron and manganese measured in the preserved samples. Manganese and iron concentrations generally peaked just before the hydrograph peak associated with a rain event, as shown in Figures 35 and 36. It also appeared that there may have been other sources of iron and manganese at the Donovans site, since the higher values often measured there were not always observed downstream.

The podzolic soils of the basin contain varying degrees of organic matter, iron and aluminum (Batterson, 1984) which is reflected in

FIG.31 VARIATION OF SILICA CONCENTRATION AT COMMONWEALTH

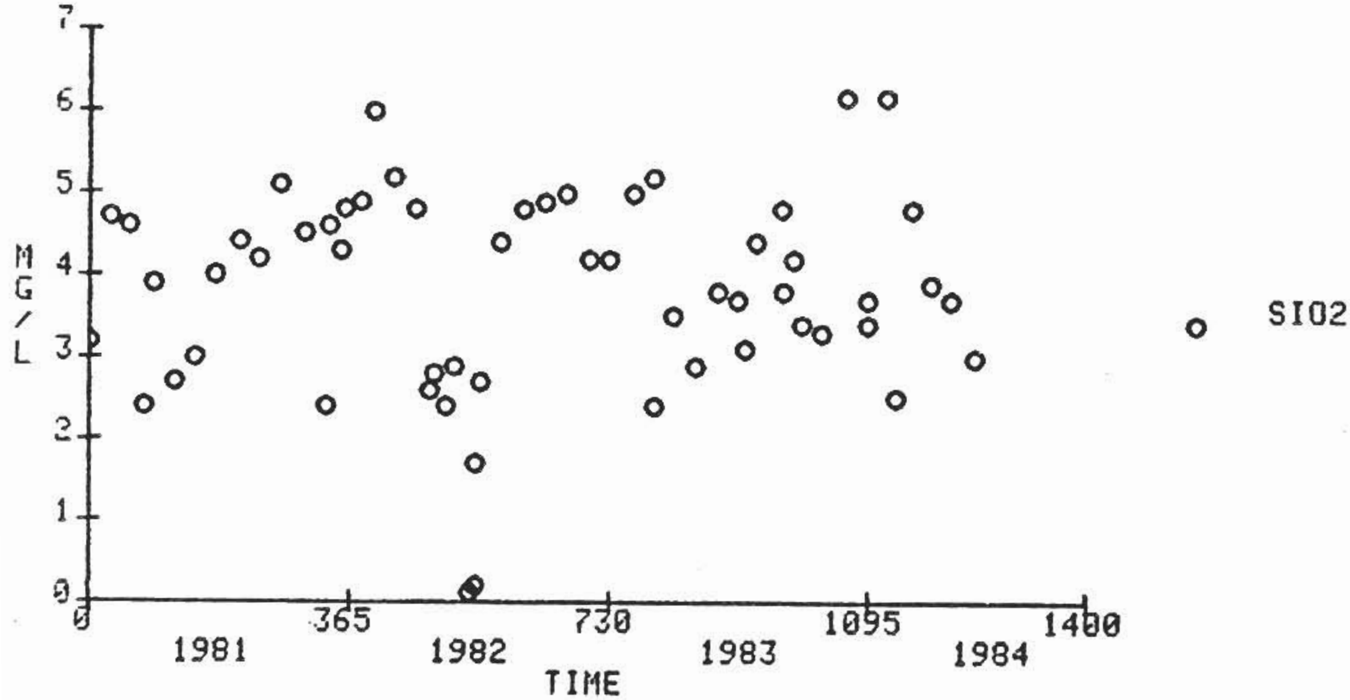


FIG.32 VARIATION OF SILICA CONCENTRATION AT HEAVY TREE

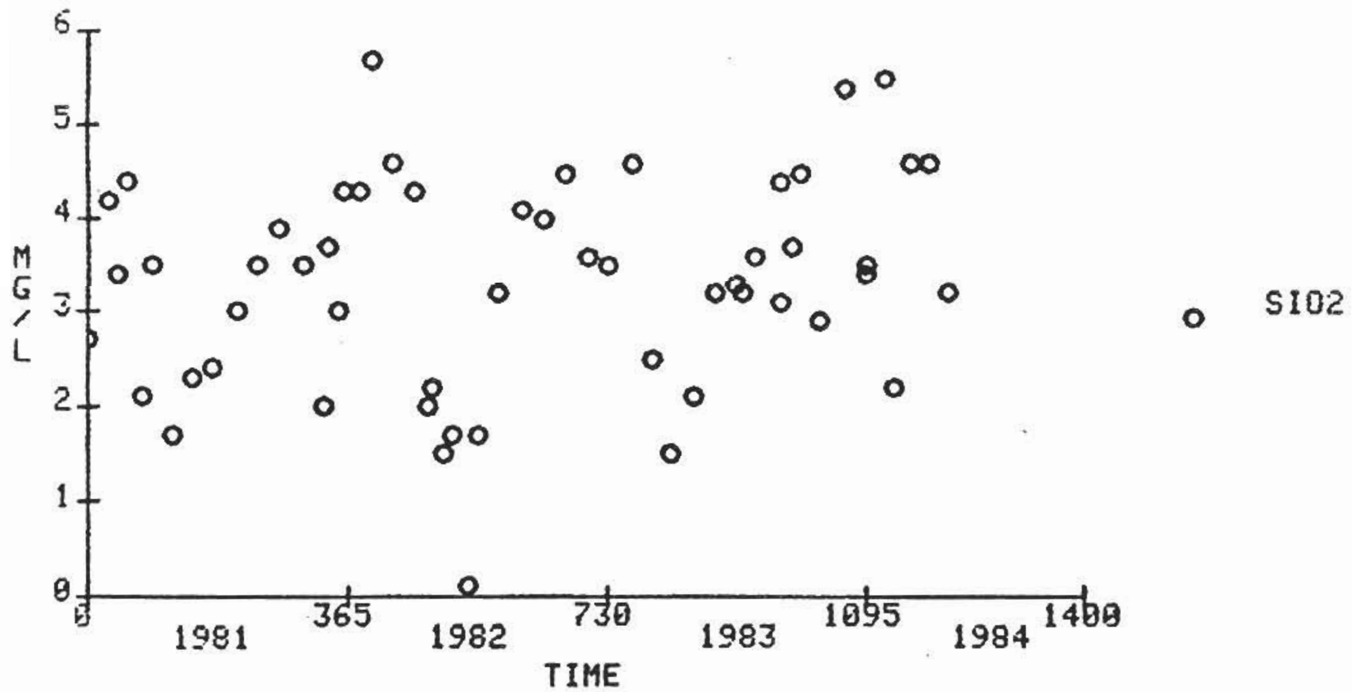


FIG.33 VARIATION OF POTASSIUM CONCENTRATION
AT DUNNS

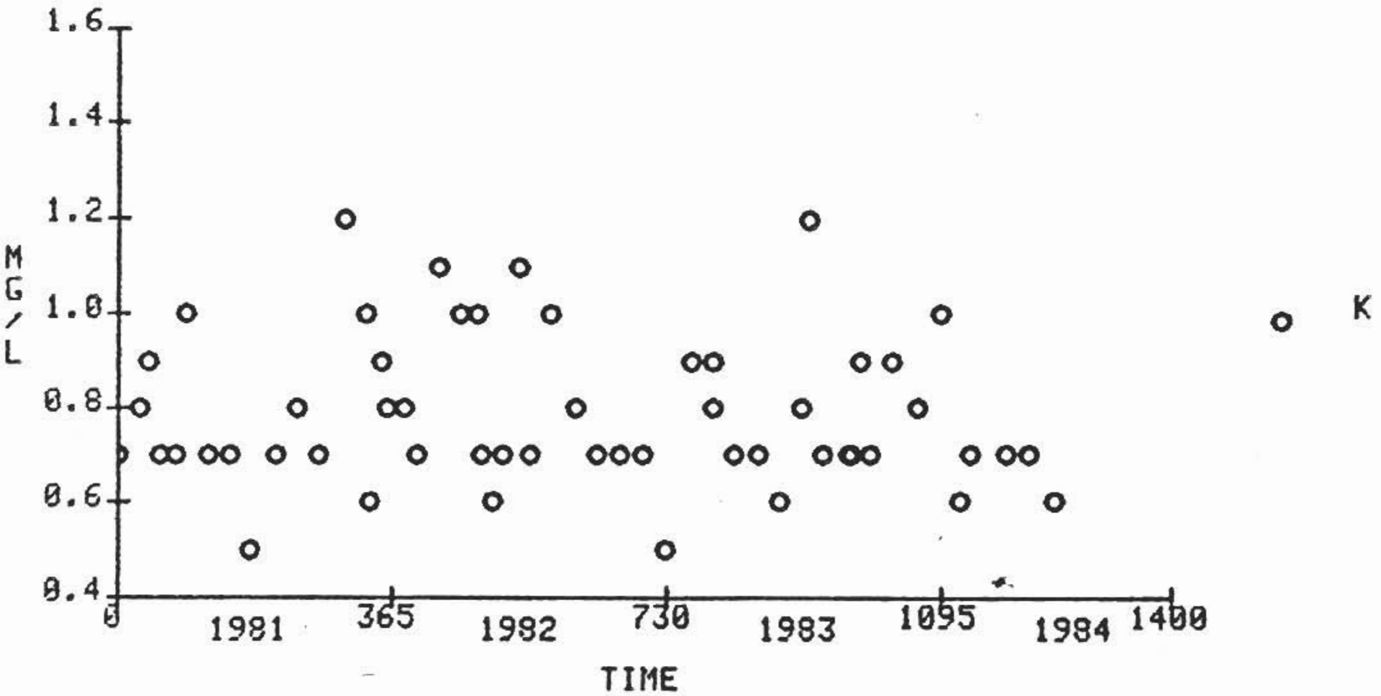
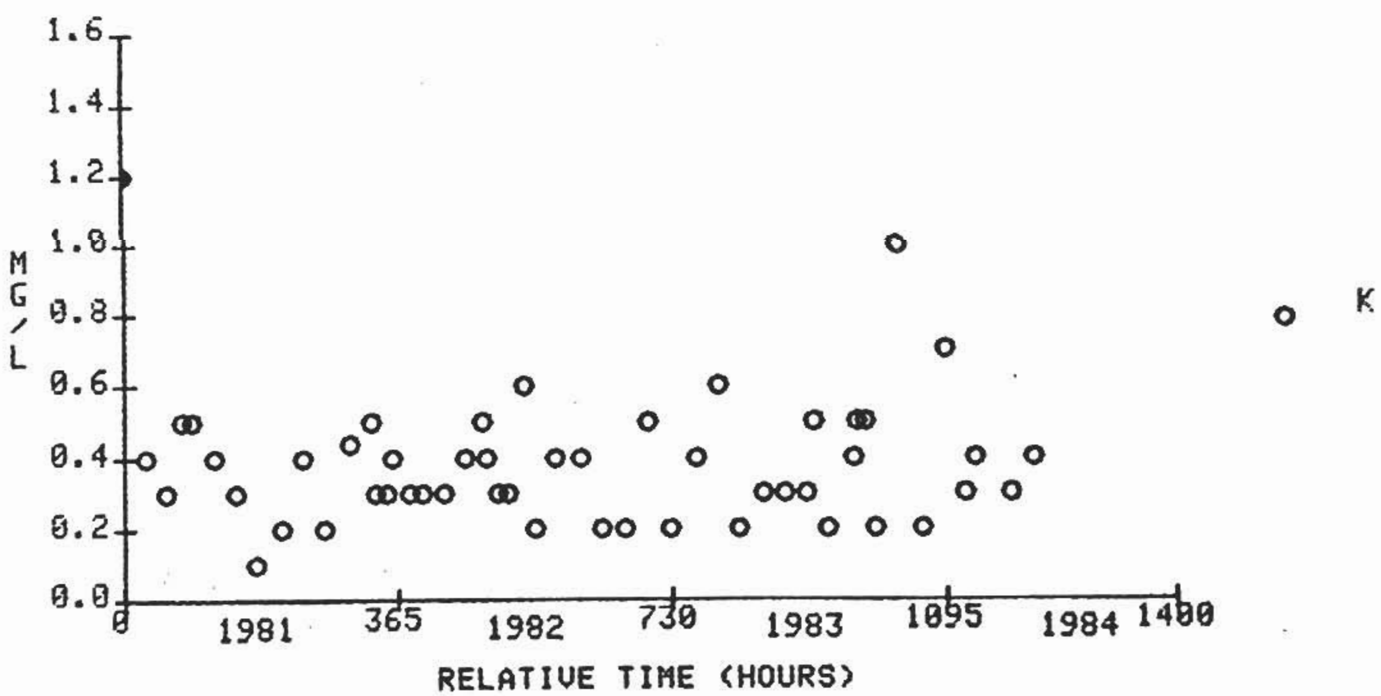


FIG.34 VARIATION OF POTASSIUM CONCENTRATION
AT HEAVY TREE



surface waters in the basin. The Waterford River water at the 3 most upstream surface water stations had typical iron concentrations of over 0.5 mg/L whereas at the two South Brook stations, the iron concentrations typically were about 0.30 mg/L. As previously stated, the turbidity was generally much lower in the South Brook waters which explains the lower iron concentration.

Manganese followed the same pattern as iron, presenting higher concentration at the 3 upstream stations on the Waterford River at typically 0.3 mg/L compared to 0.1 mg/L at the South Brook stations. A good relationship was observed between iron and water colour for the South Brook data set (Fig. 37). The relationship is not as good for the upper Waterford River data set (Fig. 38). This could be explained by the fact that the three stations located on the upper Waterford River frequently had low water colour values.

In the Waterford River waters, copper and lead values were generally at, or less than, the analytical detection limit. The same observations were made for the South Brook waters. The highest copper value (0.011 mg/L) was recorded at the Dunns Road station in October 1981, on a rainy day and rising hydrograph. All the other studied metals also had high values on that day. The Old Bay Bulls station also had a copper concentration of 0.011 mg/L on one occasion at high river discharge.

The highest lead value (0.30 mg/L) was recorded at the Kilbride station on a rising hydrograph, in September 1982. This detected concentration was much higher than the prescribed guideline for the protection of freshwater aquatic life (at 0.03 mg/L, McNeely, et al., 1979). However, lead concentrations higher than 0.03 mg/L were very seldom measured in the basin surface waters during this study. The Kilbride (14 occasions) and the Dunns Road (1 occasion) stations were the most affected stations, although on those occasions the flows were up. The major source of lead in the basin was suspected to be leaded gasoline. Upon combustion, lead is released to the atmosphere and then probably accumulates on the surface of parking lots, streets, snow and

FIG.35 HYDROGRAPH AT KILBRIDE DURING THE DECEMBER 20-21/82 RAIN EVENT

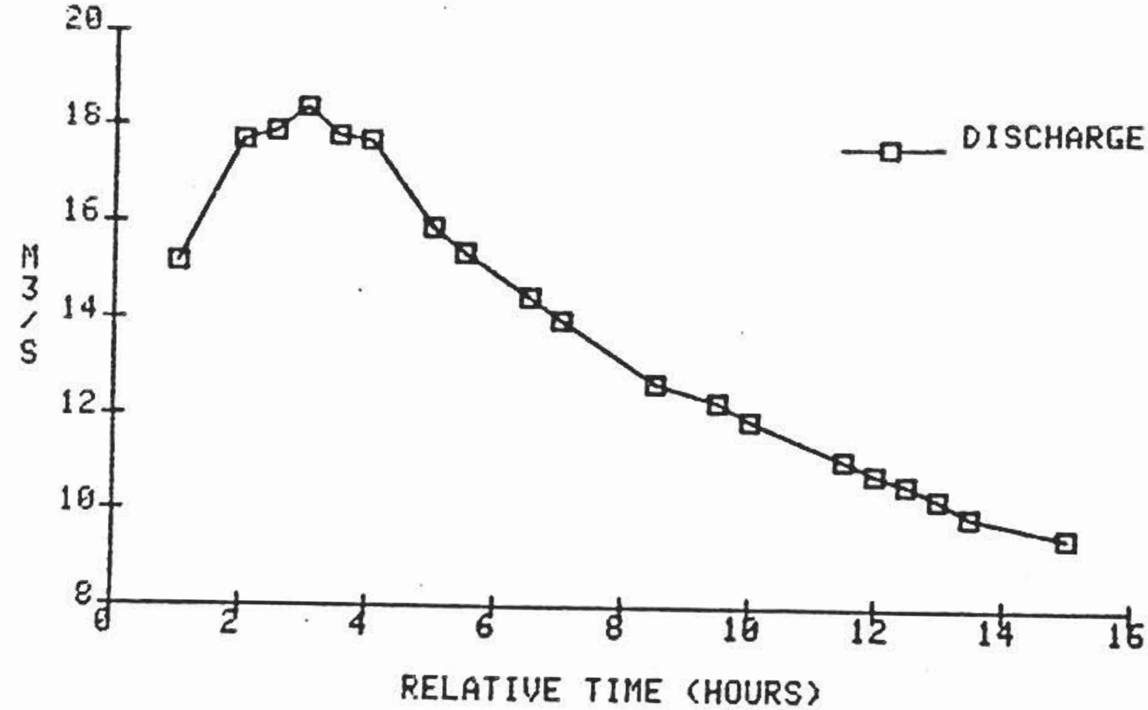


FIG.36 IRON AND MANGANESE CONCENTRATIONS VARIATION DURING THE DECEMBER 20-21/82 RAIN EVENT

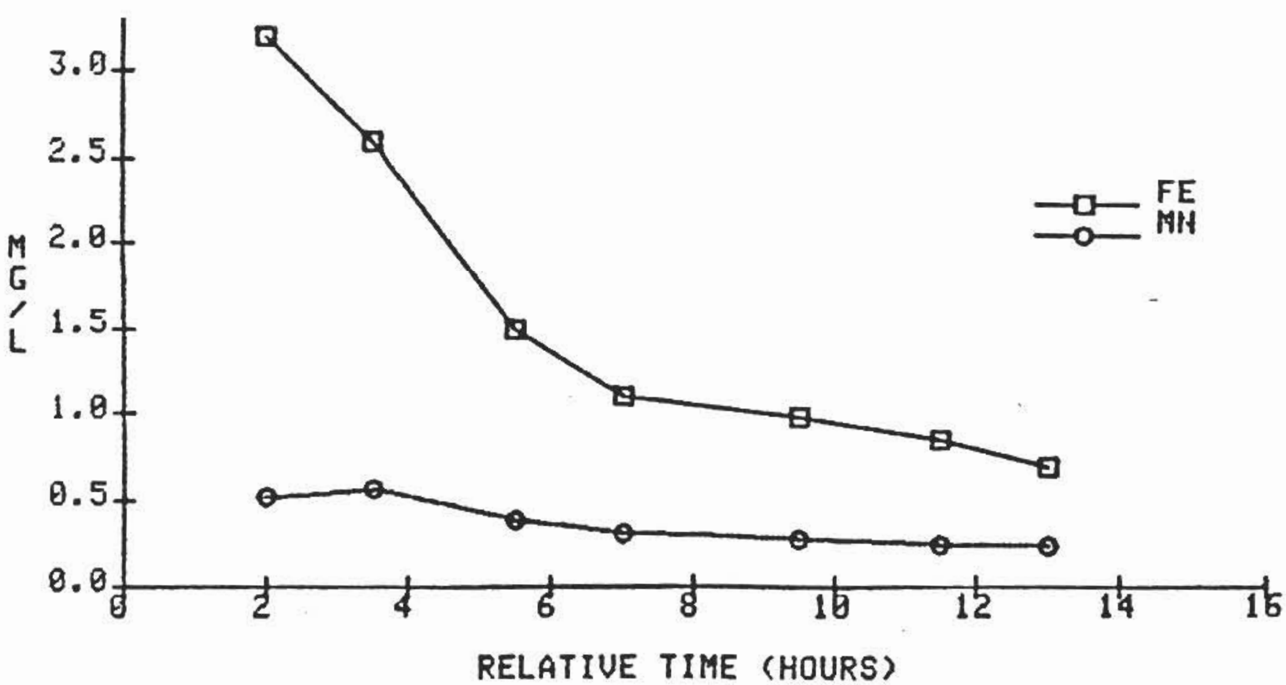


FIG.37 RELATIONSHIP BETWEEN IRON AND WATER COLOUR
FOR THE SOUTH BROOK DATA

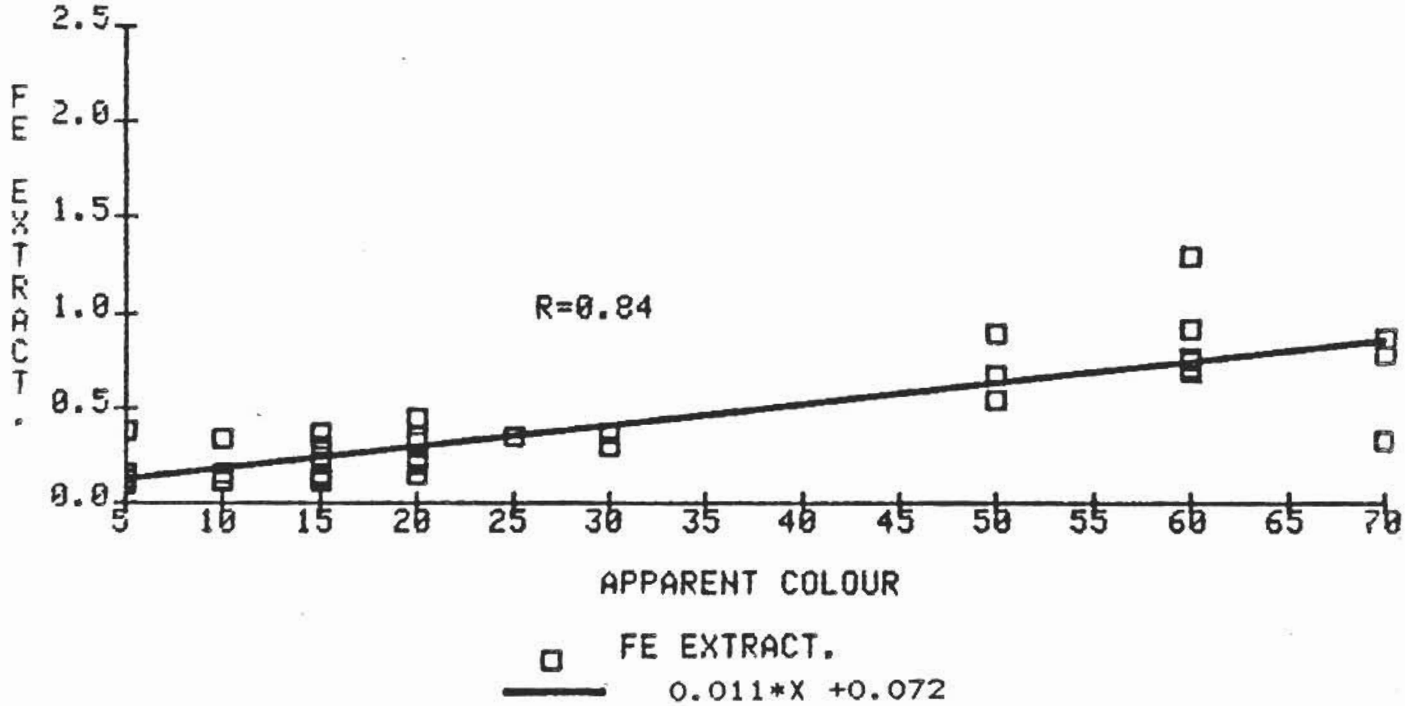
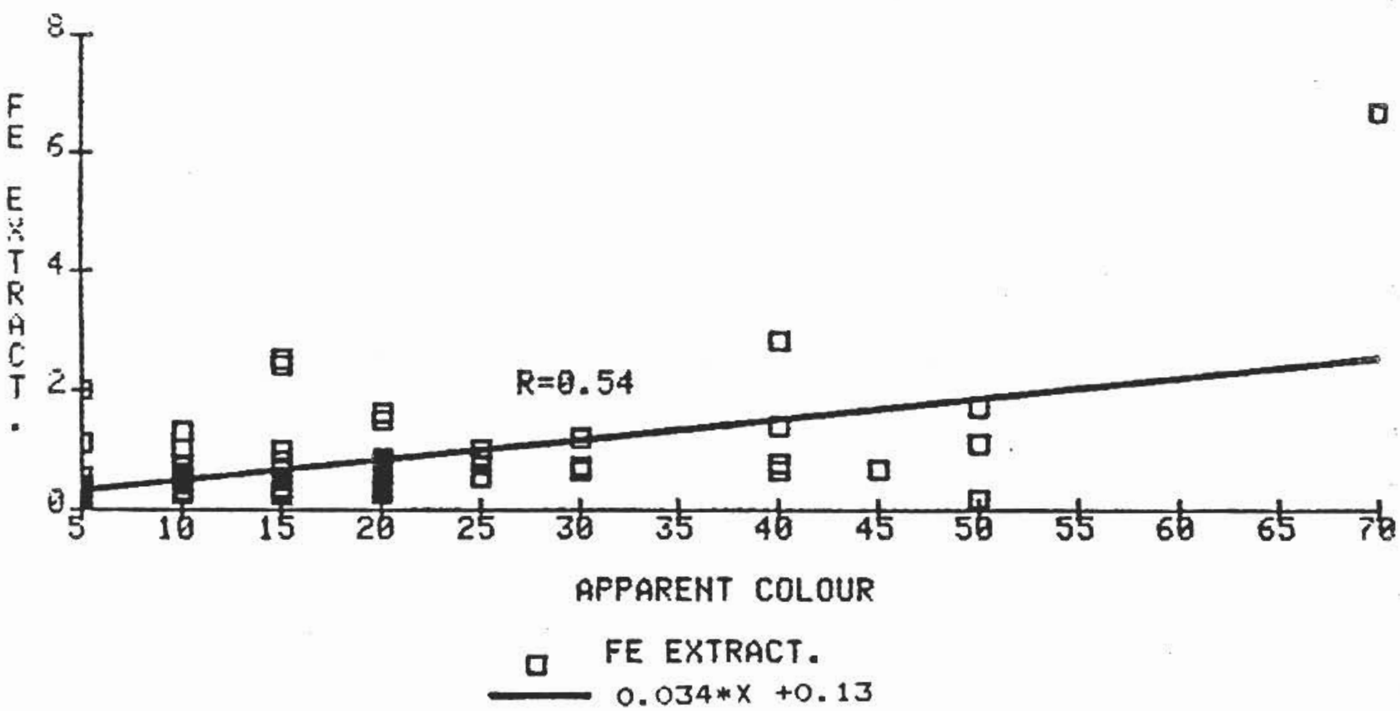


FIG.38 RELATIONSHIP BETWEEN IRON AND WATER COLOUR
FOR THE UPPER WATERFORD RIVER DATA



other surfaces, and is washed down into the river by runoff and snow melts.

The other metal investigated in this study was zinc. Usually zinc is present in trace amounts in both ground and surface waters (i.e. less than 0.05 mg/L). Zinc oxides (slightly soluble in water) are widely used in paints, rubber, textiles and other chemicals. Zinc is relatively non toxic to man. Concentrations of zinc up to 25 mg/L have shown few adverse effects (McNeely et al., 1979). However, it is acutely and chronically toxic to aquatic organisms, particularly fish. Its toxicity depends on a number of factors such as hardness, temperature increase, dissolved oxygen decrease, and the presence of copper and cadmium which enhance zinc sublethal toxicity. To protect aquatic life, a guideline for zinc concentration of 0.03 mg/L in unfiltered water samples, was prescribed (McNeely et al., 1979).

Similar to the other studied metals, the South Brook waters had the lowest concentrations of zinc, in spite of the fact that the samples at Heavy Tree Road were taken immediately downstream from a galvanized culvert. In some cases, levels of zinc of about 0.10 mg/L were detected in the water at Kilbride, at high flows. Usually concentrations lower than 0.05 mg/L were observed at all sites.

4.4 Nutrients

4.4.1 Nitrite-nitrate and total nitrogen

Nitrate (NO_3^-) is the principal form of combined nitrogen in natural waters. Nitrate ion is very highly soluble and is the most stable form of combined nitrogen in surface waters. It results from the complete oxidation of nitrogen compounds. Conversion of ammonia or nitrite to nitrate is the principal process in the nitrogen cycle. Most surface waters contain some nitrate, although its presence in concentration greater than 5 mg/L may reflect unsanitary conditions because one major source of nitrate is human and animal wastes (McNeely et al., 1979). Nitrite is unstable in presence of oxygen and therefore is usually present only in minute quantities in surface waters, typically in the order of 0.001 mg/L.

On only one occasion, during this study, the nitrite-nitrate levels were higher than 1.0 mg/L as N. It was at the Ruby Line station (1.1 mg/L as N) in February 1983. It was believed that this resulted from a contaminated sample (potassium was also extremely high at 2.5 mg/L). Usually the levels at Ruby Line and Heavy Tree Road are the lowest typically having a range of 0.02-0.05 mg/L as N. All the other sites had values greater than 0.2 mg/L as N. The sites which generally had the highest nitrite-nitrate values were the station at the Agriculture Canada farm (pasture lands) and the Kilbride station, which receives the waters from all tributaries.

The total nitrogen content in water was also measured. This included the nitrite-nitrates, ammonia (dissolved and ionic) and organic nitrogen.

The differences between the surface water from developed and undeveloped parts of the basin was demonstrated again by the observed nutrients concentrations. The mainstem usually had higher nitrite-nitrate and total nitrogen concentrations than the South Brook. In addition, the portion of total nitrogen being in the nitrite-nitrate form was higher, as expected, in the mainstem waters.

The total nitrogen content was typically 0.5 mg/L in the Waterford River waters and 0.2 mg/L in the South Brook waters. The sites with the highest total nitrogen contents were generally those located near pasture lands and farms such as Agriculture Canada farm and Old Bay Bulls Road stations, and also the Kilbride station.

In mid-1982, the procedure of adding a preservative to the sample bottles was stopped (except for phosphorus) and the analyses of nitrate-nitrite and total nitrogen were performed from the major ions bottles. This change in the procedure slightly affected the analytical results. It seems that adding a preservative into the water samples resulted in a small underestimation of nitrite-nitrate or total nitrogen concentrations. Figures 41 to 44 illustrate the variation of nitrite-nitrate and total nitrogen concentrations over time at the Dunns Road and Heavy Tree Road stations.

4.4.2 Total phosphorus

Phosphorus is a non-metallic element that can occur in numerous organic or inorganic forms, and can be present in waters as a particulate or dissolved species. Phosphorus, being an essential plant nutrient, may be a limiting factor for plant growth. Phosphorus is rarely found in significant concentrations in surface waters because it is actively taken up by plants. However, domestic sewage, phosphates from detergents, industrial effluents, and agricultural drainage from fertilized land contribute phosphorus to surface waters. Phosphorus is not commonly toxic to man, animals or fish. The total phosphorus concentration observed in uncontaminated lakes is in the order of 0.01 mg/L (McNeely et al., 1979). If sufficient nitrogen compounds are present, phosphorus concentrations above 0.1 mg/L in water may promote the development of slimes and algal growth, which affect municipal, industrial and recreational uses.

Generally the total phosphorus concentrations were higher in the Waterford River waters than those of the South Brook. Higher concentrations were frequently observed during summer and fall at all stations during a high discharge period, but to a lesser extent at the South Brook stations (Fig. 39-40). This was probably the result of a combination of inputs to the river waters from runoff such as fertilizers, animal wastes, grass clippings, etc....

To minimize the possibility of excessive algal growth, a general index of 0.10 mg/L of phosphorus was prescribed as the maximum desirable concentration of phosphorus in flowing water (US-EPA, 1976). Scrutiny of the data for the three upstream stations on the Waterford River reveals that the Donovans station frequently had the highest total phosphorus concentration. The median total phosphorus values for the Donovans

FIG.39 VARIATION OF TOTAL PHOSPHORUS CONCENTRATION AT RUBY LINE

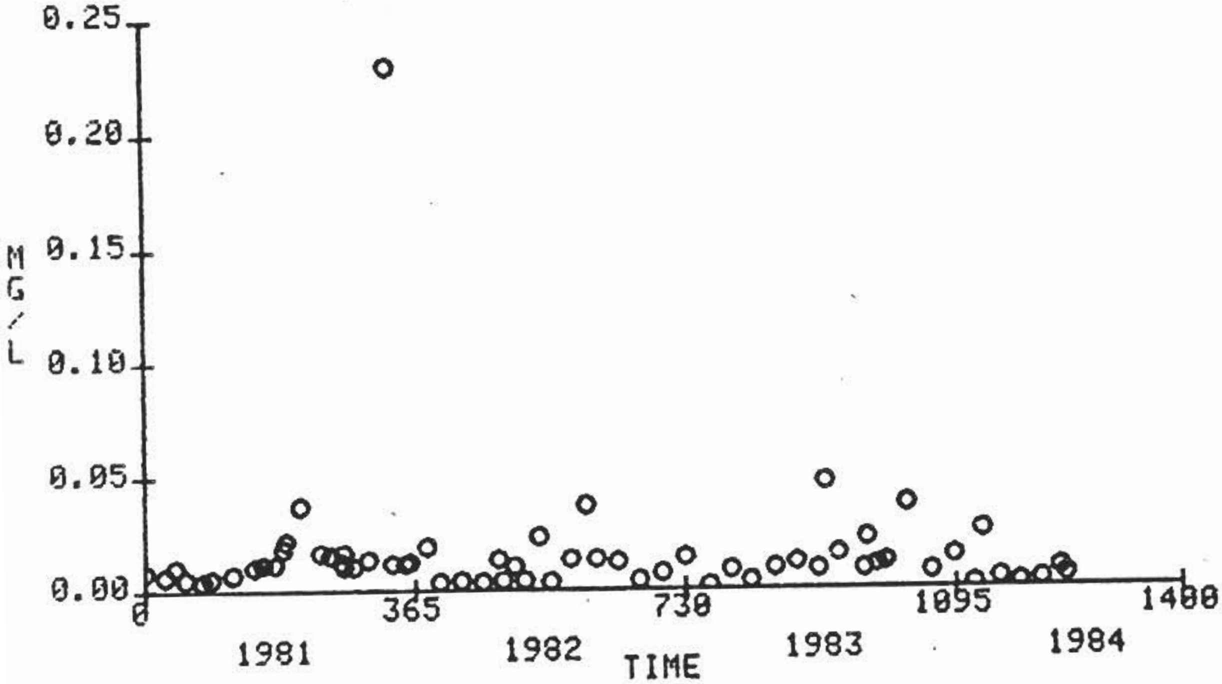


FIG.40 VARIATION OF TOTAL PHOSPHORUS CONCENTRATION AT COMMONWEALTH

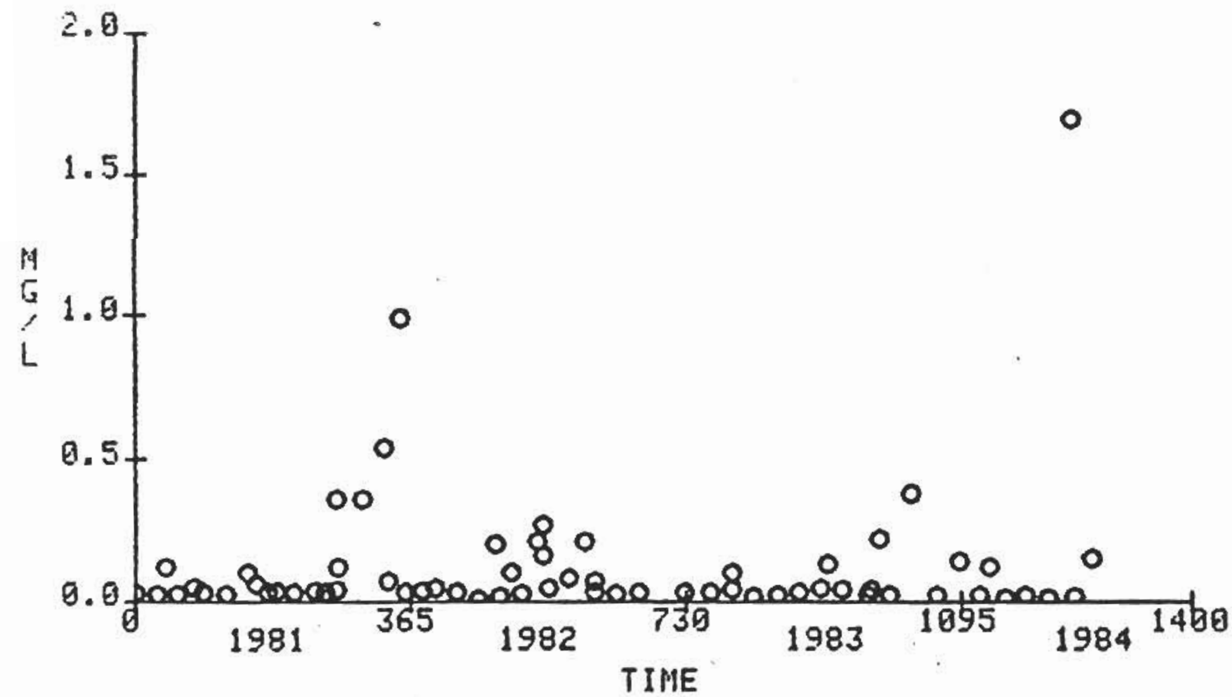


FIG.41 VARIATION OF NITRITE+NITRATE CONCENTRATION AT RUBY LINE

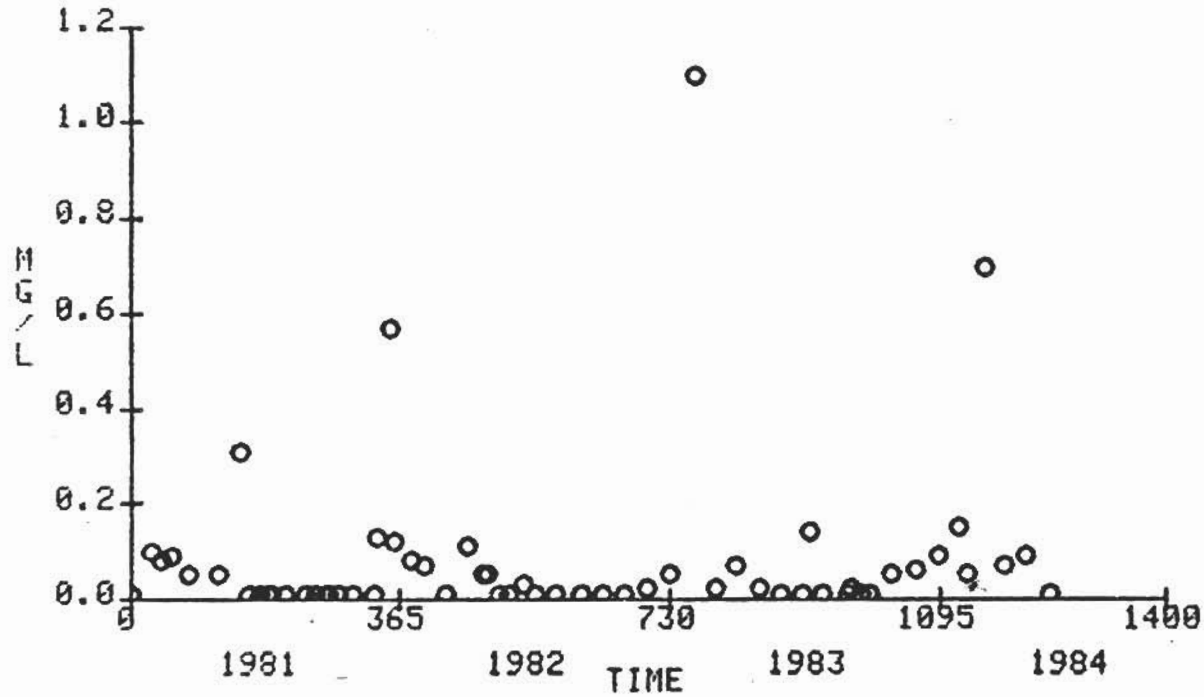


FIG.42 VARIATION OF NITRITE+NITRATE CONCENTRATION AT DONOVANS

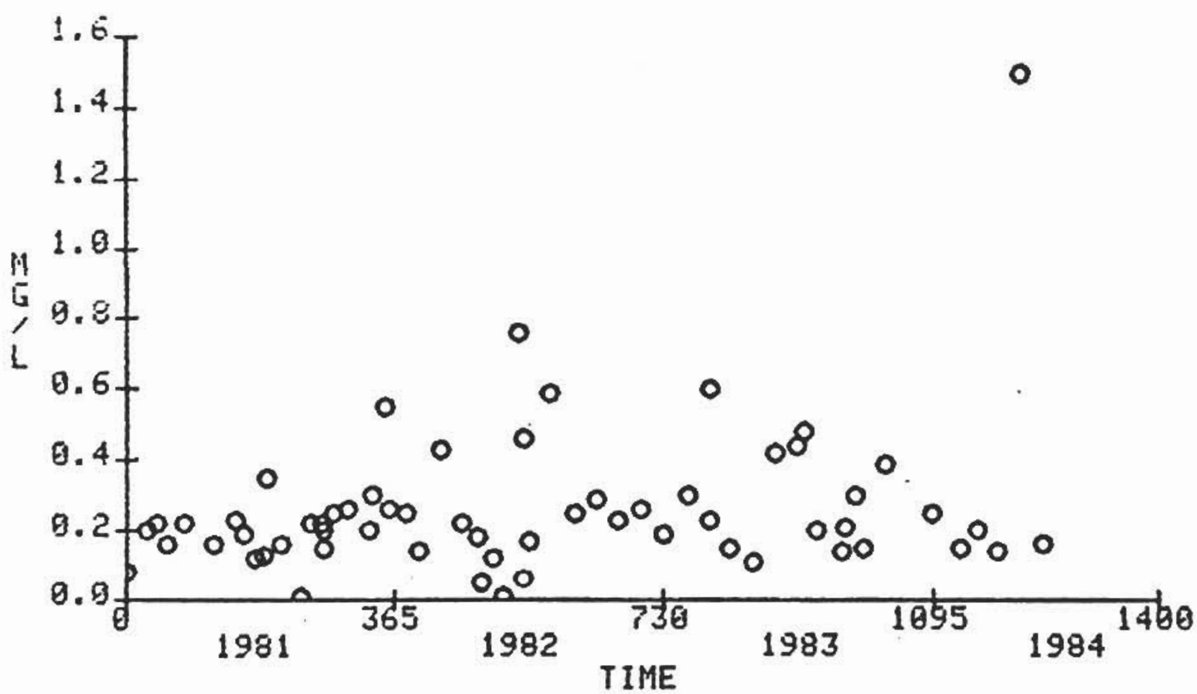


FIG.43 VARIATION OF TOTAL NITROGEN CONCENTRATION AT RUBY LINE

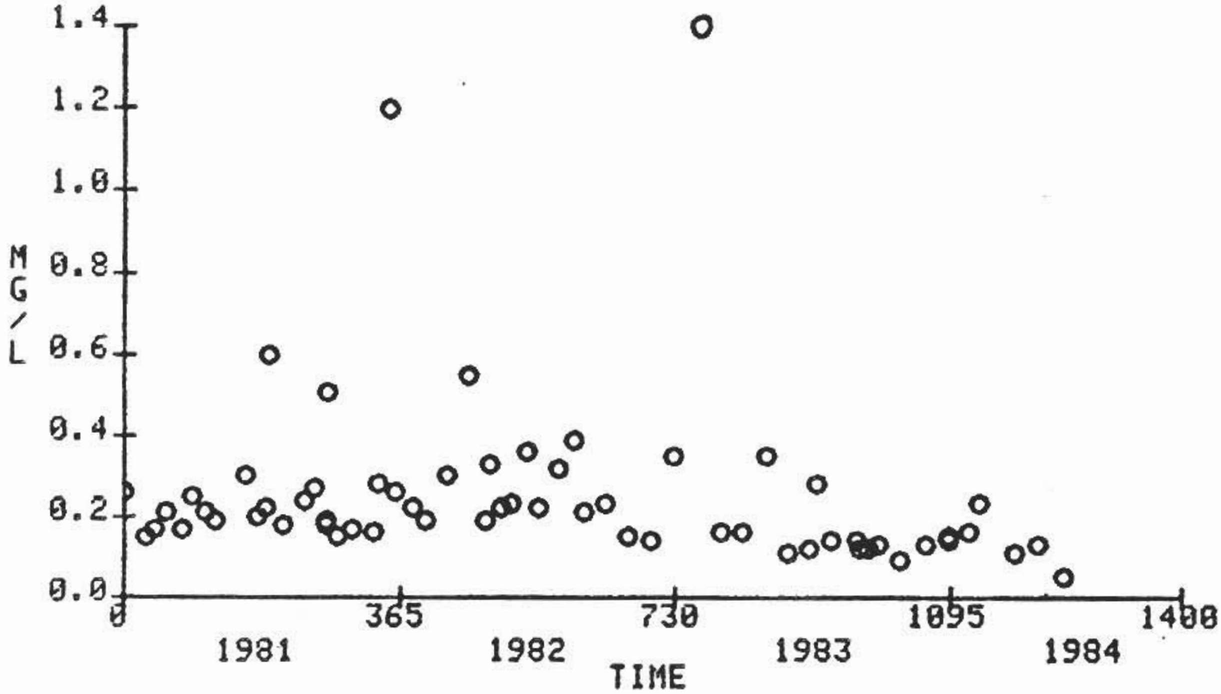
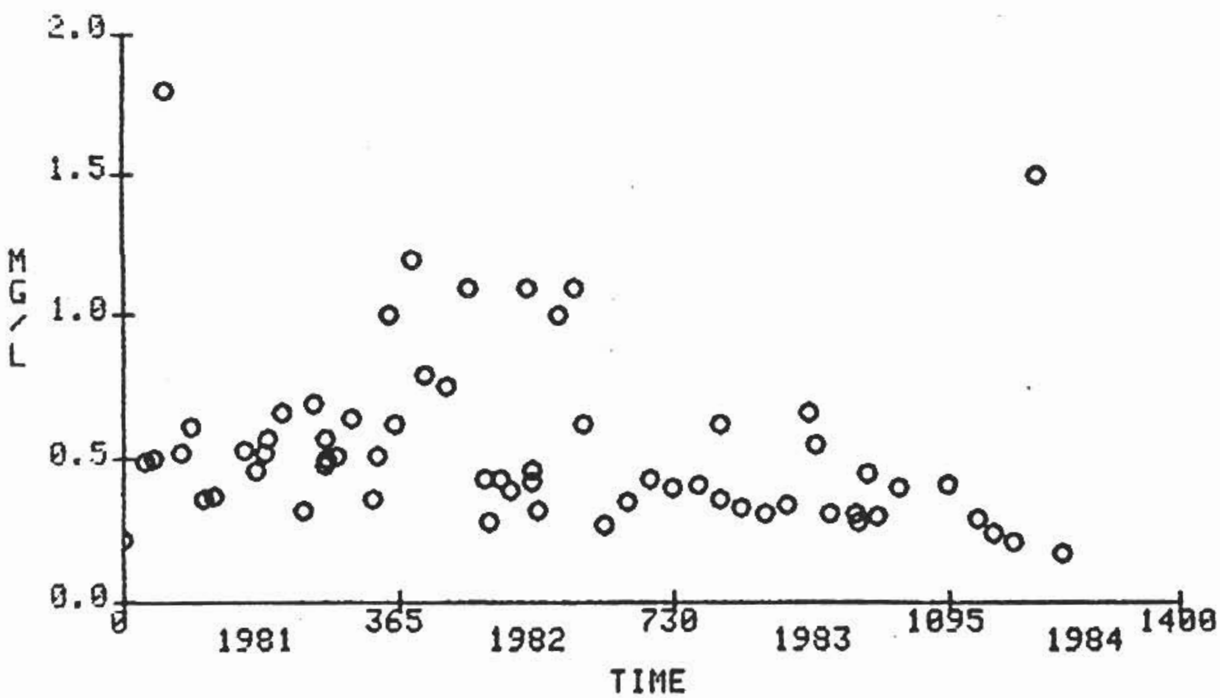


FIG.44 VARIATION OF TOTAL NITROGEN CONCENTRATION AT DONOVANS



station, the Commonwealth Avenue station, 2 km downstream, and the Dunns Road station, another 2 km more downstream, were respectively of 0.048, 0.040 and 0.034 mg/L. At the Donovans station, 20% of all samples were observed to exceed the index value of 0.10 mg/L. For the Commonwealth Avenue and the Dunns Road stations, 32% and 22% respectively of all samples had values higher than 0.10 mg/L. The maximum observed concentrations at these three stations were 0.47, 1.7 and 0.85 mg/L respectively. In addition to having the overall maximum total phosphorus concentration detected in a sample (1.7 mg/L), the Commonwealth Avenue station also had on two other occasions values greater than 0.5 mg/L. These very high total phosphorus concentrations were generally observed during high river discharges.

Overall, there is some indication of dilution effects on the total phosphorus in the Waterford River between the Donovans and the Dunns Road stations. However, there were some major peak loadings (possibly from sewers) of total phosphorus in the river water between the Donovans and the Commonwealth Avenue stations, which would explain the very high values measured at this latter site. Downstream, the Kilbride station frequently had total phosphorus concentrations exceeding 0.10 mg/L. The Agriculture Canada farm station had a median phosphorus value of 0.023 mg/L during this study and also had some extremes (range of 0.003 to 0.70 mg/L).

The tributary from Deadmans Pond at Old Bay Bulls Road station had total phosphorus concentrations similar to those observed in the Waterford River. At this site, 33% of all samples had total phosphorus concentrations greater than 0.1 mg/L. The median total phosphorus value at this station was 0.048 mg/L.

Again the Ruby Line station demonstrated some characteristics of a natural background station, with low total phosphorus concentrations (median of 0.01 mg/L) compared to the surface water stations located in the developed parts of the basin.

During this study, field personnel reported excessive aquatic plants growth in the river in the vicinity of some of the surface water stations in the Waterford River basin. The Donovans station located just downstream of an animal feed factory, was the most affected. Generally, in mid-summer and during low flow periods, the Waterford River just upstream from the Donovans station was almost choked with aquatic plants. Thus during low river discharge periods in the summer months, increased water residence time allows nutrient uptake and increased primary production.

Overall, the total phosphorus concentrations in the stretches of rivers located in the developed parts of the basin were typically in the range of 0.01 to 0.05 mg /L with frequent peaks of over 0.1 mg/L, up to 1.7 mg/L (mainly during high flows). Obviously, these concentrations are of some concern in regards to uses or potential uses of the river. However, it seems that flowing waters do not permit accumulation of the total phosphorus and other nutrients that could lead to excessive autotrophic productivity. In addition, the peak total phosphorus concentrations were usually observed at high flows. These high total phosphorus concentrations did not prevail for a long period of time in the river water, being transported by the flowing waters to the sea. According to Vollenweider (1968, taken from Wetzel, 1975), flowing waters with only slight loading generally have total phosphorus concentrations lower than 0.1 mg/L (100 mg/m^3). This was observed on most occasions in the Waterford River basin waters.

4.4.3 Organic carbon

Prior to May 1982, total organic carbon (T.O.C.) analyses were performed on all samples. At that time, a change to dissolved organic carbon (D.O.C.) analyses was made.

Organic carbon is both an indicator of basin productivity and urbanization. Waters containing less than 3.0 mg/L total organic carbon have been observed to be relatively clean (McNeely *et al.*, 1979). Excessive concentrations of organic carbon can lower dissolved oxygen to levels below that required by aquatic organisms.

During this study, high total organic carbon concentrations (up to 85 mg/L at the Agriculture Canada farm) were generally observed in summer and fall at high flow when the suspended matter content was also high. Variations of T.O.C. and D.O.C. over time for the Ruby Line and Donovans stations are illustrated in Figures 45 and 46.

High dissolved organic carbon concentrations were measured frequently at the two South Brook stations. This was related to the influences of the marshy South Brook headwaters. However, it was the Old Bay Bulls Road station that most frequently had the highest dissolved organic carbon, as was observed for total nitrogen and total phosphorus. As previously stated, the apparent water colour was also frequently high at this site. In addition this site usually had very high total and fecal coliforms and fecal streptococci counts, with FC/FS ratios indicating human pollution. This will further be discussed in Section 7.

A relationship between apparent water colour and dissolved organic carbon was observed, as was expected since a good portion of water colour is due to dissolved organic matter. This is illustrated in Figure 51 and 52 with both the upper Waterford River and South Brook data sets.

FIG. 45 VARIATION OF TOTAL AND DISSOLVED ORGANIC CARBON CONCENTRATIONS AT RUBY LINE

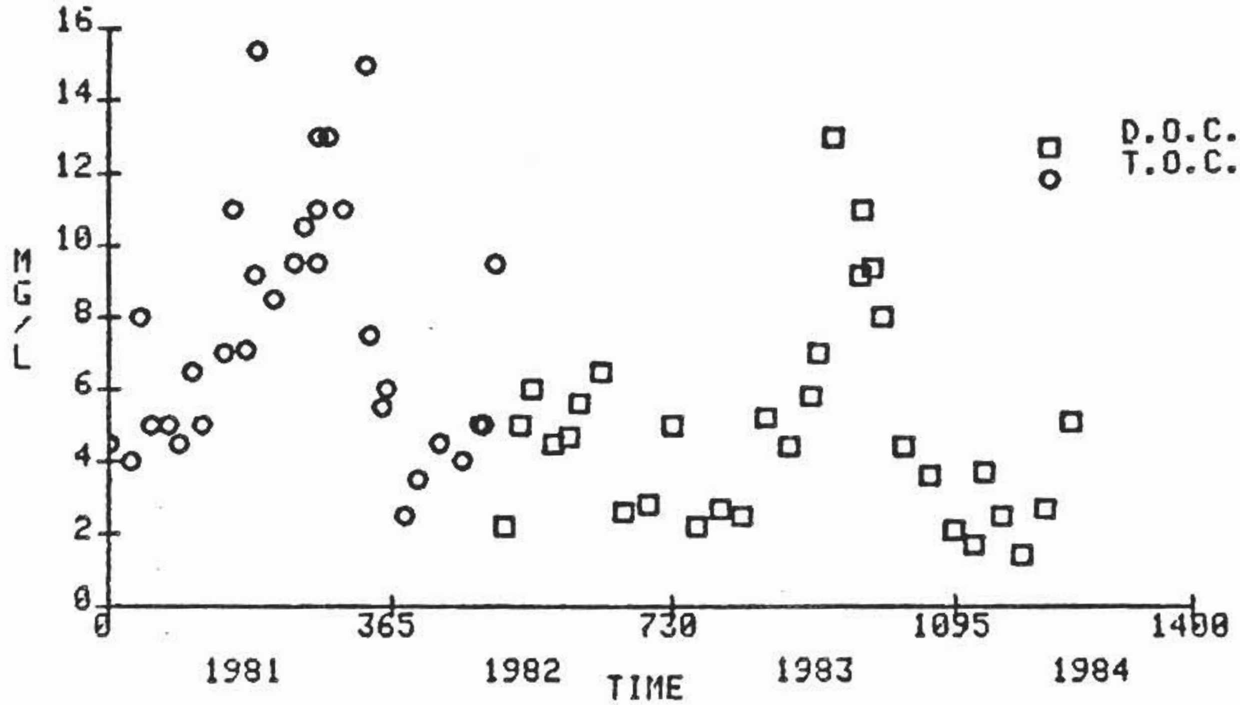


FIG. 46 VARIATION OF TOTAL AND DISSOLVED ORGANIC CARBON CONCENTRATIONS AT DONOVANS

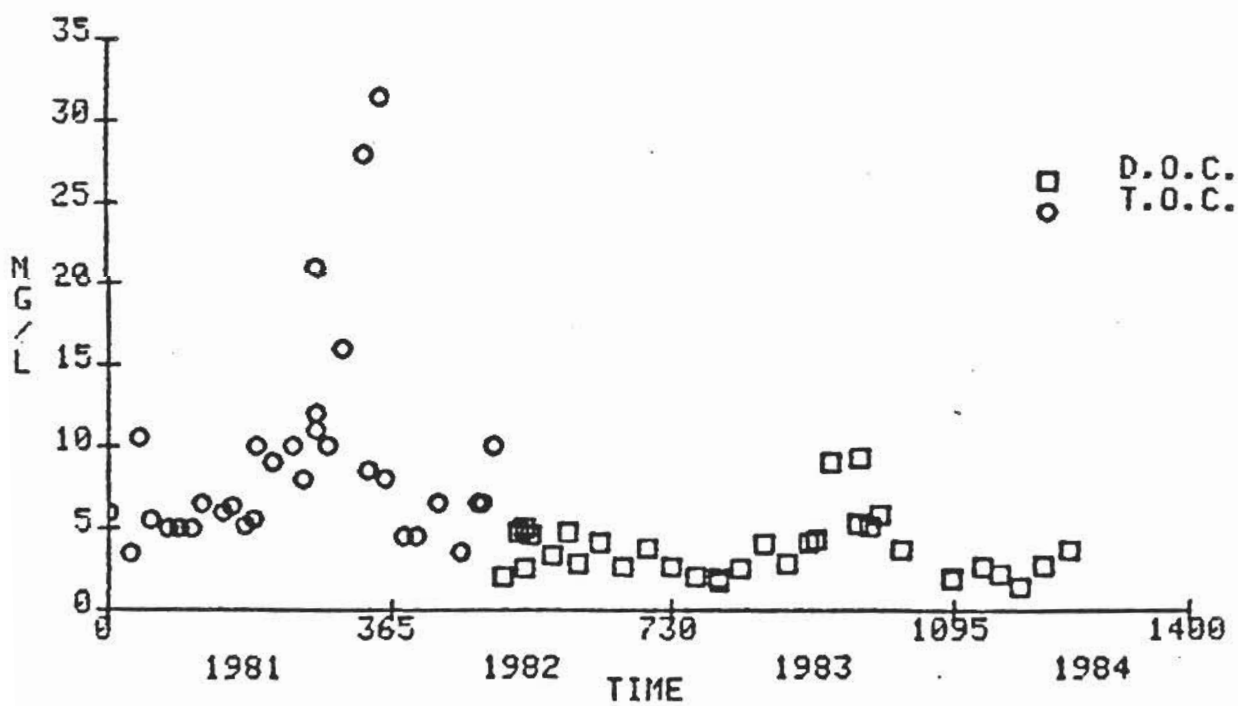


FIG.51 RELATIONSHIP BETWEEN DISSOLVED ORGANIC CARBON AND APPARENT WATER COLOUR FOR THE SOUTH BROOK DATA

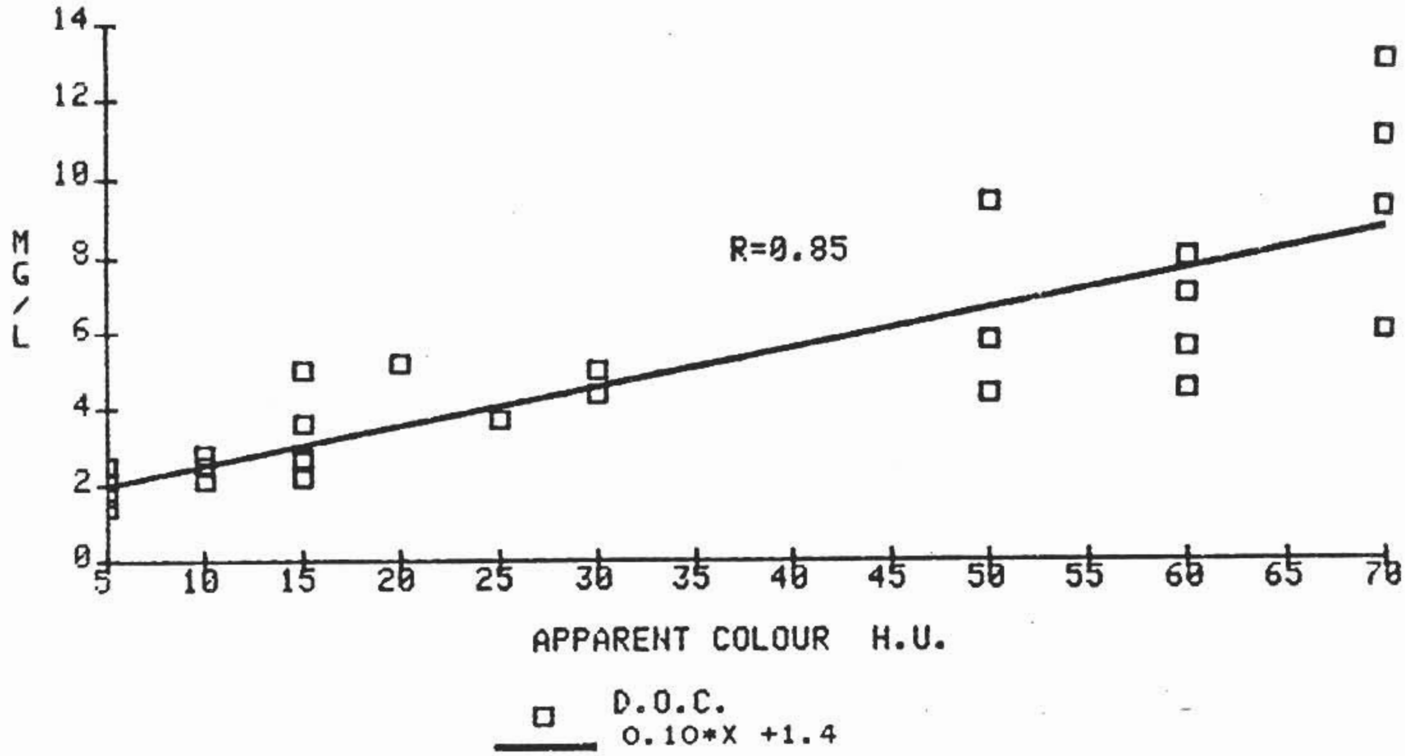
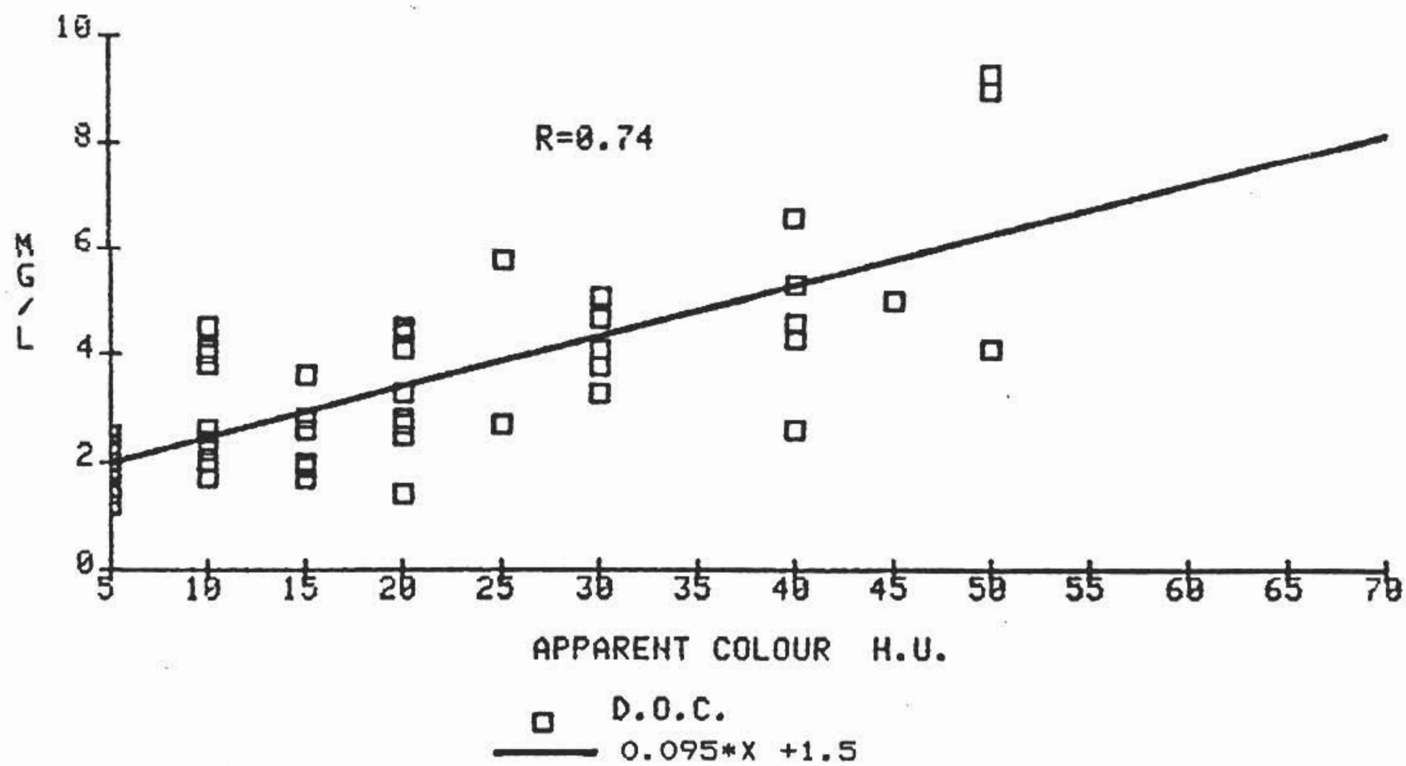


FIG.52 RELATIONSHIP BETWEEN DISSOLVED ORGANIC CARBON AND APPARENT WATER COLOUR FOR THE UPPER WATERFORD RIVER DATA



5.0 VARIATION OF WATER QUALITY PARAMETERS WITH THE HYDROGRAPH

As indicated earlier, the river was monitored during many rain events, with the aid of an automatic sampler (CAE type) located at the Kilbride station. This was done in order to follow the variations of water quality parameters with the changing river discharge. Many factors have to be taken into account to explain the variation in river water physical and chemical characteristics during and after a rain event. The season in which a particular event occurs is of great importance because summer and winter runoff may be different in what they carry to the river. A period of drought or of consecutive rain events, prior to a particular rain event, will influence the river water chemistry in different manners. Other factors could be road salting, land uses, relative importance of the rain event (volume of water and duration), permeability of soils, groundwater contribution, drainage basin slope, temperature, snow accumulation, wind, quality of the rain water, ...etc.

Evidently, urban activities produce pollutants including suspended solids, nitrogen, phosphorus and some heavy metals. It is believed that these pollutants accumulate on the basin surface during dry weather periods and are subsequently washed off during the periods of runoff. The importance of the impact of runoff on the receiving water quality is increased by the fact that the pollution loads of runoff may be *concentrated in a small number of rain events of relatively* short duration. The receiving waters could then experience shock loadings due to such concentrated discharges. Figures 47 to 50 illustrate the Waterford River hydrographs at Kilbride during various rain events. For the purpose of illustration of overall flow conditions at Kilbride, Table 26 gives the monthly mean and total discharge values for the period 1981 to 1984.

Most of the water physical parameters had irregular variation during rain events in relation to flow rates. pH values frequently varied one full unit (generally between 6.2 and 7.2) during events.

FIG.47 HYDROGRAPH AT KILBRIDE ON THE 02,03-10-82 RAIN EVENT

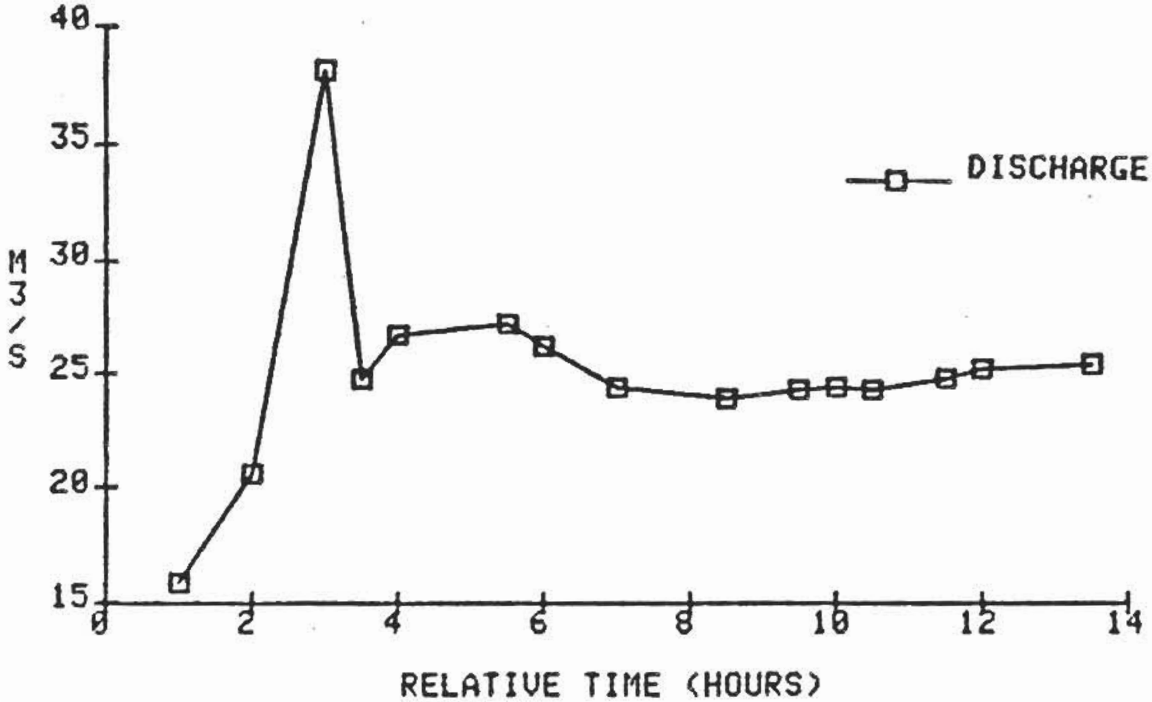


FIG.48 HYDROGRAPH AT KILBRIDE ON THE 03 TO 05-03-83 RAIN EVENT

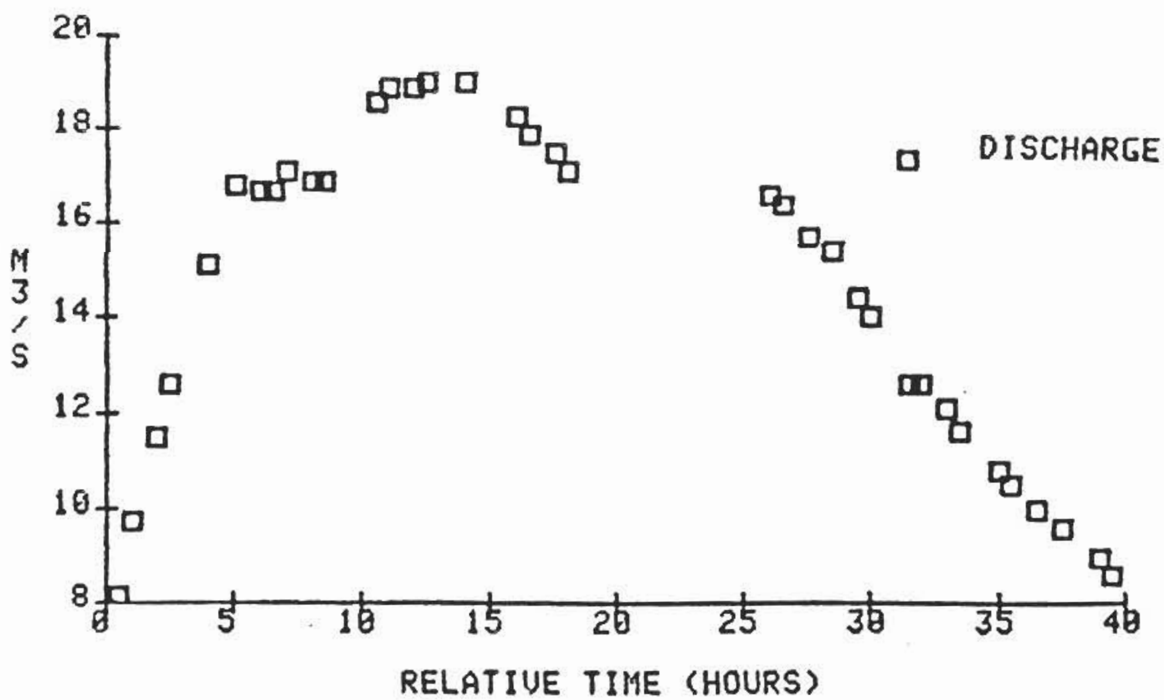


FIG.49 HYDROGRAPH AT KILBRIDE ON THE 13-03-83 RAIN EVENT

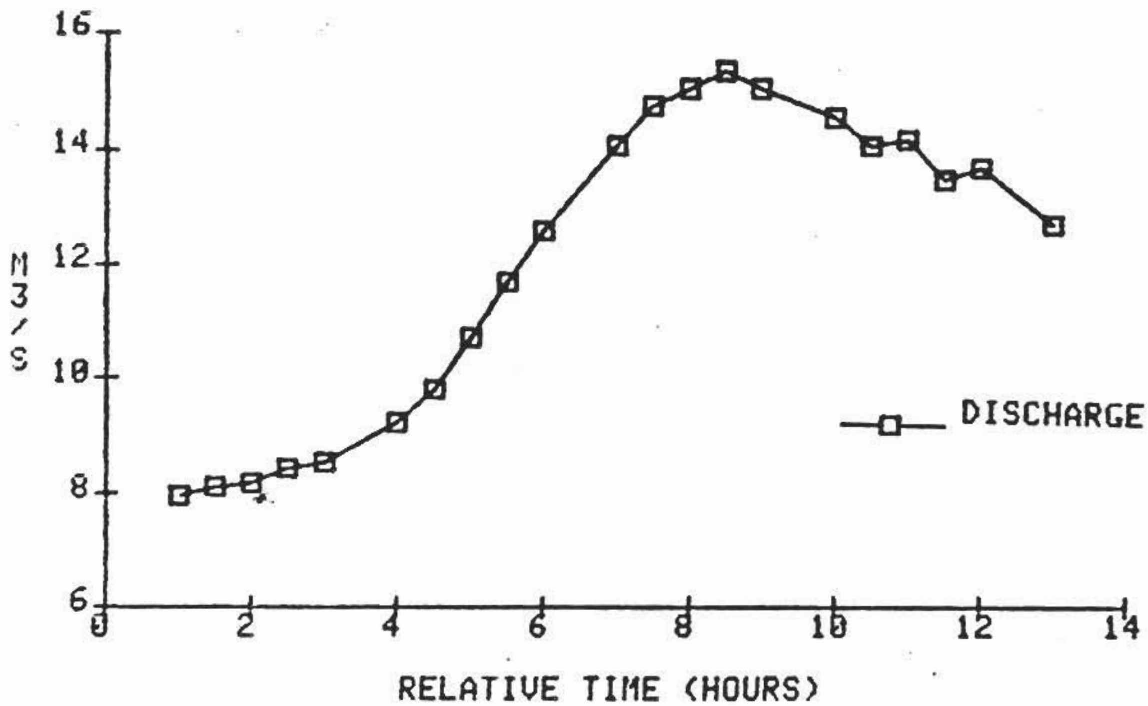


FIG.50 HYDROGRAPH AT KILBRIDE ON THE 15-09-83 RAIN EVENT

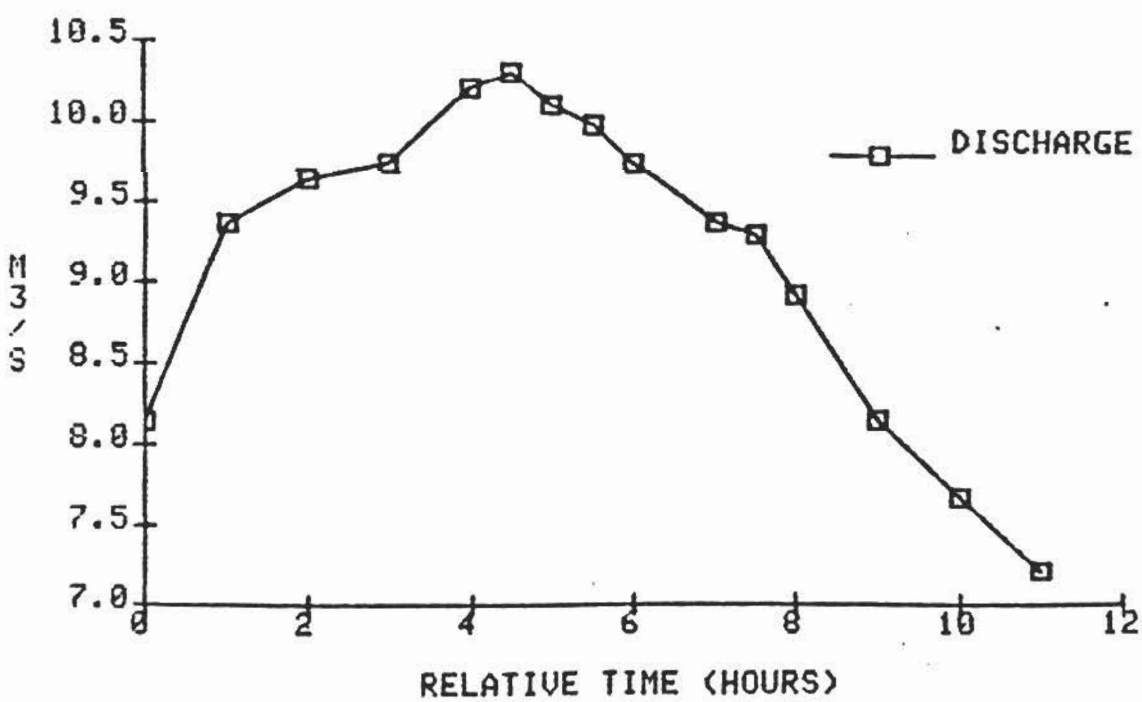


TABLE 26

Monthly mean and total river discharges at Kilbride

	1981		1982		1983	
	Mean m^3/s	Total $x1000\ m^3$	Mean m^3/s	Total $x1000\ m^3$	Mean m^3/s	Total $x1000\ m^3$
Jan.	3.13	8380	1.56	4180	2.66	7120
Feb.	2.68	6480	1.80	4400	1.15	2780
Mar.	3.28	8790	3.21	8600	4.91	13200
Apr.	2.70	7000	4.31	11200	2.87	7440
May	1.05	2810	3.63	9720	1.20	3210
June	1.33	3460	1.93	5000	1.16	3010
July	1.58	4220	0.977	2620	0.869	2330
Aug.	0.840	2250	0.620	1660	1.07	2860
Sep.	2.02	5220	2.67	6920	1.86	4820
Oct.	5.08	13600	3.20	8570	2.56	6860
Nov.	4.49	11600	1.05	2720	2.33	6040
Dec.	1.90	5090	3.05	8170	1.68	4500
Year	2.50	78900	2.34	73760	2.03	64170

- Data provided by Water Survey of Canada

However, no consistent variation was observed between consecutive samples taken during the course of a rain event. Similar trends were observed in the case of apparent water colour. In some cases, apparent water colour peaked (up to 70 H.U.) with the rising hydrograph but in other cases this trend was reversed.

As previously discussed, turbidity generally followed the hydrograph, although it did not necessarily peak at the same time as the river discharge. This was not unexpected considering that turbidity is a measurement of suspended particles and that a major portion of these particles were brought into the river by runoff. The fact that turbidity and suspended solids often peaked before the actual hydrograph peak suggest that the retention capacity of the drainage basin is low and that the slope is steep enough to rapidly bring into the river the particles accumulated on the basin surface prior to the event.

The parameters most affected by rain events and resulting runoff are the metals which in some cases had very high concentrations in the river water at Kilbride. Copper and zinc were not analyzed because of contamination problems associated with the sampling mechanism of the automatic sampler which is partly made of brass, a copper and zinc alloy. As previously stated, the measurements performed in the laboratory were for the determination of extractable metals, and samples were acidified, which released some metals adsorbed on suspended particles in the samples. Early during an event, the river water generally had very high turbidity values (>200 JTU), consequently, the extractable metals concentrations in those samples were also very high. As an event followed its course, turbidity values were observed to decrease as did the metals. Although metals concentrations may seem extremely high in some samples collected during rain events, because of higher turbidity, it is believed that these are not totally readily available as dissolved species to the aquatic biota. In addition, soon after an event, all parameters rapidly attained their lower "typical" levels in the river water.

The general pattern for sodium and chloride concentrations (and specific conductance) in the river water at Kilbride during a rain event period was dilution. As the flow peaked to a maximum, sodium and chloride concentrations were generally at a minimum. However, during some rain events in the winter time, high sodium and chloride levels (and specific conductance) were recorded during peak flows. Obviously road salting was the cause of this. The other major ions studied generally showed random variations during rain events. Magnesium, potassium and silica concentrations generally had small variations in the river water at Kilbride during rain events.

Nutrient concentration variations also had irregular patterns. However, similar to turbidity and metals, the highest nutrients concentrations were generally observed before the river discharge peaked and lower concentrations were observed during the recession period.

6.0 BACTERIOLOGICAL WATER QUALITY

6.1 General

This part of the study was carried out by the Newfoundland Public Health Laboratories. The aim was to determine the bacteriological water quality in the Waterford River Basin. For this purpose, tests for detection and enumeration of indicator organisms were utilized rather than specific pathogenic organisms.

The indicator organisms used in this study are the coliform group of bacteria and a sub-group of coliform bacteria, fecal coliforms, and fecal streptococci. Extensive studies have established the significance of coliform group density as a criterion of the degree of pollution and thus of sanitary quality of the sample. The significance of the tests and the interpretation of results are well authenticated and have been used as a basis for standards of bacteriological water quality. The differentiation between fecal and non-fecal coliform organisms yields valuable information concerning the possible source of pollution, and especially the remoteness of this pollution, because the non-fecal members of the coliform group may be expected to survive longer than the fecal members in the unfavourable environment provided by the water.

In recent years, increasing attention has been paid to the potential value of fecal streptococci as indicators of significant fecal pollution of water. Determination of fecal streptococci density has been found to be particularly useful when carried out in conjunction with that of fecal coliform bacteria. Fecal coliform/fecal streptococcus ratios provide information on possible sources of pollution (Geldreich and Kenner, 1969). A ratio of greater than 4.1 is considered indicative of pollution derived from domestic waste composed of human excrement, whereas, ratios less than 0.7 suggest that pollution was due to non-human sources. Ratios between 0.7 and 4.1 usually indicate wastes of mixed human and animal sources.

A number of important points should always be considered in interpreting bacteriological data. Spatial and temporal variation of bacterial density in a large body of water not only depends on physical or chemical characteristics of the water, but are also influenced by climatic, biogeographic and hydrographic factors. The total coliform group of bacteria has some distinct weaknesses as an indicator of water quality because the group defined by laboratory test procedures includes organisms that are common to vegetation and soil. Consequently, numbers may fluctuate widely with rainfall and surface runoff and be unrelated to pollution. The fecal coliform group is a more reliable indicator of sewage or other fecal pollution. Because these bacteria die quite rapidly in the environment, they are also indicative of fairly recent pollution.

6.2 Results of Bacteriological Analyses

6.2.1 Waterford River sub-basin stations

Results of this study are presented in Tables 17 to 25. The Donovans station showed highly fluctuating levels of bacterial density with no specific seasonal variation. Total coliform counts range from 220 to 160000/100 mL. Fecal coliform counts were correspondingly high and fluctuating. The density of both total and fecal coliforms reached a peak during the month of September 1983. However, throughout the 1984 study period, fecal coliform counts were relatively low and stable. The *range of fecal streptococcus counts was from 80-3200/100 mL. FC/FS ratio* showed mostly mixed human and animal pollution. This indication was more evident during 1984. The high bacterial counts observed may be attributed to collection of feed residue upstream which was discharged from a commercial firm. It is possible that the feed residue enriched the water by providing more nutrients for bacterial growth and also attracted birds, resulting in pollution.

At the Commonwealth Avenue station, 2 km downstream, the bacterial counts were relatively high with total and fecal coliforms ranging from 1800 to 32000/100 mL and 230 to 9000/100 mL respectively. High levels

TABLE 17

BACTERIOLOGICAL DATA: DONOVANS STATION (00NF02ZM003)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	7,600	450	420	1.1
June 1983	3,400	470	560	0.8
July 1983	3,200	1,000	NT	-
Aug. 1983	7,000	800	420	1.9
Sept. 1983	56,000	22,000	400	55
Oct. 1983	12,000	2,900	600	4.8
Nov. 1983	14,000	5,800	100	58
Dec. 1983	15,000	4,600	3,200	1.4
Jan. 1984	540	350	120	2.9
Feb. 1984	12,000	310	400	0.78
March 1984	520	250	340	0.74
April 1984	220	180	80	2.2
May 1984	6,000	330	190	1.7
June 1984	160,000	200	80	2.5

NT - Not Tested

TABLE 18

BACTERIOLOGICAL DATA: COMMONWEALTH AVE. STATION (00NF02ZM0004)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	4,400	600	240	2.5
June 1983	4,600	1,600	1,000	1.6
July 1983	9,200	1,000	NT	-
Aug. 1983	7,000	800	420	1.9
Sept. 1983	32,000	4,300	180	2.4
Oct. 1983	7,200	1,000	360	2.8
Nov. 1983	16,000	5,300	1,600	3.3
Dec. 1983	9,800	3,400	680	5.0
Jan. 1984	9,400	4,200	680	6.2
Feb. 1984	1,800	1,100	120	9.2
March 1984	8,000	5,000	120	42
April 1984	10,000	9,000	230	39
May 1984	2,400	500	390	1.3
June 1984	5,200	230	200	1.2

NT - Not Tested

TABLE 19

BACTERIOLOGICAL DATA: DUNNS ROAD STATION (00NF02ZM0012)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	4,000	1,200	680	1.8
June 1983	3,400	470	560	0.8
July 1983	3,200	430	NT	-
Aug. 1983	11,000	8,000	360	22
Sept. 1983	14,000	1,400	220	6.4
Oct. 1983	5,000	2,100	480	4.4
Nov. 1983	10,000	900	760	1.2
Dec. 1983	4,400	960	1,600	0.6
Jan. 1984	2,400	700	440	1.6
Feb. 1984	1,200	530	340	1.6
March 1984	200	110	10	11
April 1984	740	220	0	-
May 1984	780	90	520	0.17
June 1984	6,000	220	150	1.5

NT - Not Tested

TABLE 20

BACTERIOLOGICAL DATA: EXP. FARM STATION (00NF022M0006)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	500	140	60	2.3
June 1983	1,200	1,100	460	2.4
July 1983	3,000	1,100	NT	-
Aug. 1983	760	800	540	1.5
Sept. 1983	1,400	100	400	0.3
Oct. 1983	1,400	400	380	1.1
Nov. 1983	760	300	100	3.0
Dec. 1983	3,800	940	1,000	0.9
Jan. 1984	2,400	2,700	1,400	1.9
Feb. 1984	980	470	90	5.2
March 1984	380	100	20	5.0
April 1984	-	120	20	6.0
May 1984	600	410	110	3.7
June 1984	820	400	190	2.1

NT - Not Tested

TABLE 21

BACTERIOLOGICAL DATA: RUBY LINE STATION (00NF022M0001)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	160	L 10	100	L0.1
June 1983	140	20	60	0.3
July 1983	1,160	30	NT	-
Aug. 1983	300	100	60	1.7
Sept. 1983	180	10	0	-
Oct. 1983	80	100	80	1.3
Nov. 1983	260	60	20	3.0
Dec. 1983	20	20	40	0.5
Jan. 1984	L20	L10	50	L0.5
Feb. 1984	L20	L10	120	L0.01
March 1984	L20	L10	0	-
April 1984	20	L10	0	-
May 1984	300	L10	410	L0.01
June 1984	20	30	30	1.0

NT - Not Tested

TABLE 22

BACTERIOLOGICAL DATA: HEAVY TREE ROAD STATION (00NF02ZM0007)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	60	L10	100	L0.1
June 1983	60	60	10	6.0
July 1983	180	40	NT	-
Aug. 1983	120	60	160	0.38
Sept. 1983	60	60	0	-
Oct. 1983	60	50	20	2.5
Nov. 1983	100	50	120	0.4
Dec. 1983	20	L10	40	L0.2
Jan. 1984	L20	L10	10	L0.1
Feb. 1984	L20	L10	160	L0.1
March 1984	L20	L10	40	L0.1
April 1984	20	10	0	-
May 1984	100	L10	180	L0.01
June 1984	40	L10	160	L0.01

NT - Not Tested

TABLE 23

BACTERIOLOGICAL DATA: OLD BAY BULLS ROAD STATION (00NF02ZM0008)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	22,000	6,000	1,160	5.2
June 1983	24,000	15,000	1,460	10.3
July 1983	54,000	9,000	NT	-
Aug. 1983	30,000	4,400	2,020	2.2
Sept. 1983	54,000	26,000	1,000	26
Oct. 1983	11,000	5,000	2,320	2.2
Nov. 1983	14,000	6,000	660	9.1
Dec. 1983	18,000	6,600	760	8.7
Jan. 1984	8,600	5,300	720	7.4
Feb. 1984	15,400	11,000	110	100
March 1984	6,400	5,400	300	18
April 1984	6,600	7,000	0	-
May 1984	9,000	2,800	290	9.7
June 1984	13,000	2,800	220	12.7

NT - Not Tested

TABLE 24

BACTERIOLOGICAL DATA: KILBRIDE STATION (00NF02ZM0009)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	8,200	2,600	2,740	0.9
June 1983	10,000	3,100	860	3.6
July 1983	9,600	3,900	NT	-
Aug. 1983	120,000	26,000	2,480	10
Sept. 1983	18,000	6,000	1,260	4.8
Oct. 1983	7,000	3,800	980	3.9
Nov. 1983	11,000	5,900	400	14.8
Dec. 1983	6,400	1,600	200	8.0
Jan. 1984	3,400	2,300	540	4.3
Feb. 1984	6,400	1,500	70	21
March 1984	2,000	1,800	140	13
April 1984	1,600	800	0	-
May 1984	4,400	2,000	420	4.8
June 1984	3,200	1,200	50	24

NT - Not Tested

TABLE 25

BACTERIOLOGICAL DATA: STORMSEWER OUTFALL STATION (21NF02ZM0001)

DATES	TC/100 mL	FC/100 mL	FS/100 mL	FC/FS
May 1983	4,000	1,300	240	5.4
June 1983	76,000	45,000	380	118
July 1983	9,600	200	NT	-
Aug. 1983	9,000	2,200	1,080	2.0
Sept. 1983	14,000	3,700	920	4.0
Oct. 1983	2,400	800	80	10
Nov. 1983	1,600	340	180	1.9
Dec. 1983	9,800	5,500	400	14
Jan. 1984	2,000	600	140	4.3
Feb. 1984	840	330	400	0.8
March 1984	180	70	100	0.7
April 1984	200	90	0	-
May 1984	220	80	110	0.73
June 1984	30,000	510	350	1.5

NT - Not Tested

were measured in the September 1983 sample. This sample was collected during a low river discharge period. FC/FS ratios mostly indicated mixed bacterial pollution of both human and animal origins. The samples taken between December 1983 and April 1984 clearly indicated fecal pollution of human origin. A stormwater outfall located approximately 10 m upstream of the sampling site is a likely source of this pollution.

The Dunns Road station had low to moderate levels of bacterial counts. The counts were especially low during the months of February to May 1984. Total coliform counts ranged from 200 to 14000/100 mL and that of the fecal coliform from 90 to 8000/100 mL, and the highest levels were observed in the August 1983 sample. FC/FS ratios indicated pollution of human and animal origins.

There was no correlation existing between the levels observed at these three upper Waterford River stations, where high levels of fecal pollution could be detected at one site and not be observed at the other sites on the same date. However, all three stations had FC/FS ratios indicating pollution of human and animal origins.

At the Agriculture Canada Farm station, bacterial density was moderate and fairly stable throughout the study period. Total coliform counts ranged from <20 to 3800/100 mL and fecal coliform and fecal streptococcus counts were correspondingly low. FC/FS ratio mostly indicated pollution of water by excreta of mixed human and animal origins. It is significant that at this site the stream flows through some sheep pasture before reaching the sampling point.

High bacterial counts were generally observed at the Kilbride station. The total coliform counts ranged from 1600/100 mL to 120000/100 mL and, except for a sharp increase observed in the August 1983 sample, the levels of total coliform count seemed relatively stable. Fecal coliform counts were also relatively high. Fecal streptococcus counts ranged from 0 to 2740/100 mL and high counts were observed in the May, August and September 1983 samples. The bacteriological pollution was of human origin with high FC/FS ratios observed in most of the samples.

There is a stormwater outfall located about 25 m upstream of this site and it is believed that the high bacterial counts observed were related to it. Water at this site was also observed to be more turbid than the other sites on the Waterford River.

6.2.2 South Brook sub-basin stations

The Ruby Line and Heavy Tree Road stations had uniformly low bacterial density and the FC/FS ratios generally revealed bacterial pollution of non-human sources. The water at these sampling sites were always observed to be clear (non-turbid), even during rain events. Although not a reliable indicator of bacteriological water quality, this seems to correlate well with the low levels of bacterial pollution observed there. Overall, it is the Heavy Tree Road station that had the lowest bacterial counts in the basin.

The Old Bay Bulls station consistently had high bacterial counts and some of the highest counts were observed at this site. Total coliform counts ranged from 6400/100 mL to 54000/100 mL, with higher counts observed during the months of May to September 1983. However, this trend was not observed during 1984. Fecal coliform counts ranged from less than 3000/100 mL to 26000/100 mL and closely paralleled that of total coliform counts. The range for fecal streptococci was of 0 to 2320/100 mL. FC/FS ratio generally indicated human fecal pollution in the river water at this station. Existence of a poorly placed and managed local septic tank system near this site is considered to be responsible for the heavy pollution with bacteria of human origin.

6.2.3 Stormsewer outfall site

The station located at the stormwater outfall in Mount Pearl had highly fluctuating bacterial density levels. Counts were relatively low during 1984 with the exception of the sample taken in June. The highest levels were observed in the months of June 1983 and 1984. FC/FS ratios indicated pollution from both human and animal sources. This leads to the assumption that there are cross-connections between storm and sanitary sewer systems in Mount Pearl and also probably at other locations on the basin.

6.3 Discussion of Results

This bacteriological water quality investigation produced limited data and did not permit detailed analysis in relation to other studied parameters. However, it shed some light on the bacteriological characteristics of the surface water in the basin. Obtaining precise and accurate estimates of bacterial populations in river water is complicated by the highly non-random distribution of the bacteria.

There were no specific patterns in the distribution and density of the indicator organisms except that in most sites, the peak bacterial density was recorded during the summer months of June, July and August. Some sites also had high counts during the month of September. The existence of high fecal pollution in the study area was documented; this could be mostly attributed to both human and animal sources. The likely contributing physical factors could also be identified in some instances. The two surface water stations located on the upper South Brook were observed to have low bacterial counts. This was not unexpected considering the dilute physical and chemical water characteristics observed at these sites, which are located in the most undeveloped part of the basin.

7.0 DISCUSSION

This study has evidenced the fact that urban and industrial development on the Waterford River Basin affected the surface water quality. An important contrast in water characteristics between undeveloped and developed parts of the basin was observed. One aspect was the major ions, which were dominated, as expected, by sodium and chloride, but had levels in urbanizing areas far exceeding the typical concentrations observed in "natural" Newfoundland surface waters, as was demonstrated by the Ruby Line background station. High levels of nutrients which could lead to extreme autotrophic productivity under certain conditions of low river discharge, and very high trace-metals concentrations with their potential toxic effects on some of the aquatic biota in the river, were observed. However, these very high nutrients and metals concentrations generally were observed during high river discharge periods when the water turbidity was high, and did not prevail for a long period of time in the river. Their pollutional effects are therefore limited.

The high bacterial counts and FC/FS ratios observed are additional indications of the degree of pollution of the surface water caused by urbanization. Obviously, raw sewage is being directed into the river by cross-connections between storm and sanitary sewer systems and poorly placed and managed septic systems. All stations located near stormwater outfalls and the Mount Pearl stormwater outfall station had FC/FS ratios revealing human pollution. In addition, the Old Bay Bulls Road station was suspected to be polluted by effluent from a nearby septic tank. Again the contrast was consistently observed between all the stations on the developed parts of the basin and the stations on the mainly forested upper South Brook sub-basin.

It was also observed that the surface water quality was deteriorating on the downstream course of the South Brook, where human presence becomes more important. From this, it is believed that further development of the South Brook sub-basin would create a situation similar to what is observed on the developed mainstem sub-basin and changes in the surface water quality would follow.

This study proved very useful for determining the state of the surface water quality in the basin, and to evaluate the effects of urbanization on the surface water quality. The location of the surface water stations was planned to observe the water quality from developed and undeveloped parts of the basin. However, it seems that it would have been useful to set another surface water station on the mainstem, upstream from the Donovans industrial park. This would have permitted an evaluation of the river water quality before it passes through the industrial park on a regular basis during the study period. Sampling was however performed once in June 1984 at the outflow of the two headwater ponds of the Waterford River and the water had more dilute characteristics in those ponds (with lower sodium and chloride levels) than observed in the river past the industrial park. Sampling in the Waterford River in the Donovans industrial park for major ions analyses should be performed to pinpoint the salt source (other than the road salt depot) that was suspected to be located in the park. This might explain the high sodium and chloride concentrations observed in the Waterford River past the park.

The automatic river water event sampling program at Kilbride was very useful to further illustrate the importance of runoff loadings on the surface river water quality. Section 5 of this report provided a *general description of the behaviour of the water quality* parameters in relation to changes in flow rates monitored during rain events on the basin. In addition, references to the rain events data set or part of it was made throughout this report to support the regular sampling data set. It is interesting to note that without the rain events sampling program, most of the peak metals and nutrients concentrations would not have been detected, even though the regular monitoring program was rigorous and included grab samples collected at least once a month during various climatic and flow conditions, for a period of more than three years. The major drawback in this program was the copper and zinc contamination problem due to the automatic sampler.

Although there are obvious physical, chemical and bacteriological water quality problems (a good portion of these seem to originate from sanitary and stormsewer cross-connections) in the Waterford River basin, a healthy trout population was reported and salmon fry planted in the river have survived and are growing well. As previously stated, good oxic conditions were observed at all surface water station in the basin and most of the peak concentrations of suspended solids, nutrients and metals were observed during periods of high flow and were the results of the washing effect of rain events and related runoff.

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The surface water characteristics differences, observed between urbanized and forested areas in the Waterford River Basin, suggest that urbanized areas are contributing dissolved and suspended inorganic and organic matter to the surface waters, as well as bacteriological inputs. Peak loadings of suspended solids and other turbidity causing agents, nitrite-nitrate, total nitrogen, total phosphorus and extractable metals were observed during early runoff periods. However, high concentrations of these parameters did not prevail long in the river.

Taking into consideration the fact that the Waterford River water is not used for domestic consumption purposes and that healthy trout populations were reported in the river, in addition to results observed in this study, it can be said that its surface water is in good quality condition. One concern may be for contact recreational waters because of some high bacterial counts measured during this study in the developed areas.

As for high sodium chloride concentrations observed in the Waterford River compared to the Upper South Brook, it is felt that these allochthonous salt inputs are not of great concern. The salt levels measured in the Waterford River do not diminish any recreational potential of the river. In addition and for the purpose of illustration, water for domestic consumption is acceptable with levels of sodium and chloride up to 270 mg/L and 250 mg/L respectively (Sourcebook, WQB, 1979), which is about ten times higher than typical levels observed in the Waterford River.

The flowing waters of the Waterford River did not permit accumulation of phosphorus and other nutrients. Thus, excessive autotrophic productivity was not a problem in the basin, except for rare cases of extremely low discharge conditions, at some of the sites.

As previously stated, the automatic sampler was a useful tool to illustrate the effects of rain events on surface water quality. However, the CAE type sampler used at Kilbride did not permit to follow copper and zinc concentrations in the river water during rain events because of contamination problems.

In view of the results of this study, the monitoring program was adequate and permitted evaluation of the variation of water physical and chemical characteristics on a monthly and rain event basis for more than three years. However, it seems that two years of data was enough and that the last year of the regular monitoring program did not contribute much more information to the study.

The number and location of sampling sites permitted evaluation of the effects of various land uses on surface water quality in the basin. It is felt however, that one of the three Upper Waterford River stations (possibly the Commonwealth Avenue station) could have been moved somewhere upstream from the Donovans Industrial Park. In retrospect this could have been done sometime after the first year of the sampling program, because these three stations had similar water characteristics, thus taking one out would not have affected the program. This would have provided a measure of the quality of the water upstream from the park, on a continuous basis.

The list of parameters studied was sufficient, as it permitted characterization of surface waters in the basin and discrimination between developed and undeveloped areas.

Keeping in view that no systematically monitored data were available in the Province of Newfoundland, it is felt that this study was worth the cost in the long term. Future studies of this type in Newfoundland will profit from the experience gained in this study, also a large data base is now available for comparison or for possible modelling purposes.

8.2 Recommendations

1 - The high bacterial counts measured in the developed areas warrant further investigation. This could be done in the form of an intensive study.

2 - Sampling in the Waterford River in the Donovans Industrial Park for major ion analyses could be performed to pinpoint the salt source (other than the known road salt depot) that was assumed to be located in the park.

3 - If zinc and copper are to be monitored during rain events in future studies, the CAE type automatic sampler should be either modified or replaced by some other type to prevent contamination with these metals.

4 - In future studies, it could be useful to measure dissolved metal species, which require field sample filtration, in addition to extractable metals, during the first year of the program. Then, a decision should be made on which types of metals to continue monitoring.

5 - Enough flexibility should be provided in future monitoring programs to permit relocation of some of the initial sampling station, in light of emerging questions from the early data analyses.

6 - As part of a quality assurance program, replicate sampling should be performed in future studies. It is suggested that at least 10% of all samples should be done in sequential triplicate during the first year. This would evaluate the representativeness of sampling methods and point out contamination and/or analysis problems.

7 - The present data indicate that two years of the combination of monthly grab, event and sequential automatic sampling would suffice for such a study. A reduced sampling effort for longer periods would be required for long term trend studies.

8 - The first year of monitoring in future studies of this type should include a similar list of parameters. After first year data scrutiny, parameters that don't contribute much to the program could be removed.

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