Government of Newfoundland
and Labrador

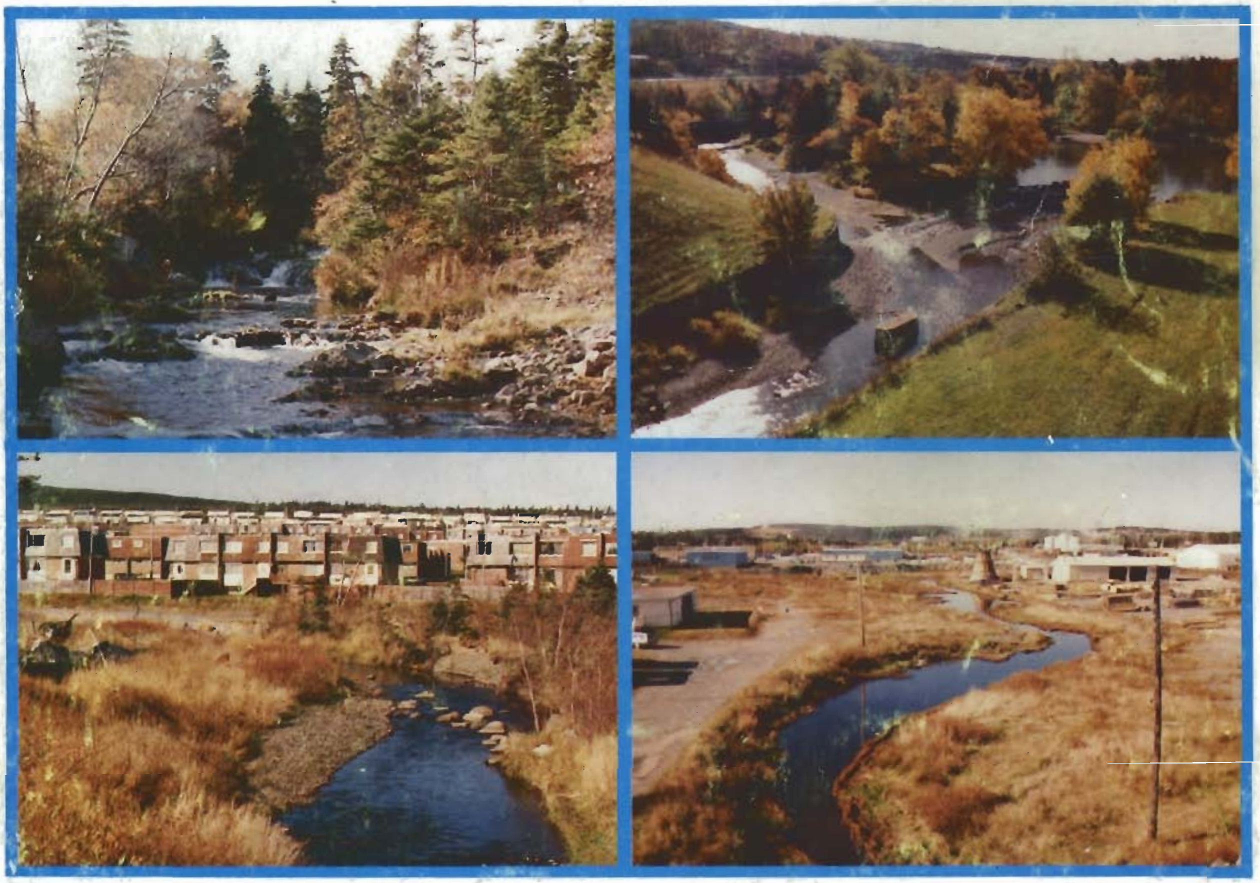
Department of Environment
Water Resources Division
St. John's, Newfoundland

Government
of Canada

Environment Canada
Inland Waters Directorate
Dartmouth, Nova Scotia

National Water Research Institute
Burlington, Ontario

MAIN REPORT



Urban Hydrology Study of the Waterford River Basin

TECHNICAL REPORT No.

UHS-WRB 1.13

MAIN REPORT

URBAN HYDROLOGY STUDY OF THE WATERFORD RIVER BASIN

Technical Report No. UHS - WRB 1.13

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June 1992

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18 June, 1992

The Steering Committee for the Urban Hydrology Study of the Waterford River Basin.

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and

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Dear Gentlemen:

It gives me great pleasure to present to you a copy of the **Main Report** of the **Urban Hydrology Study of the Waterford River Basin**. The report is the result of many years of dedicated work by the Water Resources Division of the Newfoundland Department of Environment and Lands and by the Inland Waters Directorate and the National Water Research Institute of Environment Canada. It represents a major contribution to the knowledge of the hydrology of Newfoundland.

Yours truly,

Wasi Ullah
Chairman
Technical Committee

ABSTRACT

A comprehensive multidisciplinary study of the hydrology and water quality of the Waterford River Basin was undertaken. The Waterford River drains an urbanizing basin (52.8 square kilometres) on the western outskirts of St. John's, and flows directly into St. John's harbour. Separate studies of land use, water quality, groundwater, aquatic biology, storm drainage (using the Rational Method, SWMM, and ILLUDAS), basin hydrology (using HYMO and HSPF), and flooding (using HYMO and HEC-2) were jointly conducted over a 5-year period by the federal and provincial governments.

Results generally showed the effects of urbanization to be noticeable, but not serious. Urbanization has minimal impact on flooding because of the naturally large basin runoff yield (81%). Water quality (except for fecal coliforms emanating from cross-connections) is fair to good in most places, and the aquatic biology has acceptable quality indices. Groundwater quality is good. The greatest land use changes are from productive to nonproductive categories, rather than from non-urbanized to urbanized. Despite recent growth in the Mt. Pearl and Donovans areas, the basin is still mostly rural.

The project provided a valuable hydrologic data base for this urbanizing area, and afforded training and development opportunities for government and university staff. Some of the results will have generic applicability to the Province.

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 perceived to be serious enough that the Newfoundland Department of the Environment identified the Waterford River basin as a high priority area.

The five year study, which began in 1980, was mostly completed by March, 1985. The 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 Waterford River Basin.*

3. *To recommend solutions to specific water management problems in the 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 are related 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 socioeconomic 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, from each of the governments, was established. Subsequently the Technical Committee appointed subcommittees and working groups to prepare and carry out the work plans for the various components of the study.

The report which follows is a compendium of the component studies and contains conclusions and recommendations which are basin specific as well as generic for Newfoundland.

ACKNOWLEDGEMENTS

Many people have contributed to the *Urban Hydrology Study of the Waterford River Basin*.

The authors of the component studies would like to acknowledge the following people for their guidance and encouragement.

The Steering Committee:

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Mr. S.L. Fenety	Inland Waters Directorate, Environment Canada

The Technical Committee:

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For their dedication and perseverance we acknowledge the Working Groups and Subcommittees:

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1 INTRODUCTION

The Waterford River Basin covers an area of 52.8 square kilometres, and is located on the western outskirts of the City of St. John's. The watershed drains major residential and industrial suburbs of St. John's. Despite its relatively small size, the basin is characterized by a variety of water management problems. Urbanization of the drainage area has created both water quality and water quantity concerns over the past several years.

1.1 Urban Hydrology Study of the Waterford River Basin - Rationale

Changes in land use can cause significant changes in the hydrologic behaviour of a drainage area, particulary if that drainage area is small, as is the case of the Waterford River Basin. The hydrologic impacts of urban growth can include changes in streamflow characteristics, groundwater supply and quality, erosion and sediment patterns, and water quality deterioration. There is considerable evidence in the hydrologic literature that urbanization substantially modifies the hydrologic response of both surface and groundwaters. Water quality and any dependent ecosystem elements are also adversely impacted. No detailed investigation of the processes leading to these impacts has previously been conducted in the Province of Newfoundland.

1.2 Background

The Waterford Basin has experienced some of the typical problems associated with urbanization. Urban drainage and sewer networks have been installed with resulting impacts on flow rates and water quality in the Waterford River. Water quality deterioration in the watershed has resulted in a health hazard, reduction in recreational potential, aesthetics and sport fishing (Ref. 1). Urbanization is expected to continue in the basin in the coming years and these problems are likely to become more serious. This has created a need for a better understanding of the Waterford River basin's hydrologic regime in order to develop appropriate management measures and guidelines for residential and industrial development on a pilot basis. To some extent these measures and guidelines could be applied to other urban watersheds in Newfoundland.

To address these problems, an urban hydrology study of the Waterford River Basin had been proposed. The Governments of Newfoundland and Canada agreed to undertake a five-year study on a cost/work shared basis starting April 1, 1980. The basis of the agreement is contained in the following reports: "*Waterford River Basin Urban Hydrology Study Plan*" prepared by the Environmental Management and Control Division of the then Department of Consumer Affairs and Environment (Ref. 1) and the "*Waterford River Basin: Background Report*" prepared by the Hydraulics Research Division of the National Water Research Institute, Environment Canada (Ref. 2).

1.3 Objectives and Scope

In the Waterford River Basin Urban Hydrology Study Plan (Ref. 1), the following objectives were established for the urban hydrology study of the Waterford River Basin to alleviate the negative impacts of urbanization:

1. *To examine (both quantitatively and qualitatively) the many processes leading to changes in the hydrologic regime of the Waterford River watershed. This involves the*

monitoring and evaluation of all significant hydrologic changes caused by urbanization. It also entails the study of rainfall-runoff relationships in the system as well as the type and magnitude of chemical and fecal bacterial pollution in the urban environment of the watershed.

2. *To utilize the information obtained in (1) above in the development and application of a hierarchy of hydrologic and water quality models, ranging from models for storm sewer systems, to those for major tributaries and finally to the Waterford River itself. These models would be developed specifically to evaluate the impacts urbanization has on the water resources of the basin, and*

3. *To utilize the models developed in (2) above to recommend solutions to specific water management problems of the Waterford Basin as well as similar problems in other watersheds in the province. This phase involved the development of planning and management criteria for all aspects of urban development that relate to the environmental protection of the water resources involved. Specifically, hydrologic and hydraulic design criteria for storm sewer systems will form part of the output of the program. Guidelines for environmental impact assessment will also result from the analysis.*

The achievement of the above objectives will require a systematic and detailed study of several aspects of the urban hydrology of the Waterford River Basin. The elements of this study were: water quality, storm drainage, land use, groundwater, flooding, biological assessment and water modelling.

The complexity of the problems called for a comprehensive approach which included hydrometric surveys, hydrological modelling, groundwater studies, biological surveys, water quality assessment, investigations of flooding and land use changes. Because this study was the first of its kind in the province, there was a need for completeness in all areas that are associated with urbanizing watersheds and the problems that arise as a result of urbanization. This study will provide a framework for similar studies in Newfoundland and Labrador. Also the recommendations and conclusions of this study should be generally applicable to other areas of the Province.

1.4 Resources - Funds and Manpower

The study was cost/work shared between the Governments of Newfoundland and Canada on a 50/50 basis. Because no funds were available under the Canada Water Act, Environment Canada participation was limited to work-shared items. All capital costs and some operational and maintenance costs were borne entirely by Newfoundland. Newfoundland also participated in some work-shared items.

1.5 Duration of the Study

The study was conducted for a period of five years, starting on April 1, 1980. The initial plan called for field studies over a five year period. Before March 31, 1985, the results were critically examined to ascertain if the desired objectives had been accomplished. Some results were found to be inconclusive, so the Technical Committee recommended continuation of those components of the study for one or two more years. The extension was approved by both governments.

1.6 Administrative Structure

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. The Technical Committee was responsible for planning, supervision, accounting, administration of the program, reporting of progress and submission of the final report of the study. The Committee approved work plans for each component of the study and reviewed the progress.

The Committee was also responsible for the submission of the final report, which contained the results, costs, recommendations, etc. of the program.

The Technical Committee appointed seven subcommittees for the following components of the study: hydrometric survey, water quality, flooding, groundwater, biological study, hydrologic modelling and land use. The list of membership of these committees is given in the *Acknowledgements* section of this report.

1.7 Outline of Report

This report summarizes the results of various components of the study, which have been published in a series of 12 reports (Ref. 3-1 to 3-12) listed in Table 1.1. The report briefly outlines the objectives of the various component studies, methodology, data collection program, analysis and interpretation of data, and results. The results of these component studies are discussed in light of the objectives of the overall study leading to some conclusions and specific recommendations. For further details, readers are advised to refer to the specific reports in the areas of their interest.

Table 1.1 URBAN HYDROLOGY STUDY OF THE WATERFORD RIVER BASIN

LIST OF REPORTS

No.	Title	Report No.	REF. NO.
1	Surficial Geology of the Waterford River Basin	UHS-WRB 1.1	3-1
2	Geology of the Waterford River Basin	UHS-WRB 1.2	3-2
3	Land Use Report	UHS-WRB 1.3	3-3
4	Surface Water Quality Report	UHS-WRB 1.4	3-4
5	Storm Runoff Study of Newtown Urban Catchment	UHS-WRB 1.5	3-5
6	Groundwater in the Waterford River Basin	UHS-WRB 1.6	3-6
7	Installation and Testing of the Monitoring Well Network	UHS-WRB 1.7	3-7
8	Biological Study	UHS-WRB 1.8	3-8
9	Data Summary Report Vol I Vol II	UHS-WRB 1.9	3-9
10	Watershed Modelling Report, HYMO, 1988	UHS-WRB 1.10	3-10
11	Flood Study Vol I Vol II	UHS-WRB 1.11	3-11
12	Streamflow Modelling Using HSPF	UHS-WRB 1.12	3-12

2 STUDY AREA DESCRIPTION

2.1 Study Area

The Waterford River Basin, shown in Fig 2.1, is located on the western outskirts of the City of St. John's and has an area of 61 km^2. It extends 13.5 km from the confluence of brooks flowing from Bremigans Pond and Brazil Pond to St. John's Harbour in the east. This corresponds to an elevation difference of approximately 170 m (Topographic map reference - 1N/10 East). The major tributary of the Waterford River is South Brook which extends 11 km from the marshy headwaters, where flow is intermittent, to its confluence with the Waterford River at Bowring Park. Other smaller tributaries drain either into the Waterford River or South Brook. Some of these tributaries have intermittent flows.

The study area comprised only the portion of the Waterford River Basin extending upstream from the hydrometric station at Kilbride and having a drainage area of 52.8 km^2. The remaining downstream portion of the basin is highly urbanized and, in several places, the drainage system has been modified. Also, there are several unidentified cross-connections between sanitary and storm sewers in the area downstream of the gauge at Kilbride which might have created problems in the interpretation of water quality results.

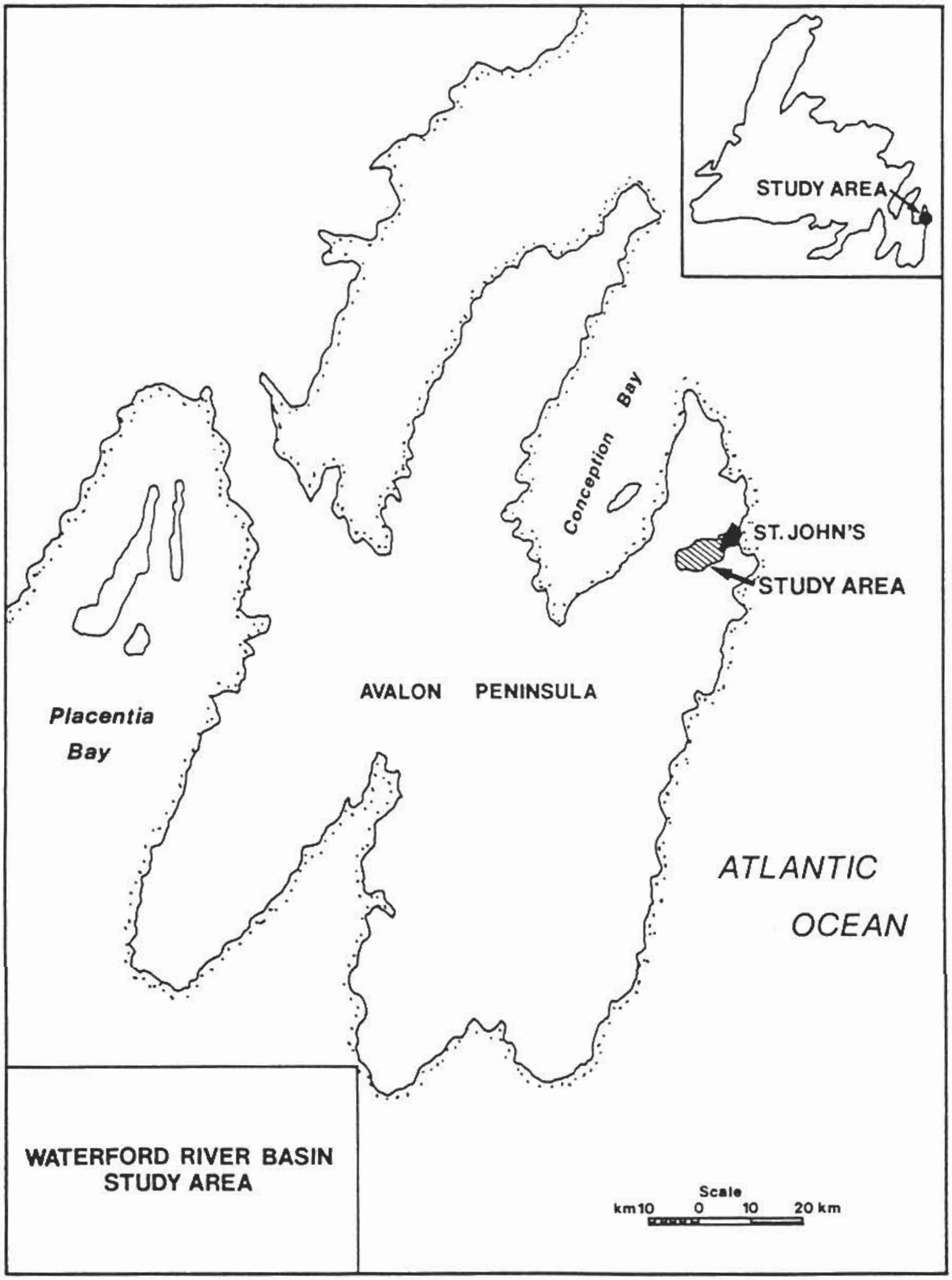


Figure 2.1 WATERFORD RIVER BASIN STUDY AREA

2.2 Physiography

2.2.1 Topography

Significant relief features in the Waterford River Basin are confined to the basin perimeter. Kenmount Hill in the north is the highest peak (261 m above sea level), but its outline is generally smooth due to glacial action. In contrast, the South Side Hills display a more rugged outline, the result of a combination of lithology and the paucity of glacial deposits. Turtle Hill (206 m above sea level) is the highest feature there.

The lack of significant relief has resulted in generally very gentle (<2%) to gentle (2-5%) slopes across the area. Steeper slopes of about 10-30% occur only around Kenmount Hill, the South Side Hills and the hills north and south of the headwaters of South Brook.

The principal geomorphological features of the entire Waterford River Basin are summarized in Table 2.1.

The Waterford River is partially channelized below Bowring Park, its banks sustaining mostly grass interspersed with a few bushes. In some areas, the natural banks have been replaced by concrete walls, which allow little or no riparian vegetation. Above Bowring Park, the river runs through areas ranging from suburban developments, where the banks may have been bare or channelized, to relatively undisturbed areas with healthy grass, bush or tree growth on the banks.

The bottom sediments of the Waterford River are mostly gravel with a small portion being sand, mud or bedrock. According to a survey conducted by Arambarri et al. (Ref. 4), the river bed consisted of 50% gravel, 34% rubble, 11% bedrock, 1% sand, and 4% mud along its entire length. The river sections were composed of 69% riffle, 29% pool, and 2% falls. Instream vegetation occurred on 25% of the river bed.

South Brook flows through farm and forested terrain for its entire length. The brook had 80% riffle, 19% pool, and < 1% falls. The river bed was composed of 65% gravel, 25% rubble, 5% bedrock, < 1% sand and 1% mud. Instream vegetation occurred on 6% of the river bed.

Table 2.1 **GEOMORPHOLOGICAL CHARACTERISTICS OF THE WATERFORD RIVER BASIN**

Drainage Area	61 km^2
Mean Width	4.2 km
Axial Length	13.4
Basin perimeter	41.1 km
Maximum Relief	260 m
Channel Slope (up to hydrometric station)	.0141
Length of Channel	
Waterford River	14.1 km
South Brook	10.2 km
Tributaries	33.6 km
Drainage Density	0.94 km^{-1}

The following obstructions in the main river and its major tributary affect river hydraulics and fish migration:

Main River

- *dam at Boat Pond in Bowring park; complete obstruction*
- *falls in Bowring Park (4 m high); partial obstruction*
- *falls at Dunn's Bridge; partial obstruction*
- *Twin Falls in Mount Pearl; complete obstruction*

South Brook

- *dam in Bowring Park; complete obstruction, removed in fall*
- *falls approximately one mile upstream of the dam; complete obstruction*

2.2.2 Bedrock and Surficial Geology

Surficial and bedrock geologic studies of the basin were conducted by Batterson (Ref. 3-1) and King (Ref. 3-2), respectively. Bedrock geology largely controls the physiography of the basin. Bedrock of the area consists mostly of sedimentary Precambrian materials, but with some volcanic deposits. The principal rock types are Hydryian siltstone, arkose, conglomerate, slate, and acidic to intermediate volcanic rocks. Significant features which influence the river course 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 precipitates along fractures in some formations, including thinly bedded sandstones, which can adversely affect water quality.

Unconsolidated materials within the basin are generally thin (< 60 cm) and are underlain by a shallow parent material consisting of glacial till. Two distinct layers of till are found in the basin. The underlying unit is found throughout and consists of a very compact lodgement till. This is overlain, especially in the west, by a less compacted, coarser supraglacial deposit which is often only 50 cm thick. The lodgement till is much less permeable being less coarse and having a higher silt-clay content. Percolation, therefore, would be relatively fast through the upper till layer, where it exists, and slower through the lodgement till beneath. Soil fractures which would normally provide conduits for water appear to be lacking in this lower till.

During precipitation, the upper supraglacial unit is rapidly saturated causing perched water table conditions. Where the supraglacial till is absent, ponding of water will also occur in topographic lows. Such conditions promote the rapid response of the drainage basin to precipitation events. These also result in slow but continuous discharge through the lower till unit even through long periods of drought.

Due to the thinness of the overburden mantle, the bedrock exerts a critical control over the topography and thus the movement of water throughout the basin which is generally rapid. The only exception is the slow release storage provided by the lodgement till and the numerous bogs that are found in the area. These in turn have been formed in post glacial ponds due to the impermeable nature of the underlying till.

2.2.3 Soils and Vegetation

Most of the basin is covered by materials of glacial origin. The formation of the soil profile has resulted from weathering of the surficial parent till materials. The soils are generally coarse textured and contain stones, gravel and boulders. Two major soil orders occur within the basin. The most common is the podzols which cover at least 75% of the basin. Gelysolics cover the remaining 25% of the land area. The major difference between these two soil groups is drainage condition. Podzols are well to imperfectly drained soils while gelysolics are saturated and are generally confined to the valley bottoms of the Waterford and South Brook rivers and to the lower, poorly drained areas south of Ruby Line.

The variation in drainage in podzols gives rise to a further differentiation of this classification. About 50% of the study area exhibits undulating to hilly terrain and the podzols here are moderately stony and moderately drained. The other 25% is divided between the two extremes. Imperfectly drained, less stony podzols, are found on less steeper slopes and are well drained. Excessively stony podzols are interspersed between rock outcrops on moderate to steep slopes.

In general, all soils in the area exhibit low potential with regard to agriculture and forestry due to unfavourable topography, stoniness, and shallow depths of soil. Podzols support coniferous and mixed forest vegetation especially balsam fir, black spruce and birch. Gleysolic soils support hydrophytic vegetation such as tamarack, black spruce and heath plants.

2.3 Land Use

A compilation of land uses in the study area based on the 1973 map prepared for this study (Ref. 3-3) is presented in Table 2.2.

Table 2.2 **WATERFORD RIVER BASIN LAND USE, 1973**
Data based on 1973 map

Land Use Category	Total Area (km^2)
Residential	5.0
Commercial/Industrial	1.4
Agriculture	7.5
Forest	21.9
Unproductive Lands	13.3
Other (recreation, ponds, lakes, etc.)	3.7
Total	**52.8**

Forest

As of 1973, the area under forest was slightly over 41% of the study area. Because of unfavourable soil conditions, the trees are small and have stunted growth. The regeneration process is also very slow. The main types of trees are black spruce, white spruce, white or yellow pine and balsam fir. There are no forest management plans designed to improve the stand. The forest resource, therefore, is unlikely to become a significant source of economic activity in the study area.

Agriculture

Relatively small areas of land are suitable for agricultural development and there are many individually owned farms in the study area. The principal farming activities consist of dairy farming and vegetable gardening, especially root crops such as potatoes, turnips, carrots, beets, etc. There is no extensive application of fertilizer in the area but application of lime to improve the soil reaction is a common practice.

The Canada Department of Agriculture Research Station, Mount Pearl, occupies about 74 hectares of land, of which 40 hectares are cultivated. The Station uses fertilizers and herbicides in the cultivated areas but not near the two streams which run through the farm. The area surrounding the streams is used for raising pasture. The only livestock on the farm are a few sheep used for experimental purposes.

The agricultural activities in the area are slowing down due to rapid urbanization of adjoining areas and the accompanying changes in socio-economic conditions. There is sufficient indication that urban and sub-urban developments in the area will gradually extend to these agricultural lands if necessary controls are not applied in time.

Urban and Sub-urban Development

The urban and sub-urban areas include residential, commercial, institutional and industrial areas, roads, transmission lines, etc. There are no long-term development plans available for the area which would indicate the extent of future developments. But it is anticipated that the present proportion of the area under urban and sub-urban development (24.2%) will substantially increase in the coming years to accommodate the projected population and its socio-economic needs. This may result in drastic hydrologic changes in the area.

Most of the urban areas are served by separate storm and sanitary sewer system. The storm sewer systems discharge their waters at various locations into the Waterford River and its tributaries.

All sanitary sewage is transported through the Waterford Valley trunk sewer to the sea except the sewage from Evergreen Trailer Park and the Westhill Subdivision which is discharged into the Waterford River after treatment. The industrial effluents are discharged into the Kenmount Valley sanitary sewer system.

Some of the houses in scattered locations are not connected to the municipal sanitary sewer systems. These houses are served by septic tanks and cesspools.

Recreation

Bowring Park is the major recreational area (approximately 200 acres) in the basin. There are also a few small municipal parks in Mount Pearl.

2.4 Climate

The climate of the Avalon Peninsula is more temperate than that of the remainder of the Island. The modifying influence of the sea results in the absence of extreme temperatures, generally causing the winters to be mild and the summers cool. 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 that June and July receive relatively less rainfall. Significant variations in annual precipitation have occurred; the standard deviation of total precipitation during 1951-80 was approximately 210 mm.

Cyclonic activity causes the weather of the region to vary considerably within short periods of time. Most of the rainfall received is the result of these cyclonic disturbances. Thunderstorms are infrequent (averaging five per year) due to the proximity of the sea which cools the surface layer of air.

Snowfall accounts for about one third of the total annual precipitation (Ref. 5). The snow accumulation is not usually very great due to frequent thawing periods during winter months.

Snowmelt has a substantial impact on the observed streamflows during mild rainy periods in the winter and in the spring when the hibernal accumulation of snow melts in a relatively short period. Although the highest monthly flows usually occur in April, high flows occasionally occur in late fall. Low flows generally occur in June, July and August; however, low flows have also been experienced in February because the precipitation is predominately snowfall.

The cool maritime climate has relatively low evapotranspiration resulting in high basin yields. The ratio of annual streamflow to precipitation in the Waterford River Basin is about 0.81. A survey showed that neighbouring basins also had similar ratios.

2.5 Water Resources

2.5.1 Hydrology

There are three streamflow gauging stations on the Waterford River. Two stations, Waterford River at Mount Pearl (02ZM010) and Waterford River near Donovans Industrial Park (02ZM011), were established as a result of this study. The Waterford River at Kilbride (02ZM008) station was established in the fall of 1973. A summary of the streamflow characteristics of the area based on the records obtained from the Kilbride station is presented in Table 2.3.

Table 2.3 STREAMFLOW CHARACTERISTICS-WATERFORD RIVER AT KILBRIDE-02ZM008

Year	Max Instant Dis. (m^3/s)	Max Daily Dis. (m^3/s)	Min Daily Dis. (m^3/s)	Min. Yearly Dis. (m^3/s)
74	30.9 @ 03:16 NST-AU 31	17.2 -DE 11	0.150 -FE 17	2.23
75	21.8 @ 20:37 NST-AU 23	13.2 -MY 7	0.201 -AU 12	1.77
76	28.3 @ 05:21 NST-AU 9	22.6 -JA 9	0.187 -JL 24	1.91
77	40.2 @ 12:34 NST-DE 27	24.7 -DE 27	0.224 -AU 17	1.68
78	30.9 @ 15:39 NST-JA 27	18.7 -JA 27	0.272 -AU 22	1.91
79	34.5 @ 22:32 NST-JA 29	28.5 -JA 28	0.145 -JL 28*	2.42
80	22.7 @ 19:49 NST-OC 7	14.8 -DE 31	0.227 -FE 15	2.70
81	66.1 @ 16:37 NST-NO 26*	27.8 -NO 26	0.356 -JN 6	2.50
82	53.4 @ 01:07 NST-OC 4	25.3 -OC 4	0.150 -AU 18	2.32
83	41.7 @ 14:23 NST-OC 26	18.8 -OC 25	0.266 -OC 25	2.03
84	36.6 @18:27 NST-FR 7	24.5-AP 15	0.259 -AU 11	2.22
85	NOT AVAILABLE	32.5-MY 25*	0.222 -SE 25	1.61

* EXTREME FOR THE PERIOD OF RECORD

LOCATION	LAT 47°31'47"N	DRAINAGE AREA 52.8 km^2	
	LONG 52°44'34"W	NATURAL FLOW	

MONTHLY MEAN DISCHARGES IN CUBIC METRES PER SECOND FOR THE PERIOD 1974 TO 1984

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2.70	1.76	2.80	4.13	2.55	1.18	0.719	0.893	1.60	2.64	2.22	2.64	2.15

As mentioned previously, the maximum monthly flow usually occurs in April due to the combined effect of snowmelt and rainfall. A secondary peak is also typically observed in late fall. The minimum flow normally occurs in July or August, but winter flows can occasionally be as low as the summer flows after a persistent spell of cold weather.

2.5.2 Water Use

Municipal/Industrial

The Waterford River and its tributaries are not being used for municipal water supply. Bremigens Pond, located in the headwaters area of the basin, is used as a source for water supply for Newfoundland Hardwoods, Crossroads Motel, Supersweet Feed and a few houses in the area. Powers Pond is also connected to Bremigens Pond system to provide additional water when needed. Water supply for the urban population of the study area is obtained from the St. John's Regional Water Supply systems. In some cases, groundwater from dug and drilled wells is used for domestic purposes.

There is no expectation of a demand on the Waterford River for municipal water supply in the near future. It could possibly be used for industrial water supply in the future.

Fishery

Fish species present in Waterford River and its tributaries are brook trout, brown trout, stickleback and eel. Migratory fish are excluded by obstructions. Despite considerable pollution, brown trout are found in abundance. Brook trout and eel are lesser in number. Brown trout are the dominant species in most sections of the river. Brook trout are most abundant in the upper portion of the South Brook.

Though the river system in the study area has potential for recreational fishing, it is not currently used because of the possible effects of the relatively polluted water on fish quality.

Recreation

The water-related recreational opportunities in the area are presently limited and are below their potential because of pollution. Fecal bacterial contamination makes the water unfit for all water contact recreational activities despite some existing facilities for swimming, boating, etc. The pond in Bowring Park is used for limited boating. The loss of recreational and aesthetic values in the study area has aroused considerable public awareness and concern. Efforts are being made by both provincial and local governments and private organizations to rectify the problem of pollution and to restore the recreational use of these waters.

Wastewater Discharge

The municipal sewage disposal system in the study area is connected to the City of St. John's sewer system which discharges into the harbour. The only sewage that is discharged into Waterford River after treatment comes from the Trailer Park and the Westhills Subdivision.

There may be several unidentified cross-connections between sanitary and storm sewers in Mount Pearl and adjacent areas of St. John's which may be partly responsible for pollution of the river. Disposal of domestic sewage by means of improperly constructed or operated septic tanks in several individual houses in the area has also resulted in considerable localized contamination of groundwater which, in turn, adversely affects surface water. It is likely that in some locations, untreated domestic sewage and septic tank effluent directly enters into these waters. The wastewater from the industries located in Donovans Industrial Park is discharged into the Kenmount Valley Sanitary Sewer System. The Waterford River and its tributaries receive stormwater from all storm sewer systems in the area through sewer outfalls (200 mm to 1050 mm diameter) located at various points along the river.

2.5.3 Hydrologic Problems

General

In general, the creation of impervious areas by urbanization causes an increase in both the total volume and peak rate of runoff. This can create serious problems of flooding, erosion and sedimentation in low lying areas. The other significant effect of urbanization is the concomitant reduction in low flows which may adversely affect water quality and, in consequence, aquatic life. The reduction in infiltration caused by an increase in impervious areas results in reduced recharge to groundwater which may cause a lowering of water table and a reduction in base flow.

Urban runoff has also increasingly become a source of water quality problems in receiving waters. The type, magnitude, and sources of pollution and their effects on water quality in relation to the existing and potential water uses, require careful evaluation in order to develop an effective water quality management program. This includes the development of criteria and standards for construction activities which create major problems of erosion, sedimentation and deterioration of water quality.

One of the major problems of urban runoff management is the hydrologic design of storm sewers and storm drainage systems which can safely handle design runoff. In order to translate rainfall quantities into runoff, it is necessary to use techniques which can account for the intricate drainage patterns and the great variation in loss rates that occur in urban areas. These require adequate hydrologic data in order to evaluate the effects of urbanization on the runoff response.

Changes in the Hydrologic Regime

Surface Water

Before the initiation of this study, it was hypothesized that urbanization might be causing increased rates of flows in the Waterford River. The variability of weather conditions and sequence of rainfall and snowfall (and its accumulation) makes it difficult to obtain an accurate trend based on a few years of data. It will require more years of data to determine the degree of changes in peak flows and other hydrologic characteristics that may result from urbanization of the basin. Changes in low flows and flow duration characteristics also could not be determined definitely from the few years of data available at the start of the study.

Groundwater

Several houses in the study area are dependent on groundwater obtained from either dug wells or drilled wells according to the Study Plan. It was reported in the past that water levels in dug wells were lowered due to construction of roads, storm and sanitary sewers in several locations. No quantitative data were available for the area. It is likely that some of the drilled wells may also be affected because of loss of recharge areas but no such information was available at the start of the study. Because of data limitations discussed in the previous section, no conclusions about groundwater characteristics could be established from analysis of base flows.

Flooding

No severe flooding involving extensive damage to property or loss of life has been experienced in the area, but certain segments of Waterford River have problems of frequent localized flooding. Some flooding incidents were:

- *In 1951, a retaining wall protecting the CNR track was damaged by flood water.*
- *In 1962, the concrete spillway of Bremigens Pond was washed out by flooding in the Donovans area. Newfoundland Hardwoods boiler room had over one metre of water, and homes and the CNR track downstream in Mount Peal were flooded.*

- *There were several other incidents of flood damage to CNR track and culverts in the basin (1970 : 3, 1971 : 2, 1973 : 1).*
- *In 1968 homes were flooded on both sides of the river near Wilson Avenue.*
- *A footpath bridge was washed out near Mary Queen of the World School. Homes, roads and rail lines were flooded in this area.*
- *On May 24-25, 1985 heavy rain in the St. John's area (85 mm in 33 hours) caused the Waterford River to overtop its banks in Donovans, Mount Pearl, Bowring Park and Kilbride areas. Flooding also occurred on South Brook. There were no reports of major damage.*
- *On April 11, 1986 about 70 mm of rain fell in 22 hours creating flooding problems in many parts of St. John's. The Waterford River overflowed its banks in several areas including Kilbride, where a section of the Waterford Bridge Road near Corpus Christi Church flooded.*
- *The Waterford River overflows its banks almost every year (sometimes more than once) and floods the road near Newfoundland Hardwoods Plant.*

There are other areas in the basin which are subject to flooding especially in the lower reaches of Waterford River, but no detailed information is available. In several locations in downstream sections of the river, retaining walls and embankments have been constructed to protect property from floodwater. These may prove inadequate in the future if peak flows were to substantially increase due to urbanization. Since part of the floodplains and adjoining lands have been urbanized, any increase in flow rates has the potential to create severe flooding problems in the area.

Water Quality

The problem of pollution is perceived to be serious, complex and widespread in the study area. Water quality may have deteriorated to the extent that it has become unfit for recreation, fisheries, and other uses.

The quality of stormwater runoff from a developed urban area is usually significantly different from that of a developing area; runoff from a developed area is commonly higher in dissolved solids, nutrients, oxygen demand and metals, and somewhat lower in suspended solids.

Prior to this study no systematic water quality monitoring had been done in the area except a survey by the then Newfoundland Department of Consumer Affairs and Environment during 1977. Water samples were collected from seven locations on Waterford River and its tributaries, and analyzed for routine physical, chemical and bacteriological parameters. Total Coliform bacteria counts ranged from about 1000 to a maximum of 200,000 counts per 100 millilitres.

Other physical and chemical parameters such as iron, manganese, ammonia, nitrate, chloride, colour and dissolved oxygen have also frequently exceeded the water quality standards.

The sources of pollution may be point sources, such as treated effluent from the two sewage treatment plants, cross-connections between storm and sanitary sewers, and septic tank effluents; and non-point sources such as runoff from parking lots, streets and roof-tops. Erosion and sedimentation in the affected areas and stream channels adversely affect water quality, stream channel morphology and the aquatic environment. Because of pollution, the Waterford River and its tributaries have lost some of their aesthetic value, recreational potential and potential for sport fishing.

Urban Drainage

The impact of urbanization on flow rates should be considered in hydrologic and hydraulic design of drainage systems to ensure economy in cost and safe disposal of stormwater with minimum environmental impacts. The hydrologic design of urban drainage systems is often based on empirical standards which may possibly result in either overdesign or underdesign of the systems. Lack of specific hydrologic data for the area precludes any evaluation of the adequacy of the existing empirical design standards.

Erosion and Siltation

The proportion of undeveloped areas in the Waterford Valley is gradually diminishing. Construction activities for residential, commercial and industrial developments are proceeding in the Kitty Gauls Brook, Glendale, Mt. Pearl, Newtown, Kilbride, Donovans and Paradise areas.

Major water quality problems in developing urban areas are often associated with soil disturbance which increases the rates of erosion and siltation processes which, in turn, increase the levels of suspended and total solids, and turbidity of the receiving waters. The introduction of silt-laden water into the Waterford River is a serious problem. Settling pools used in dewatering operations are usually poorly constructed or nonexistent. In some instances, turbidity level has exceeded the recommended value for direct recreational contact.

High turbidity may adversely affect aquatic communities. Organisms can be affected directly, such as when food collection or respiration is obstructed, or indirectly, such as when depletion of the resources on which they depend occurs. Suspended or deposited sedimentary material is deleterious because it reduces light penetration and, consequently, plant growth; and fills interstices within the substrate resulting in burial of spawning grounds.

In summary, high turbidity levels caused by erosion and the resulting sedimentation reduce photosynthesis of submerged, rooted aquatic vegetation and algae, decrease the diversity of aquatic insects, degrade the habitat for fish and decrease the value of the river for recreational activities, and impair its aesthetic value.

2.6 Political Jurisdiction

The Waterford River watershed is now being administered by four major municipalities. They are St. John's, Mount Pearl, Paradise and St. John's Metropolitan Area Board. The political jurisdictions in the basin are shown in Figure 2.2.

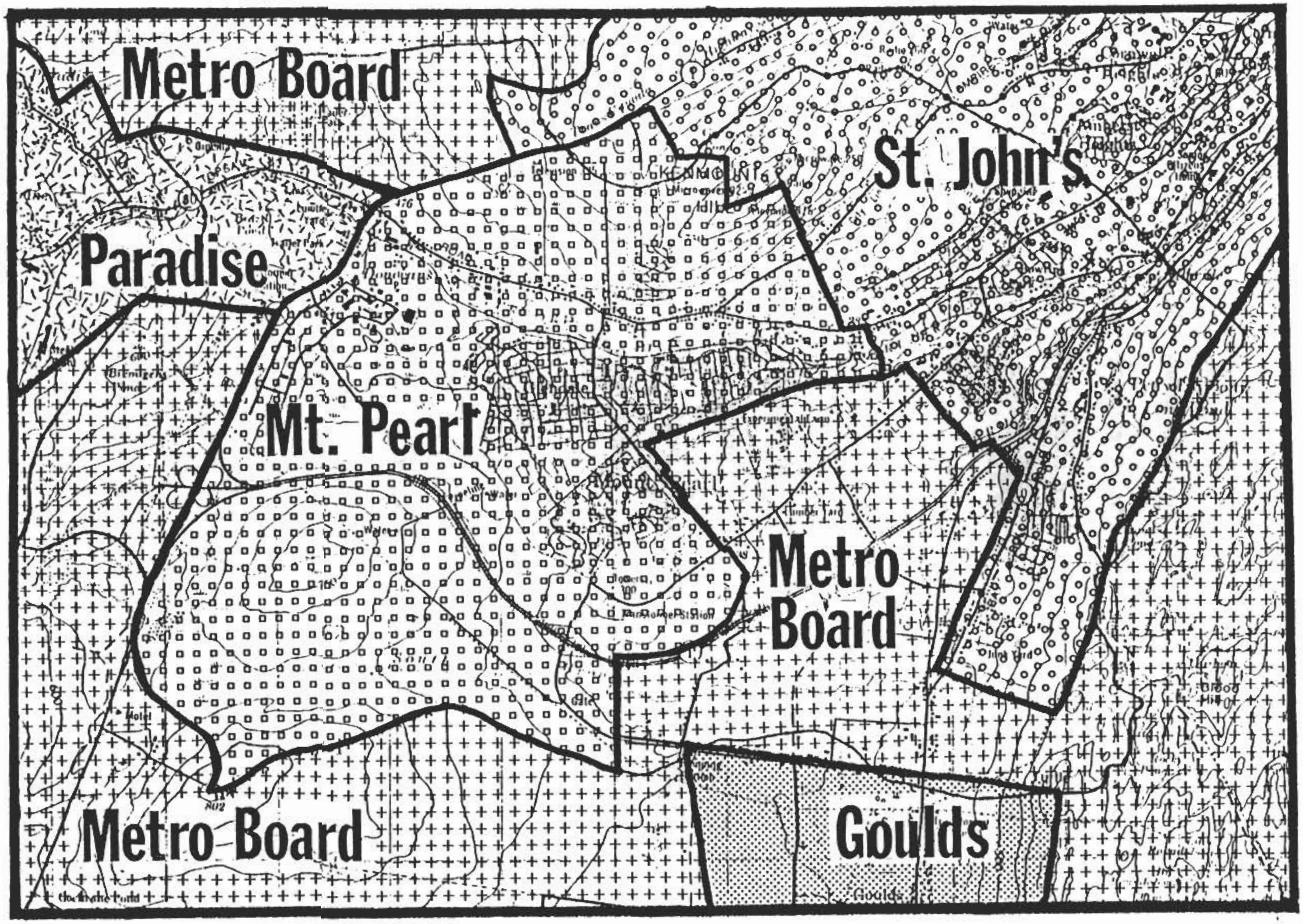


Figure 2.2 WATERFORD RIVER BASIN POLITICAL JURISDICTIONS (1985)

St. John's

In 1985, St. John's extended its boundary within the watershed to the northwest and to the southeast. Major residential developments in the northwest led to the incorporation of this area into the jurisdictional control of St. John's. Kilbride to the southeast was incorporated as a result of the expansion.

Mount Pearl

In 1983, Mount Pearl extended its boundary exclusively within the watershed and to the watershed boundary in the north and south. To the west the boundary was extended to the Trans Canada Highway. Major residential developments to the north and south and major industrial developments to the west triggered the jurisdictional expansion.

Paradise

The jurisdictional boundary of Paradise has remained unchanged over the life of the study. It encompasses the area just west of the Donovans overpass on Topsail Road.

St. John's Metropolitan Area Board

The expansion of St. John's and Mount Pearl has decreased St. John's Metro Board's jurisdictional control to three areas bordering on the watershed boundary. The three areas and land uses are: north of Paradise and west of the Trans Canada Highway, south of

Paradise and west of Trans Canada Highway (both areas have rock quarry developments), and an area southeast of Mount Pearl and southwest of St. John's (this area has an agricultural land freeze).

Other

The Goulds municipal boundary, as before, extends to the south of Ruby Line which is approximately the limit of the watershed boundary.

2.7 Population

The population of St. John's and the surrounding area has been increasing gradually over the last few decades. The rate of growth increased temporarily with the prospect of offshore oil. The population of the Waterford River basin was 32,400 in 1981, and increased to 37,400 in 1986. It is anticipated that the population of the basin will be more than 40,000 by 1990.

3 STUDY COMPONENTS - OBJECTIVES, METHODOLOGY AND RESULTS

The *Urban Hydrology Study of the Waterford River Basin* is divided into seven component studies for the ease of administration and implementation of various study plans. The study components are: Land Use, Urban Runoff, Urbanizing Watershed Hydrology, Flooding, Water Quality, Biological Survey, and Groundwater. Each of these component studies has its own objectives. Collectively, the results of the component studies satisfy the objectives of the overall study.

The subcommittees and working groups, with the guidance of the Technical Committee, devised and implemented a detailed work plan for each of the respective component studies. In this section, the approach, methodology, data collection, analysis and interpretation of results obtained from each component study are briefly outlined. For further information, the original component study reports (Ref. 3-1 to 3-12) should be consulted.

3.1 Land Use Study

3.1.1 Objectives

The primary objective of the Land Use component study (Ref. 3-3) was to provide information on patterns, trends and changes in land use during the period 1973 - 1984 for correlation with hydrologic data to permit a better understanding of the impact of urbanization upon the hydrology of the study area. Results of this study provided input data to the various hydrologic models which were used for the assessment of the impact of urbanization. The data on land use changes was also used in the interpretation of the data on physical, chemical and biological quality of water.

3.1.2 Methodology

A land use map was first prepared based on information available as of 1981. Once this was done, a rough comparison was made with available photography. This comparison revealed that there had not been significant changes in the watershed since the start of the Waterford Study in 1979. Accordingly, it was decided that a land use map would be prepared for 1973 instead of 1979, as had originally been planned. The year 1973 was selected because the hydrometric station at Kilbride began operating in the fall of that year, and it was considered that baseline land use information to accompany the baseline hydrometric information would be a useful contribution to the modelling study. Therefore, 1973 became the "*base year*" for the Land Use study, and interpreted maps were subsequently prepared for 1981 and 1984.

An operating scale of 1:12,500 was established for all land use interpretations because a working map already existed at this scale. Details of land use could be accurately portrayed at this scale.

Three series of black and white photographs, taken in 1973, 1981, and 1984, were used in the interpretation of land use. The classification system that was used in the interpretation of air photos was derived from the specific requirements of the HSPF model.

Three base maps were based on the results of photo interpretation. Further information on the classification system used for interpretation and mapping is given in Ref. 3-3.

3.1.3 Results

Present Land Use

Table 3.1 summarizes the land use statistics in the Waterford River Basin in 1984.

Table 3.1 LAND USE IN THE WATERFORD RIVER BASIN (1984)

Waterford Land Use Area	Area		% of Total Area
	Hectares	km^2	
Forest	1717.8	17.2	32.5
Unproductive	1527.5	15.3	29.0
Agricultural	587.3	5.9	11.2
Commercial/Industrial	289.6	2.9	5.5
Residential	724.4	7.2	13.7
Other	430.4	4.3	8.1
Total	**5277**	**52.8**	**100%**

Forest land use (33%) is found predominantly in the southwestern and western sections of the basin surrounding South Brook, Bremigans' Pond and Donovans Industrial Park and in the northern and northeastern sections, north of Donovans and in the Kenmount Hill areas.

Unproductive lands (29%) occur throughout but are more concentrated in the western half of the basin.

Agricultural land use (11%) is concentrated in the eastern half of the basin, largely in the areas of Ruby Line, Bay Bulls Road, Petty Harbour Road and Brookfield Road. Small pockets also exist along Topsail Road and in the northeastern and northwestern sections of the basin.

Commercial, industrial, and institutional (6% of the basin area) activities are concentrated in the Donovans Industrial Park, along Topsail Road, in the area adjacent to and west of Kilbride, and at a few scattered locations along Brookfield Road and Bay Bulls Road.

Residential land use (14% of the total area) is centred in the areas of Mount Pearl, Bay Bulls Road, Petty Harbour Arterial Road, and along the Trans-Canada Highway.

Other land use (8% of total area) includes land in transition, excavation, and road construction activities. It is found largely in the northwestern and southwestern sections of the basin.

Land Use Change

Table 3.2 and Figure 3.1 show the changes occurring in six land use categories over the 1973-1984 period. It can be seen that there have been sustained gains in the residential and commercial/ industrial sectors largely at the expense of the forestry, agriculture and other categories. Land use changes were also determined at the sub-basin level.

Although there have been no large scale decreases in agriculture use, significant changes were from Agriculture to Residential and Unproductive Land Use. Also, there has been a gradual decline over the study period in the rate of change from agriculture to other uses.

Forest land use has declined throughout the study period with an increased rate of decline in the past four years. The curves in Figure 3.2 indicate short term trends. For example, the Forest category will very soon be replaced by the Unproductive sector as the dominant land use in the basin (probably within the next two years) as more forest land is cleared. Residential land use may also continue to increase within the expanded boundaries of Mount Pearl, as well as in the Bay Bulls Road, Kenmount Hills, Cowan Heights and Paradise areas. Commercial/ Industrial/Institutional land use may continue to increase, particularly within the Donovans Industrial Park area. Conversely, Agricultural land use may continue to decline, but likely at a slower rate than previously.

Table 3.2 **SUMMARY OF LAND USE CHANGE - 1973-1984**

Land Use Category	Change in km^2	Change in % of Basin	Change in % Category
Forest	-4.7	-8.9	-22%
Unproductive	+2.0	+3.8	+15%
Residential	+2.2	+4.2	+44%
Agriculture	-1.6	-3.0	-21%
Commercial/Industrial/ Institutional	+1.5	+2.8	+107%
Other	+0.6	+1.1	+16%

Basin Area: 52.8 km^2

In general, land requirements for new Residential, Commercial/Industrial/Institutional, and Other purposes were obtained from Forest and, to a lesser extent, from areas previously devoted to Unproductive and Agricultural categories.

The greatest land use changes in the basin resulted from:

A. *expansion in the Donovans Industrial Park;*

B. *residential development within the expanded boundaries of Mount Pearl;*

C. *residential development southeast of Kenmount Hill, and in the Cowan Heights, Paradise and the Bay Bulls Road areas;*

D. *excavation, aggregate extraction, and road construction at the intersection of the Trans Canada Highway and the Harbour Arterial Road; and*

E. *timber clearing in the southwestern part of the basin south of Mount Pearl.*

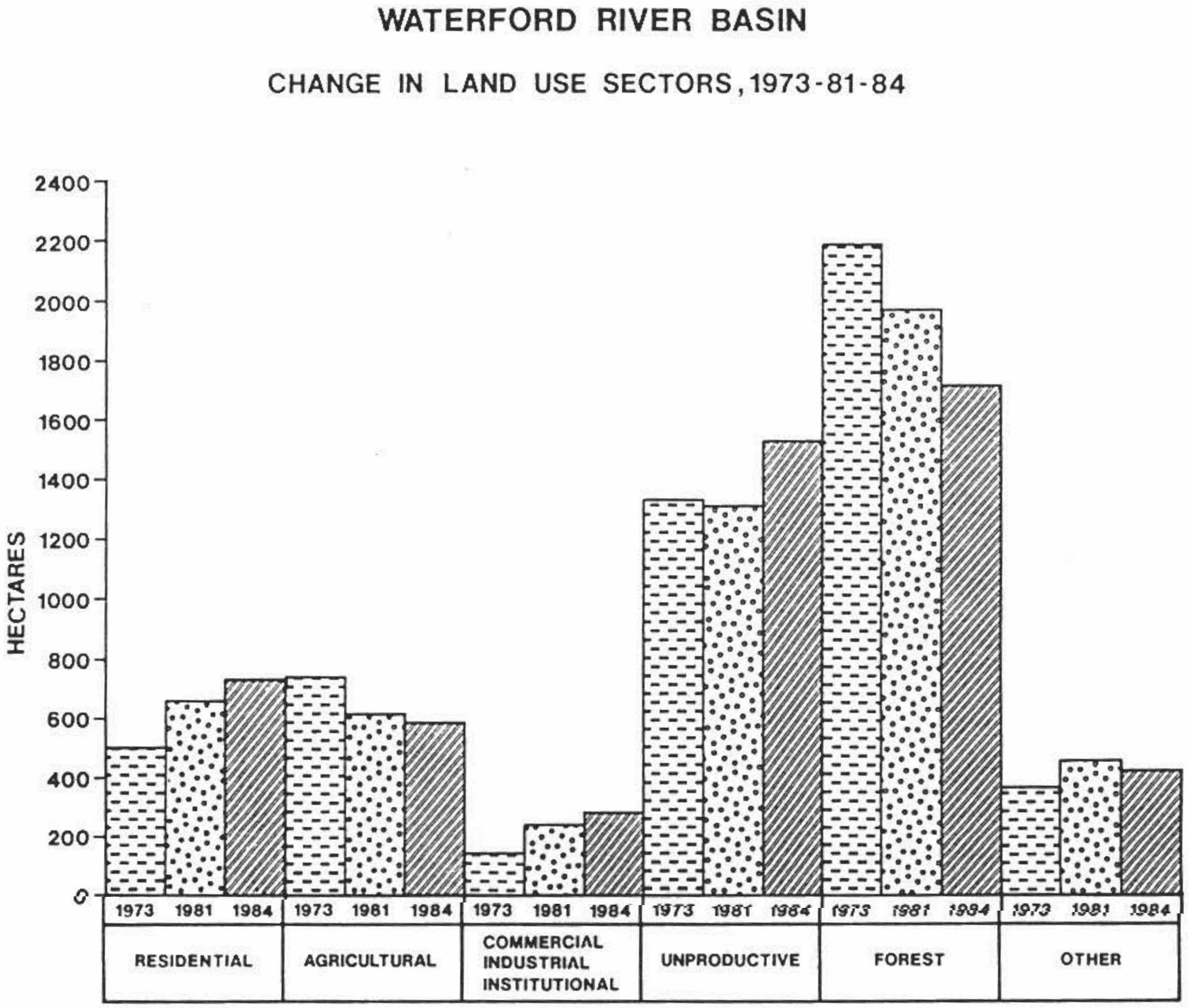


FIGURE 3.1 WATERFORD RIVER BASIN - CHANGE IN LAND USE SECTORS, 1973-1981-1984

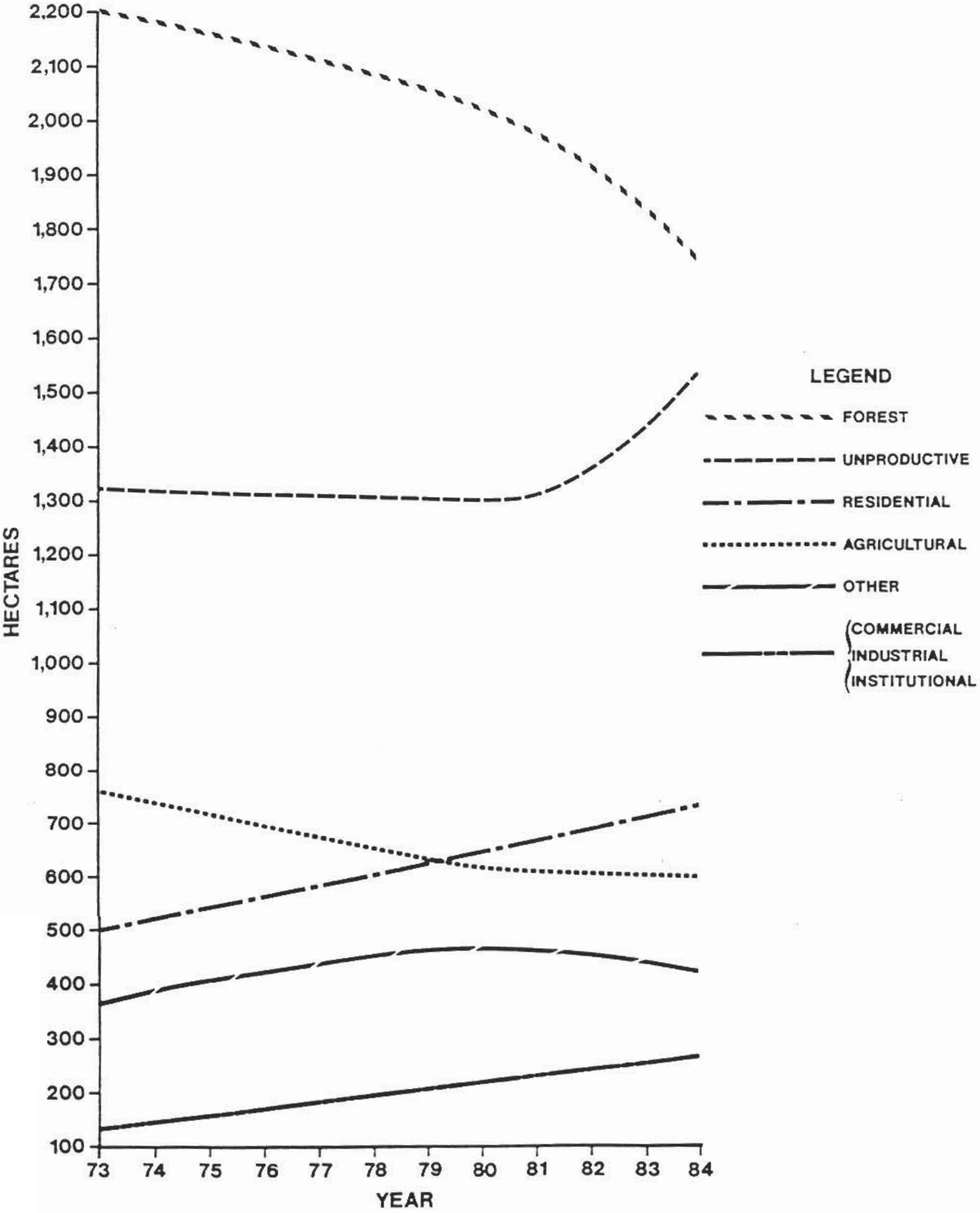


FIGURE 3.2 WATERFORD RIVER BASIN - NET CHANGE IN LAND USE 1973-1984

Some of the interesting results were (1) that the basin above Kilbride, as a whole, remains largely non-urbanized despite development of Mount Pearl and Donovans, (2) that this urbanization process is proceeding more slowly than had initially been anticipated, and (3) that the transition process is causing the largest increase in the Unproductive Land Use category.

3.2 Storm Runoff Study of Newtown Urban Catchment

3.2.1 Objectives

A study of urban runoff (Ref. 3-5) in a test urban catchment in Newtown, Mount Pearl was conducted as part of a comprehensive investigation on effects of urbanization on the hydrology of the Waterford River Basin. The objectives were to evaluate the applicability of various computational procedures including urban hydrologic models and to recommend basic principles of urban drainage in this study area and possibly others.

3.2.2 Selection of a Test Catchment

The catchment to be monitored must be representative of the hydrologic, geographic, terrestrial, and demographic characteristics of the study area. In this study, the test catchment was selected according to the following criteria: the type and state of the urban development, catchment size, drainage outfall condition, monitoring feasibility, ease of access, sewer system condition, availability of documentation, availability of electricity, and susceptibility to vandalism. Using the above criteria, nine potential test catchments in the study area were scrutinized and the Newtown test catchment was selected as the best site in terms of representativeness and suitability for instrumentation.

3.2.3 Catchment Characteristics

The Newtown test catchment, shown in Fig. 3.3, is a fully developed residential subdivision of about 13.2 ha built during the period 1976 to 1980. Catchment slopes vary from 0.025 m/m to 0.040 m/m. Local slopes depend on the grading of lots. Front yards typically slope toward streets (0.02 - 0.08 m/m) and backyards slope (0.02 - 0.04 m/m) away from houses toward the swales running along the back property lines. The slopes of streets (0.007 m/m - 0.02 m/m) follow those of the terrain.

The whole catchment is zoned as single-family residential. There are 203 houses in the catchment and all the properties are fairly new and well-maintained. Besides residential properties, there is about 0.3 ha of open land which serves as a park. The distribution of surface cover in the Newtown catchment is listed in Table 3.3. Although the total imperviousness is 38%, the effective imperviousness, including only impervious surfaces directly connected to storm sewers, is only 20%.

The pervious parts of the catchment comprise grassed areas around residential properties. It was noted that the topsoil layer was relatively thin and the predominant soils could be classified as Type B to the U.S. Soil Conservation Service. The Newtown catchment is served by a tree type, converging storm sewer system. All the sewers are made of corrugated steel pipes to which a Manning's "*n*" roughness of 0.024 was assigned. The sewer system is fairly new and in good condition. Upon completion, the system was pressure tested and found watertight. The layout of the sewer system is shown in Figure 3.4. The pipe diameters, lengths, and slopes are listed in Table 3.4.

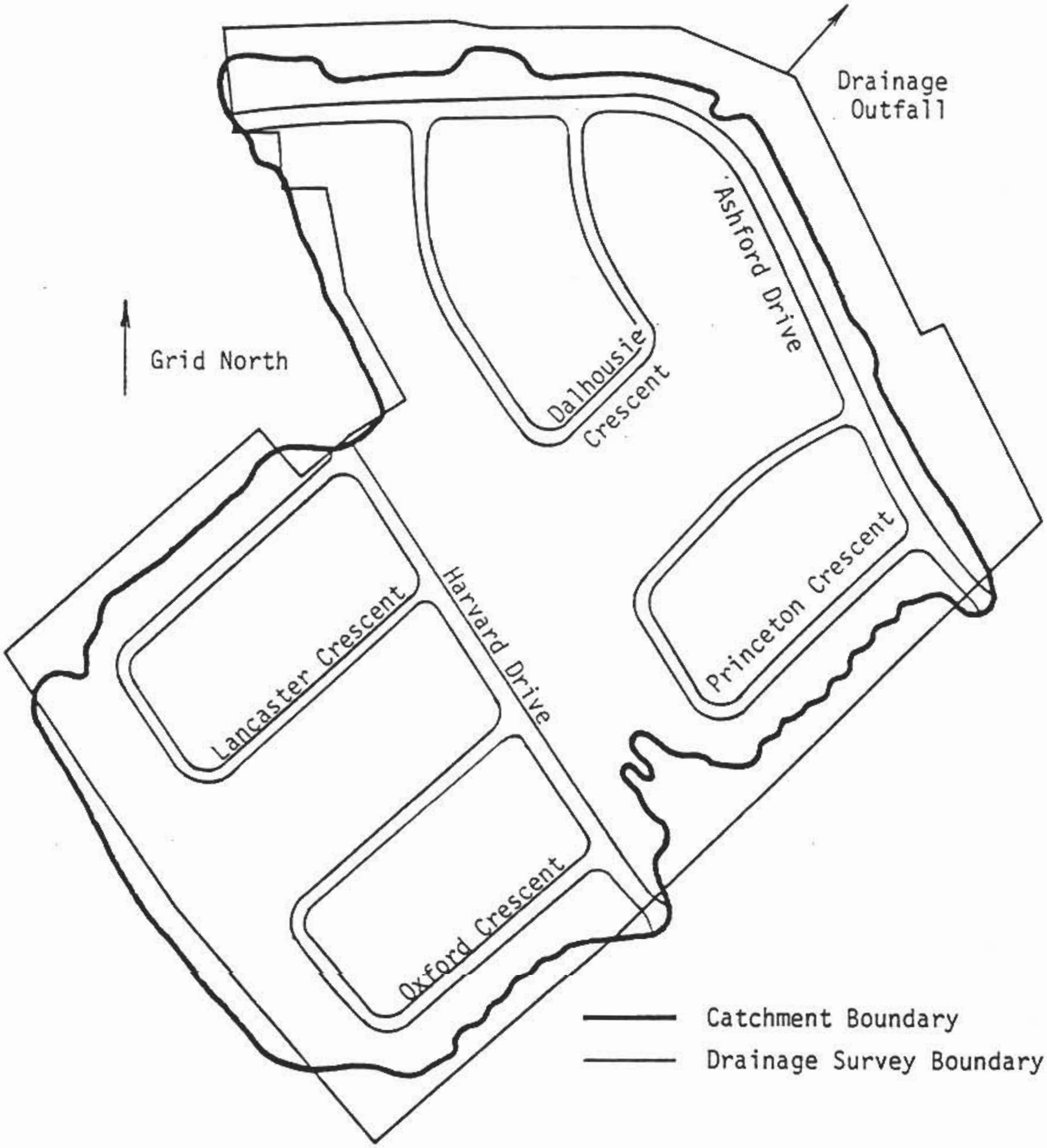


Figure 3.3 NEWTOWN URBAN TEST CATCHMENT

Table 3.3 NEWTOWN CATCHMENT: SURFACE COVER CHARACTERISTICS

Type of Surface	Area (Ha)
Impervious Surfaces	
Roads	1.75
Roofs and driveways directly connected	0.86
Effective impervious area (= 1.75 + 0.86)	2.62
Supplemental impervious area	2.43
Total impervious area (= 2.62 + 2.43)	5.05
Pervious Surfaces	
Total contributing pervious area	8.18
Total Catchment Area (= 5.05 + 8.18)	13.23

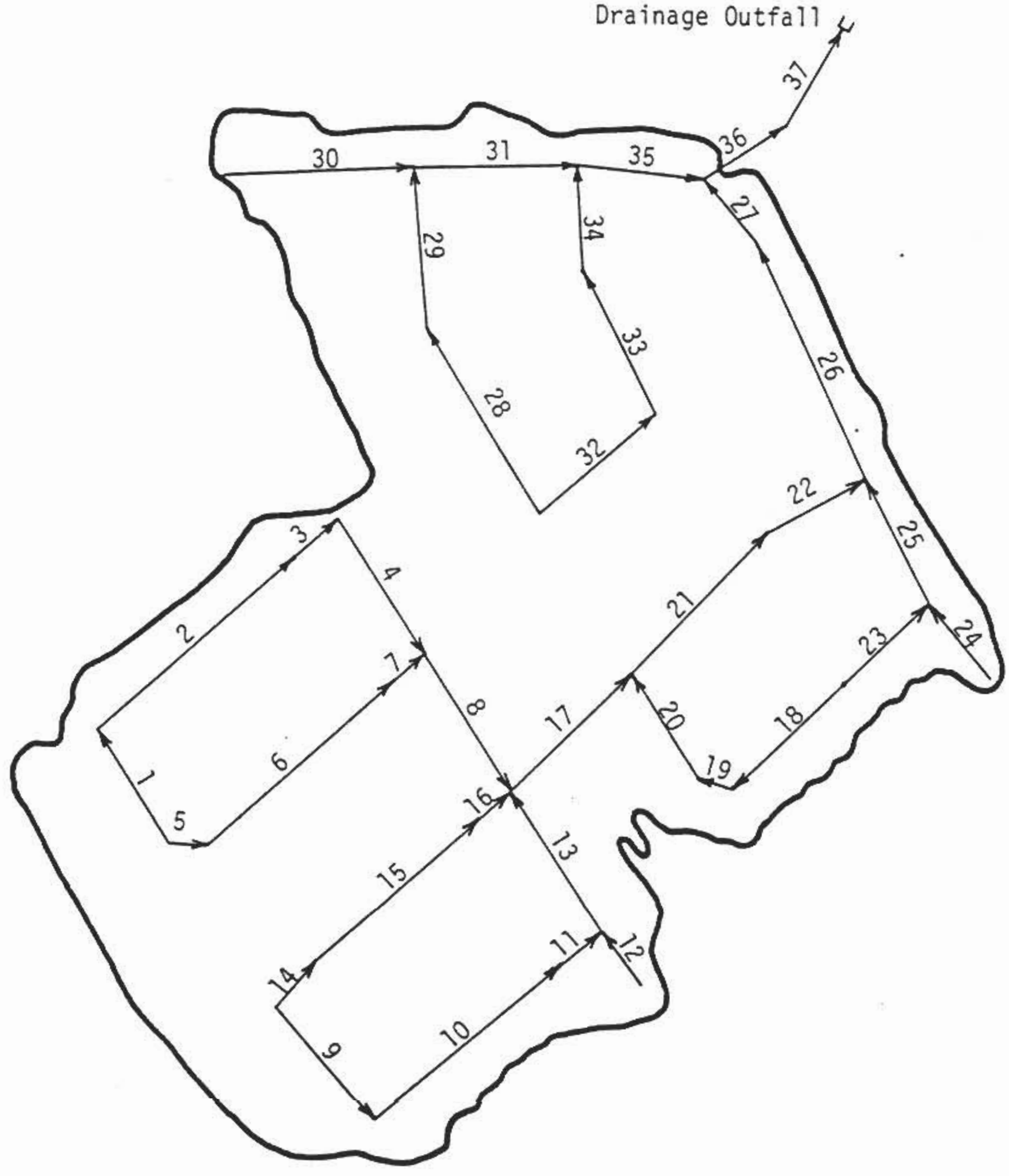


Figure 3.4 NEWTOWN STORM SEWER SYSTEM

Table 3.4 CHARACTERISTICS OF NEWTOWN STORM SEWER SYSTEM

Pipe No.	Diameter (m)	Length (m)	Slope (m/m)	Pipe No.	Diameter (m)	Length (m)	Slope (m/m)
1	0.305	67.1	0.0064	20	0.305	61.9	0.0172
2	0.305	122.0	0.0508	21	0.610	100.0	0.0152
3	0.381	28.1	0.0140	223	0.610	48.8	0.0163
4	0.534	75.6	0.0053	23	0.305	58.3	0.0262
5	0.305	19.5	0.0352	24	0.305	40.9	0.0097
6	0.305	111.9	0.0598	25	0.305	64.7	0.0184
7	0.305	19.2	0.0175	26	0.610	121.1	0.0265
8	0.610	75.3	0.0077	27	0.763	41.2	0.0082
9	0.305	71.7	0.0181	28	0.305	105.2	0.0107
10	0.305	115.9	0.0484	29	0.381	75.6	0.0165
11	0.381	22.6	0.0108	30	0.305	89.4	0.0444
12	0.305	25.3	0.0050	31	0.381	79.3	0.0223
13	0.458	74.7	0.0078	32	0.305	72.0	0.0203
14	0.305	27.1	0.0360	33	0.305	72.6	0.0235
15	0.305	104.3	0.0620	34	0.381	51.9	0.0135
16	0.381	18.3	0.0217	35	0.610	63.1	0.0058
17	0.610	74.1	0.0099	36	0.915	43.3	0.0120
18	0.305	64.1	0.0100	37	0.915	59.5	0.0065
19	0.305	20.7	0.0103				

3.2.4 Instrumentation and Data Collection

The Newtown catchment was instrumented for monitoring of rainfall, runoff and water quality. Precipitation was measured by means of both a tipping-bucket raingauge and a standard raingauge which are standard instruments used by the Atmospheric Environment Service (AES). The tipping-bucket raingauge has a tipping bucket capacity of 0.2 mm per tip and a chart speed of 15 mm/hr. The recorded rainfall depths are read in increments of 0.2 mm and can be discretized into time intervals as short as 2 minutes. The tipping-bucket raingauge was operated throughout the whole year, though no attempt was made to use it to measure snowfall. In case of malfunctions, substitute rainfall data from the St. John's West Station, located at the nearby Canada Department of Agriculture Farm, were used.

Throughout the entire study period at least one standard raingauge, with a collector diameter of 112.5 mm, was operated in or near the catchment. The gauge was read daily and readings were used to verify the rainfall depths recorded by the tipping-bucket raingauge. During periods of snowfall, estimates of 24-hour snowfall were also produced.

Runoff was monitored continuously at the outfall from the sewer system by means of a wooden weir box. Initially, a V-notch weir was used; later it was replaced by a rectangular weir to reduce the rise in the water level at the outlet and the backwater effects in the outlet sewer. Because such an installation at the outlet is unconventional, it was decided to calibrate the weir using a scale model at the CCIW Hydraulic Laboratory. After calibration, the weir rating curve was defined with an accuracy of ± 3.1% for heads smaller than 0.324 m and ± 5.2% for greater heads.

Water quality was monitored by analyzing runoff samples collected by the Sirco B/VS sampler, which uses the pressure/vacuum method for sample collection. Discrete sequential samples were collected at intervals varying from 5 to 10 minutes. Up to twenty-four 0.5-litre samples were collected during each sampling cycle. During individual events, the sampler was activated automatically by a water-level sensitive actuator and the subsequent samples were collected at constant intervals. The samples were shipped to the water quality laboratories of the Water Quality Branch, Moncton, New Brunswick; the Environmental Protection Service, St. John's; Newfoundland Department of Environment, St. John's; and the Newfoundland Public Health Laboratory in St. John's. The samples were analyzed for physical parameters, major ions, selected metals, nutrients and bacteria.

3.2.5 Rainfall Data

The observed rainfall data series was discretized into individual storm events which were separated by inter-event periods of no rainfall of three hours or longer. Rainfall data for individual events were converted into storm hyetographs which were then used in runoff simulations. When the Newtown raingauge data were missing, the St. John's West data were used. Such substitutions introduced some uncertainties into runoff simulations and comparisons with the hydrographs observed at Newtown.

3.2.6 Runoff Data

Runoff rates were recorded continuously in the form of weir heads which were then converted into flow rates using the weir rating curve. The top ten peak discharges observed during the 3 years of monitoring varied from 0.220 m^3/s to 0.390 m^3/s. All these flows occurred from July to November, thus outside of the winter months. This has some implications for assumptions in runoff calculations for design conditions.

3.2.7 Runoff Quality

Stormwater samples were analyzed for 25 parameters. The list shown in Table 3.5 includes all the parameters which are usually cited as major causes of pollution by urban runoff and also some more general parameters which may provide a link between urban runoff and the streamflow quality. The parameters which are particularly important for characterization of urban runoff quality are suspended solids, sodium, chloride, lead, zinc, nitrogen, phosphorous and coliforms.

Table 3.5 WATER QUALITY PARAMETERS

Parameter Group	Parameters
1. Physical Parameters	Water colour, temperature, dissolved oxygen, pH, specific conductance, turbidity and suspended solids.
2. Majors Ions	Sodium, chloride, magnesium, calcium, alkalinity or bicarbonate, sulphate, potassium and silica.
3. Selected Extractable Metals	Iron, manganese, copper, lead and zinc.
4. Nutrients	Organic carbon (dissolved and total), inorganic carbon, nitrogen (dissolved and total), phosphorus (dissolved and total).
5. Bacteria	Total coliform and fecal coliform.

3.2.8 Storm Runoff Models Application

In the current urban drainage practice, runoff flows are computed by empirical formulas (for example, the Rational Method) or by hydrological synthesis models, such as ILLUDAS or SWMM. Both approaches were tested in this study using the measured data from the Newtown test catchment and the results are summarized below.

3.2.8.1 The Rational Method

The Rational Method is a common empirical procedure used for drainage design. It can be expressed as:

$$Q_p = \alpha \, C \, i_{av} \, A$$

where Q_p is the peak runoff rate (m^3/s), C is the runoff coefficient (dimensionless), α is a unit conversion coefficient (0.00278), i_{av} is the average rainfall intensity (mm/hr) corresponding to the time of concentration t_c, and A is the catchment contributing area (ha). The time of concentration is usually taken as the time of travel from the most remote point in the catchment to the point under design.

In applications of the Rational method to the study area, runoff coefficients for effective pervious, supplemental impervious and pervious areas were adopted from the WPCF design manual. Composite runoff coefficients were also developed and the one adopted consisted of inputs from two types of surfaces -- the effective impervious areas and the pervious areas. Furthermore, the St. John's Airport intensity-duration-frequency (IDF) curves were used and runoff travel times and inlet times were calculated from the kinematic wave equation using the slopes and lengths measured in the field and from maps; rainfall intensities read from the IDF curves; and taking the overland flow roughness as $n = 0.013$ and 0.20 for impervious and pervious areas, respectively. The calculated inlet time for effective impervious areas was taken as 4 minutes regardless of the return period.

Results

Figure 3.5 shows a plot of calculated and observed peak flows for various return periods. The reader should refer to Ref. 3-5 for further information on the results. Some specific results related to the Rational Method application are as follows.

The highest runoff rate at the outlet was obtained for the case in which only 62% of the catchment area was contributing runoff. This area represented the entire effective impervious area and pervious or noneffective impervious areas within 15 m of streets. In this case, the composite runoff coefficient $C_c = 0.45$ ($C_{impervious} = 0.95$, $C_{pervious} = 0.22$, for all return periods studied) and the relatively high rainfall intensity corresponding to short inlet times yielded the highest runoff discharge. Using the above procedures, the peak flows calculated from the Rational Method were about 11% below the observed (or extrapolated observed) flows, which may be overestimated. For any other combinations of contributing areas, including the case of the whole catchment contributing, the calculated peak flows at the outlet were smaller because of increased inlet times and corresponding reduced rainfall intensities and runoff coefficients.

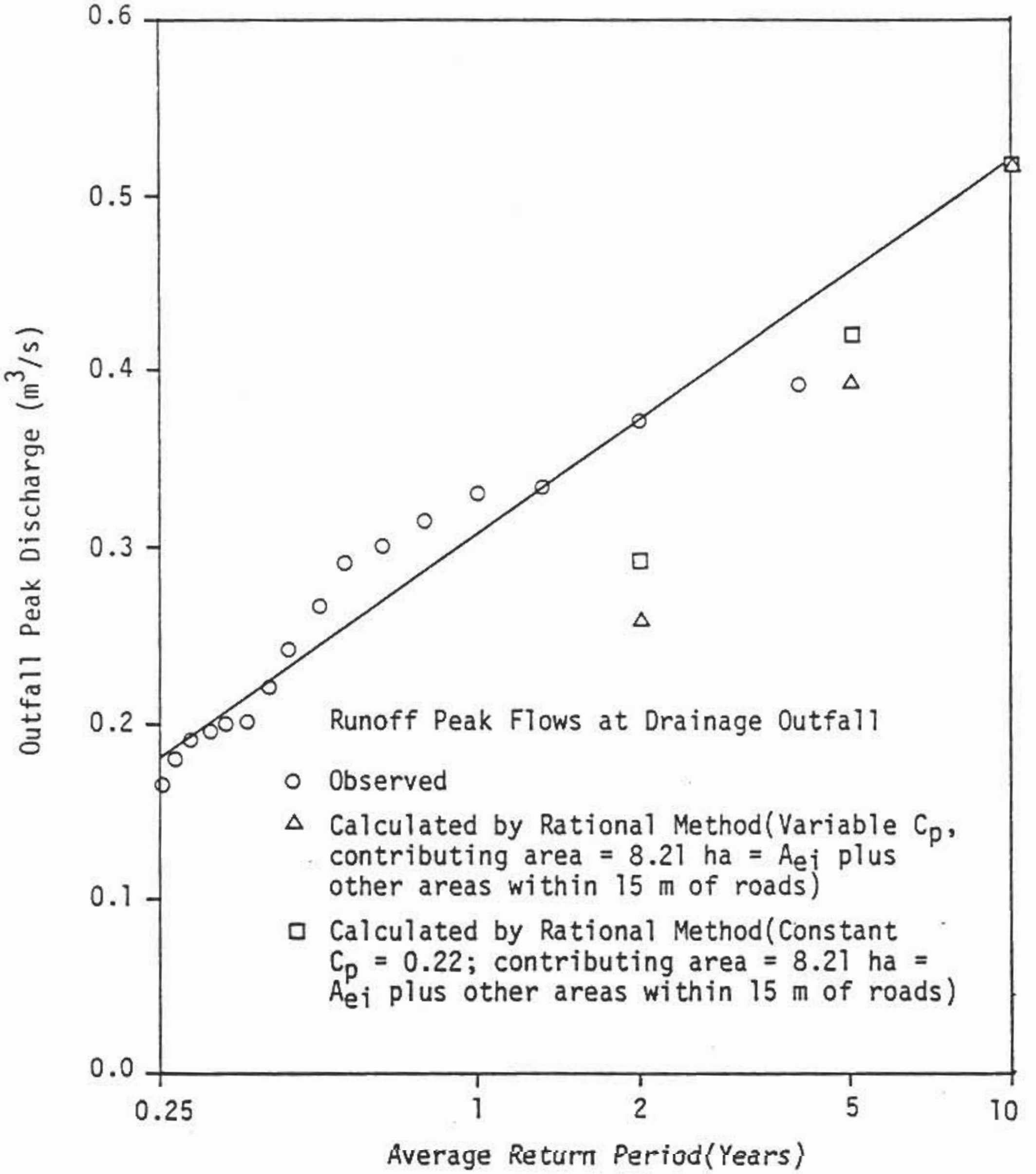


Figure 3.5 NEWTOWN RUNOFF PEAK FLOWS: OBSERVED AND CALCULATED FROM THE RATIONAL METHOD

In applications of the Rational Method, it is recommended to check flow calculations for various partial contributing areas in order to find the maximum runoff peak. It appears that calculations for three contributing areas should be sufficient to obtain a peak close to the maximum. Combinations of contributing areas that could be selected are as follows:

- Effective impervious areas only.
- Effective impervious areas plus any other areas draining directly towards streets (those are generally areas within say 10 - 30 m of the transport channels - street gutters).
- The entire catchment area.

3.2.8.2 ILLUDAS and SWMM

Nine series of simulation runs with the SWMM (Ref. 7) and ILLUDAS (Ref. 6) models were made. A summary is given in Table 3.6. For runoff volumes, 24 events with the most reliable data were used. For peaks, 29 events were selected. Winter months were avoided because of probable precipitation gauge errors.

For the purpose of runoff modelling, the Newtown catchment was subdivided into about 20 sub-catchments which were drained by 20 sewer pipes. The rainfall input data were discretized in 5 minute intervals. Using these inputs and sub-catchment physiographic data from maps and field surveys, the observed runoff events were reproduced fairly well by both models.

Volumes

Runoff volume results and statistical summaries are presented in Table 3.7 as listings of simulated values. The results are extracted from Ref. 3-5.

Table 3.6 CHARACTERISTICS OF RUNOFF SIMULATIONS FOR THE NEWTOWN CATCHMENT

Simulation Series #	Code	Model	Discretization # of Sub-catchments & Pipes	Infiltration Characteristics Max/Min rate (mm/hr)	Antecedent Moisture Conditions
1	S1	SWMM	22/37	76/13	Not considered
2	S2	SWMM	22/21	76/13	Not considered
3	S3	SWMM	22/21	51/8	Not considered
4	I1	ILLUDAS	20/20	Soil B	Rather Dry
5	I2	ILLUDAS	20/20	Soil C	Rather Dry
6	I3	ILLUDAS	20/20	Soil B	Varied according to the antecedent rainfall.
7	I4	ILLUDAS	20/20	Soil C	
8	I5	ILLUDAS	20/20	Soil A	
9	I6	ILLUDAS	20/20	Soil B	Similar to series 6-8 but slightly modified

Table 3.7 OBSERVED AND SIMULATED RUNOFF EVENT VOLUMES

Newtown Runoff Event Volumes H (mm)									
Storm No.	**SWMM Simulations**				**ILLUDAS Simulations**				
	Observed	**S1**	**S2**	**S3**	**I1**	**I2**	**I3**	**I4**	**I5**
62	3.98	5.39	5.53	5.53	5.26	5.39	5.26	5.39	5.26
63	5.08	6.45	6.48	9.29	6.49	8.81	6.49	8.81	6.10
64	4.61	5.76	5.90	5.82	5.59	5.74	5.77	9.23	5.59
69	2.49	3.30	3.46	3.45	3.21	3.67	3.96	6.00	3.43
73	23.56	14.59	15.04	26.44	17.50	28.74	15.07	20.97	14.10
76	7.01	5.53	5.67	6.59	5.51	6.62	8.86	15.03	6.37
86	4.06	4.46	4.61	4.61	4.43	4.43	4.43	4.43	4.43
123	3.05	2.87	3.02	3.02	2.86	2.86	2.86	2.86	2.86
131	5.66	4.64	4.79	4.79	4.50	4.50	4.50	4.50	4.50
135	0.75	0.86	1.01	1.01	0.61	0.61	0.61	0.61	0.61
139	1.68	1.80	1.92	1.92	1.69	1.69	1.69	1.69	1.69
140	2.24	3.34	3.49	3.46	3.30	3.33	3.31	3.73	3.30
141	3.82	3.23	3.38	3.38	3.24	3.24	3.24	3.24	3.24
142	3.59	2.92	3.08	3.06	2.74	2.78	2.81	3.75	2.74
156	1.83	3.76	3.91	3.91	3.64	3.64	3.64	3.64	3.64
157	10.31	7.71	7.86	7.87	7.65	9.25	7.65	9.25	7.65
159	3.83	3.10	3.25	3.25	3.64	3.16	3.16	3.16	3.16
173	20.97	11.77	11.92	11.92	11.90	45.65	11.90	15.65	11.65
239	1.59	1.71	1.86	1.86	1.59	1.59	1.59	1.59	1.59
246	7.11	8.00	7.92	8.31	7.67	8.88	7.66	7.84	7.66
247	3.02	2.40	2.55	2.55	2.36	2.36	2.48	4.39	2.36
248	2.35	2.48	2.63	2.63	2.21	2.21	2.27	3.42	2.21
251	5.95	6.45	6.61	6.49	6.29	7.13	6.67	8.01	6.31
253	2.34	2.02	2.18	2.18	1.90	1.90	2.15	3.46	1.98
$\Sigma H(n=24)$	130.88	114.54	118.07	133.34	115.78	138.18	118.03	150.65	112.43
Mean	5.45	4.77	4.92	5.56	4.82	5.76	4.92	6.28	4.68
St. Dev.	5.62	3.24	3.27	5.18	3.68	5.93	3.42	4.95	3.19
Data set statistics without events nos. 73 and 173									
$\Sigma H(n=22)$	86.35	88.18	91.11	94.98	86.38	93.79	91.06	114.03	86.68
Mean	3.93	4.01	4.14	4.32	3.93	4.26	4.14	5.18	3.94
St. Dev.	2.25	1.99	1.96	2.26	1.98	2.51	2.23	3.33	2.00

The simulation results indicate that the observed runoff volumes of the two largest events could not be reproduced well by simulations. This was particularly obvious for storm No. 173 in which case the closest simulated volume represented only 75% of the observed one. Furthermore, if the model parameters used to obtain this best reproduction (i.e. Series I2 and I4) were applied consistently to all other events in the set (as done in Series I2 and I4), the simulated runoff volumes would generally somewhat exceed the observed ones. For smaller events, much closer reproduction was achieved. In most runs, the cumulative runoff volume for all 22 events ranged from 100% to 110% of the observed value. Only one series (I4) seriously overestimated the observed total volume.

Further evaluations of the simulated volumes were done by examining linear correlation between the observed and simulated volumes and examining the deviations of simulated volumes from the observed ones. With the exception of Series I4, all the series yielded comparable results in terms of correlations and statistics of deviations of simulated volumes from the observed ones.

Peak Flows

Runoff peak flows were reproduced fairly well by both models. The mean value of the difference between observed and simulated peaks varied from .000 to 0.009 m^3/s for the best three simulation series. The 95% confidence limits for these means were about -0.020 and 0.030 m^3/s. The following results are extracted from Ref. 3.5.

For the 29 events selected, the runoff peaks obtained in seven series of simulations are presented in Table 3.8 together with the observed peaks corrected for baseflow. Observed peaks varied from 0.076 m^3/s to 0.391 m^3/s with the mean value of 0.195 m^3/s. Significantly larger variations were noticed for simulated peaks - from 0.165 m^3/s to 0.796 m^3/s and the series means varied from 0.165 m^3/s to 0.245 m^3/s. Table 3.8 also contains results for simulation series I6. In this series, which is similar to I3, AMC parameters of four events were changed on the basis of detailed scrutiny of the antecedent rainfall, rather than mechanically applying the ILLUDAS criteria for evaluation of AMC conditions.

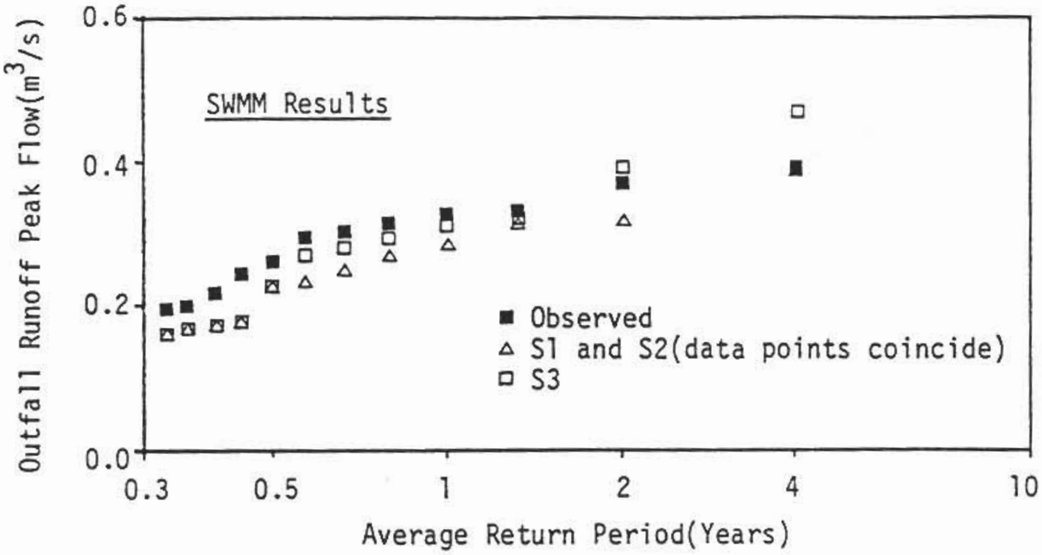
In evaluations of simulated peaks, correlations between the simulated and observed peaks were investigated and the statistics of the deviations of simulated peaks from the observed ones were also determined. The data indicate good correlation between observed and simulated peaks (r^2 = .80 to .87). The mean differences between the observed and simulated peaks varied from -0.048 m^3/s to 0.030 m^3/s. When comparing individual simulation series, it became obvious that the least satisfactory results were obtained for series I4, in which the simulated peaks overestimated the observed ones by a significant margin. The best agreement was obtained for series I6 and I3 with the remaining series being almost equal.

As a final means of evaluation of simulated peaks, the observed and simulated peaks were subject to frequency analysis The results of this analysis are shown in Figure 3.6.

Table 3.8 OBSERVED AND SIMULATED RUNOFF PEAKS AT THE NEWTOWN OUTFALL

Storm No.	Observed (m^3/s)	SWMM Simulations (m^3/s)			ILLUDAS Simulations (m^3/s)				
		S1	S2	S3	I1	I2	I3	I4	I6*
14	0.218	0.231	0.232	0.271	0.311	0.476	0.261	0.379	0.261
19	0.330	0.130	0.104	0.145	0.125	0.241	0.156	0.295	0.173
51	0.081	0.115	0.116	0.116	0.119	0.119	0.119	0.119	0.119
52	0.139	0.093	0.093	0.093	0.093	0.150	0.096	0.181	0.096
61	0.121	0.123	0.145	0.145	0.120	0.125	0.125	0.125	0.125
62	0.103	0.130	0.131	0.131	0.140	0.136	0.136	0.136	0.136
63	0.328	0.315	0.310	0.568	0.309	0.459	0.300	0.320	0.300
64	0.093	0.107	0.107	0.107	0.110	0.108	0.110	0.195	0.110
69	0.242	0.314	0.313	0.313	0.337	0.351	0.357	0.453	0.337
73	0.368	0.387	0.387	0.491	0.507	0.607	0.459	0.475	0.459
76	0.391	0.248	0.251	0.279	0.292	0.320	0.433	0.657	0.433
80	0.164	0.081	0.081	0.081	0.090	0.159	0.113	0.200	0.113
86	0.093	0.096	0.096	0.096	0.100	0.105	0.102	0.102	0.102
123	0.076	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065
139	0.114	0.116	0.116	0.116	0.139	0.139	0.139	0.139	0.139
140	0.198	0.146	0.146	0.136	0.139	0.139	0.139	0.176	0.139
142	0.301	0.230	0.231	0.231	0.238	0.244	0.244	0.266	0.269
152	0.293	0.270	0.271	0.311	0.284	0.362	0.351	0.530	0.284
168	0.176	0.167	0.171	0.171	0.184	0.190	0.201	0.218	0.201
173	0.149	0.120	0.121	0.121	0.130	0.178	0.130	0.178	0.130
198	0.156	0.088	0.088	0.088	0.119	0.127	0.119	0.125	0.119
239	0.192	0.163	0.173	0.173	0.184	0.184	0.184	0.184	0.184
246	0.314	0.284	0.284	0.294	0.277	0.343	0.277	0.283	0.277
247	0.171	0.124	0.124	0.124	0.132	0.133	0.136	0.224	0.136
248	0.165	0.115	0.115	0.115	0.108	0.108	0.110	0.181	0.110
251	0.177	0.162	0.163	0.162	0.175	0.204	0.195	0.229	0.195
252	0.064	0.079	0.307	0.079	0.079	0.079	0.079	0.127	0.079
253	0.263	0.175	0.176	0.176	0.195	0.195	0.204	0.272	0.204
258	0.169	0.117	0.117	0.103	0.125	0.133	0.125	0.133	0.125
Mean Q	0.195	0.165	0.166	0.186	0.183	0.217	0.195	0.245	0.188
St. Dev °Q	0.093	0.085	0.084	0.125	0.104	0.138	0.124	0.156	0.104

* In this series, some minor adjustments in the AMC parameter were made on the basis of detailed analysis of antecedent precipitation.



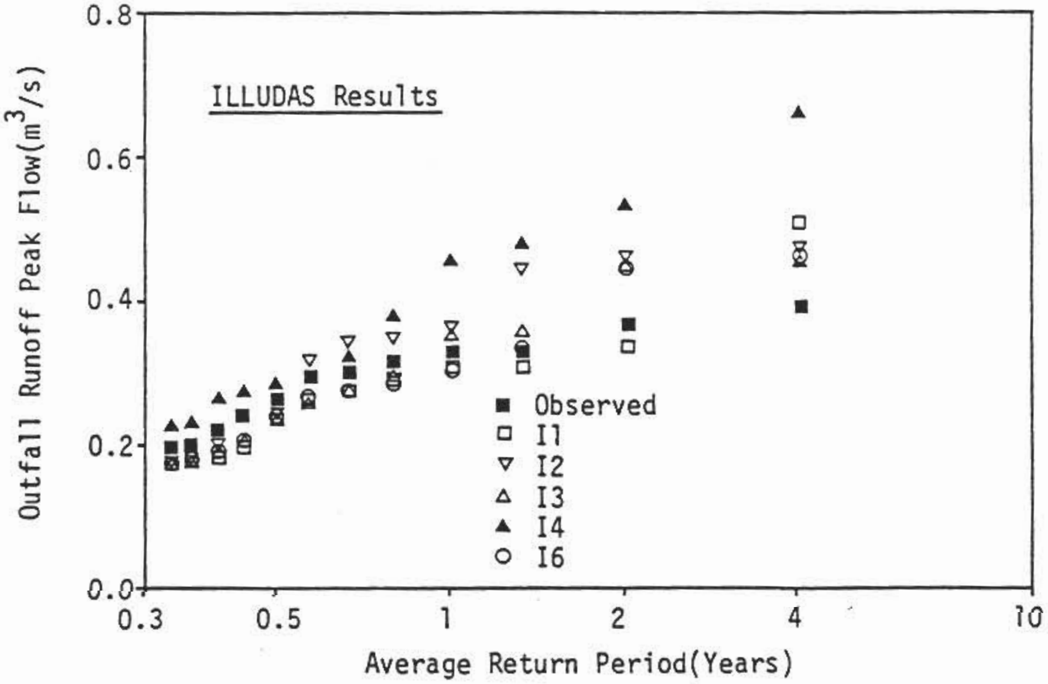


Figure 3.6 RUNOFF PEAK FLOW FREQUENCY CURVES: OBSERVED AND SIMULATED

3.2.9 Stormwater Quality

The composition of stormwater discharging from the Newtown drainage outfall was monitored by collecting samples at the outfall and analyzing them for 25 parameters. Although the ultimate goal of these investigations was to model stormwater quality, this could not be done at this time because of the lack of necessary supporting data.

Results of the sample analyses are summarized in the following series of tables giving the basic statistics of such data sets - means, standard deviations and ranges.

3.2.9.1 Physical Parameters

A summary of the results of physical parameter analyses performed on stormwater samples is given in Table 3.9. The readings of water colour, in Hazen units, varied from less than 5 to 40, with most readings between 5 and 20, and the mean value was 13.3.

The number of readings of water temperature, in-situ, was relatively limited (33 in total). Such readings are affected by the season and have no particular significance with regard to water quality in the studied case.

Dissolved oxygen values were relatively high, varying from 7.2 to 12.0 mg/L, with a mean value of 10.0 mg/L.

Table 3.9 **SUMMARY OF PHYSICAL PARAMETER DATA**

Parameter	# of Samples	Mean	Standard Deviation	Range
Water colour (Hazen units)	123	13.3	7.3	<5 - 40
Water temperature (°C)	33	7.3	3.2	0.6 - 12.5
Dissolved oxygen (mg/L)	19	10.0	1.6	7.2 - 12.6
pH (field)	32	6.6	0.22	6.2 - 7.0
pH (laboratory)	199	6.12	0.72	3.2 - 7.4
Specific conductance, laboratory (μS/cm)	172	283.3	415	19 - 3600
Specific conductance, field (μS/cm)	33	279.9	455	70 - 2070
Turbidity (JTU)	183	22.2	19.7	0.4 - 125
Total Suspended Solids (non-filterable residue, 105°C, mg/L)	207	52.4	57.7	2 - 366

Two types of pH readings were taken - in the field and in the laboratory. The former readings indicated slightly acidic to neutral conditions (pH 6.2 - 7.0) and were well within values reported for insular Newfoundland.

Two sets of data on specific conductance were produced - laboratory and in situ readings. The means of both data sets were about 280 μS/cm, with the range from 19 to 360 μS/cm.

Suspended particles in stormwater were quantified by means of two parameters - turbidity and total suspended solids. The former parameter is less commonly used for stormwater, it is more frequently used for natural waters. Turbidity of stormwater varied from 0.4 to 125 JTU, with a mean value of 22.2 JTU.

Total suspended solids (at 105°C) varied from 2 to 366 mg/L, with a mean value of 52.4 mg/L.

3.2.9.2 Major Ions

Among major ions, eight parameters were studied - dissolved chloride, sodium, sulphate, potassium, calcium and magnesium, reactive silica, and alkalinity. Characteristic values of major ions in the Newtown catchment stormwater are summarized in Table 3.10.

Among major ions, chloride and sodium occurred in the highest concentrations. The mean concentrations of sodium and chloride were 76 mg/L and 139 mg/L, respectively. Both calcium and sulphate concentrations correlated quite well with sodium chloride concentrations. The remaining major ions occurred in fairly low concentrations as can be seen in Table 3.10.

3.2.9.3 Metals

The stormwater samples collected during this study were analyzed for extractable metals only. In such analyses, the samples were acidified and the measured concentrations reflect not only dissolved metals but also metals which were originally absorbed on the particulate matter and not readily available to the aquatic biota.

Table 3.10 **SUMMARY OF MAJOR ION DATA**

Parameter	# of Samples	Mean	Standard Deviation	Range
Dissolved chloride (mg/L)	76	138.9	208.7	10.3 - 1180
Dissolved sodium (mg/L)	99	76.2	121.7	7.6 - 690
Dissolved sulphate (mg/L)	56	16.1	13.2	6.8 - 83.0
Dissolved potassium (mg/L)	100	1.5	0.74	0.6 - 2.5
Dissolved calcium (mg/L)	74	9.6	5.3	4.5 - 35.0
Dissolved magnesium (mg/L)	73	1.7	0.8	0.4 - 4.5
Reactive silica (mg/L)	101	3.6	2.1	1.0 - 8.4
Total alkalinity	97	11.1	3.5	3.6 - 18.1
Gran alkalinity (mg/L)	85	6.6	2.9	0.2 - 17.8

Concentrations of five extractable metals in stormwater are summarized in Table 3.11. From the water quality point of view, the observed concentrations of iron and manganese are of no special concern. Copper concentrations were found to be rather low with a mean value of 0.008 mg/L. Lead had a mean concentration of 0.044 mg/L. Zinc, which had a mean concentration of 0.130 mg/L, was found in concentrations (0.05 mg/L - 0.53 mg/L) typical for urban runoff.

Table 3.11 SUMMARY OF SELECTED EXTRACTABLE METAL DATA

Parameter	# of Samples	Mean	Standard Deviation	Range
Iron (mg/L)	135	0.95	1.20	0.03 - 5.20
Manganese (mg/L)	134	0.26	0.25	0.09 - 1.90
Copper (mg/L)	120	0.008	0.009	0.002 - 0.050
Lead (mg/L)	167	0.044	0.066	0.002 - 0.330
Zinc (mg/L)	187	0.130	0.060	0.05 - 0.53

3.2.9.4 Nutrients

Six forms of nutrients were studied - dissolved nitrites and nitrates (as N), total nitrogen, dissolved phosphorus, total phosphorus, dissolved organic carbon and dissolved inorganic carbon. Nutrient data are summarized in Table 3.12.

The mean concentration of dissolved nitrites and nitrates was 1.30 mg/L. The mean value of total nitrogen was found to be 1.14 mg/L. The mean concentrations of dissolved and total phosphorus were 0.011 and 0.087 mg/L, respectively. For Newtown stormwater, dissolved organic carbon had a mean concentration of 2.10 mg/L. Finally, the mean concentration of dissolved inorganic carbon was 3.20 mg/L.

Table 3.12 SUMMARY OF NUTRIENT DATA

Parameter	# of Samples	Mean	Standard Deviation	Range
NO_3/NO_2 as Nitrogen (mg/L)	78	1.30	0.75	0.25 - 4.00
Total nitrogen	132	1.14	0.74	0.25 - 4.60
Dissolved phosphorus (mg/L)	26	0.011	0.013	0.001 - 0.051
Total phosphorus (mg/L)	56	0.087	0.122	0.013 - 0.600
Dissolved organic carbon (mg/L)	122	2.10	1.26	0.8 - 9.9
Dissolved inorganic carbon (mg/L)	45	3.20	1.36	1.0 - 8.8

3.2.9.5 Bacteria

Two types of bacteriological counts were done for Newtown stormwater samples - total coliforms and fecal coliforms. These organisms are used as pathogenic bacterial indicators. The Newtown bacteria counts are summarized in Table 3.13 together with data from several other urban catchments in Ontario (Ref. 15). Total coliform densities (MPN/100 ml) in the Newtown stormwater varied from 6.4×10^2 to 7.6×10^4, with the geometric mean of 6.2×10^3. The fecal coliform densities varied from 0.9×10^2 to 4.5×10^4, with the geometric mean of 1.1×10^3. Compared to other urban runoff data, the coliform densities in the Newtown stormwater are not excessive and, as such, represent the lower end of the range of densities reported elsewhere (Ref. 15).

Table 3.13 BACTERIA COUNTS IN STORMWATER FROM VARIOUS URBAN TEST CATCHMENTS

Stormwater Origin	Total Coliform (MPN/100 mL)[1]		Fecal Coliform (MPN/100 mL)	
	Range	Geometric Mean	Range	Geometric Mean
Newtown (Mount Pearl), NF	6.4 x 10^2 - 7.6 x 10^4	6.0 x 10^3	0.9 x 10^2 - 4.5 x 10^4	1.1 x 10^3
Aldershot (Burlington), ON[2]	1.9 x 10^4 - 1.8 x 10^7	1.5 x 10^5	5.2 x 10^2 - 5.1 x 10^4	7.4 x 10^4
Barrington (Toronto), ON[2]	3.0 x 10^3 - 1.19 x 10^6	9.6 x 10^4	2.2 x 10^2 - 5.6 x 10^5	1.5 x 10^4
Brucewood (Toronto), ON[2]	2.8 x 10^3 - 3.5 x 10^4	1.1 x 10^4	1.0 x 10^3 - 1.9 x 10^4	3.9 x 10^3
Malvern (Burlington), ON[2]	1.4 x 10^3 - 5.6 x 10^6	1.5 x 10^4	1.0 x 10^2 - 3.3 x 10^5	3.6 x 10^3

[1] Bacteria count expressed as the most probable number of bacteria per 100 mL of sampled water

[2] After Ref. 15

3.3 Urbanizing Watershed Study

3.3.1 General

The Waterford River Basin is only partly urbanized and has areas with varying degrees of development within its boundary. It was, therefore, considered necessary to study the hydrologic responses of smaller sub-basins with varying degrees of urbanization and their effects on downstream hydrographs. In order to provide an indication of any significant change in the response of the Waterford River Basin to snowmelt and/or storm rainfall, two hydrologic models were calibrated in the basin. The Hydrologic Model (HYMO), a single event deterministic hydrologic model, simulated the short term response of the watershed to individual storm events. The HSPF model, a large continuous and deterministic simulation model, was also applied.

3.3.2 Application of HYMO

Objectives

The principal objectives of the watershed modelling work using the HYMO model (Ref. 3-10) were:

1. *To determine if urbanization in the Waterford River Basin above the hydrometric station at Kilbride has significantly affected peak flows in the Waterford River.*

2. *To provide an indication of the potential increases in peak flow which can be expected as a result of future urbanization, and*

3. *To provide estimates of the 20 and 100 year recurrence interval peak discharges for use in the flooding component of the Waterford River Basin Urban Hydrology Study.*

It was hoped at the onset of this study that the various influences of specific land uses (e.g. commercial, residential, forest, agriculture) on streamflows could be discerned through the use of the nested streamflow gauges on the Waterford River at Donovans, Mount Pearl, and Kilbride. The drainage areas to these gauges are 11.4, 16.6, and 52.8 km^2, respectively.

Model Application

Application of the model proceeded in seven stages.

1. *review of historical streamflow data*
2. *selection of storm events to be modelled*
3. *calibration of model at three sites*
4. *verification of model at three sites*
5. *determination of 20 year return period and 100 year return period storms*
6. *modelling of design storms*
7. *using the calibrated model to estimate effects of further urbanization in the basin.*

Analysis of Historical Data

Peak instantaneous and daily discharges at the Kilbride hydrometric station for the period 1974 to 1982 were analyzed to determine if any effect of urbanization could be discerned. No definite trend was evident. No trend was found for low flows either.

Basin Discretization

The HYMO model requires discretization of the area into sub-basins, or hydrologic units, where rainfall is transformed into runoff and then routed through the watershed reaches.

The basin was discretized into 16 hydrologic units with a minimum size of about 2.6 km^2 each in order to make use of the maximum resolution offered by HYMO. The discretization of the study area into sub-basins, or hydrologic units, was established through examination and interpretation of available 1:1,250 and 1:2,500 scale contour maps together with air photo interpretation and some field checking. The sub-basin boundaries were transferred to a 1:12,500 scale base map and the drainage area, channel length (where applicable) and elevation changes were measured for each hydrologic unit (HU).

A schematic showing the model configuration adopted for the study is shown in Figure 3.7.

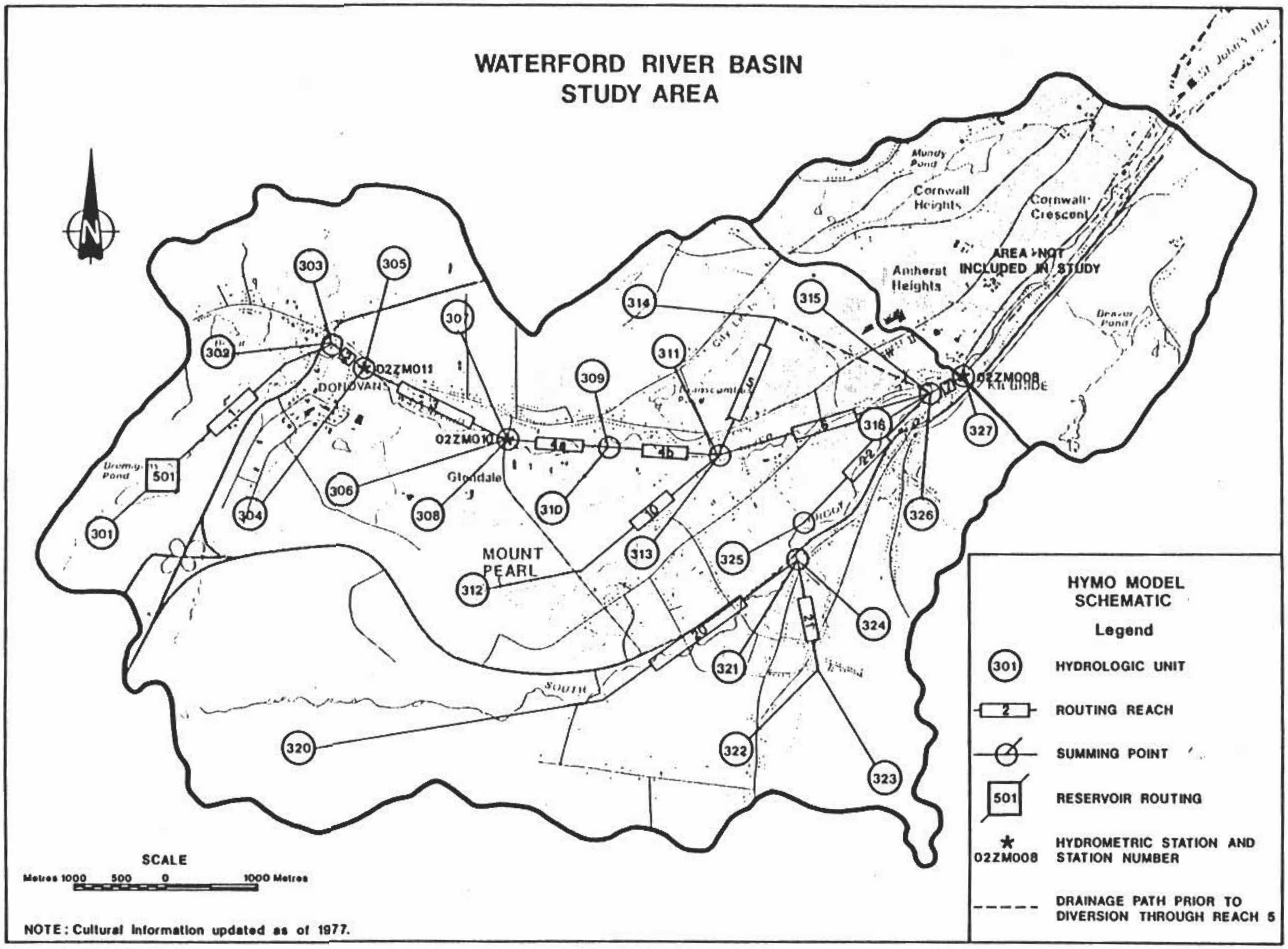


Figure 3.7 HYMO BASIN DISCRETIZATION SCHEME

In order to simulate the response of a specific watershed to a rainfall event using HYMO, three major hydrologic input parameters are required. One parameter is a runoff index factor known as the hydrologic soil cover complex number (CN), which is a function of many factors including land use, soil characteristics and antecedent moisture conditions. Two unit hygrograph parameters called the time to peak (t_p) and the recession constant (k), are also required. For their estimation, the HYMO program provides empirical equations based on the slope of the basin and its length to width ratio.

Precipitation and Streamflow Data

Precipitation and streamflow data were required for a number of rainfall events in order to calibrate and verify the model. Precipitation data had been collected since 1954 on a daily basis at the Agriculture Canada (CDA) Experimental Farm in St. John's West. During the course of the study, the Newfoundland Department of Environment installed six standard raingauges in the study area and the Atmospheric Environment Service, Environment Canada, added a recording tipping-bucket gauge to the St. John's West CDA site. Longterm (22 years) precipitation data were also available from St. John's Airport. The network was designed to provide continuous hyetographs coupled with the spatial variation in depth of rain over the basin.

In this study, standard raingauge data were "*corrected*" for possible undercatch compared to the CDA standard raingauge.

The Water Survey of Canada has operated a hydrometric station on the Waterford River at Kilbride since 1974. In 1981, two additional hydrometric stations were established in order to assess the effects of urbanization on the hydrologic regime of the sub-basins with different degrees and types of land uses. One of these is located at Mount Pearl, downstream of the Commonwealth Road Bridge (drainage area of 16.6 km^2). The other station, which has a drainage area of 11.4 km^2, is located downstream of the bridge entering the property of Newfoundland Fibreply near Donovans Industrial Park. Figure 2.1 shows the location of the three hydrometric stations.

The basic input data, required for the Variable Storage Coefficient (VSC) method of flood routing in HYMO, consists of valley cross sections, channel and floodplain slopes and the estimates of Manning's coefficient of roughness for the channel and bank. A total of 28 valley cross sections were determined from existing contour maps and field surveys and Manning's "*n*" values estimated in the range of 0.015-0.100 for the bank and 0.025-0.06 for the channel. The HYMO program computes rating curves based on the cross sections and Manning's "*n*" values.

The VSC method computes the outflow for each reach as a function of the inflow, the outflow at the previous time step and some storage coefficients dependent on the travel time through the reach as well as the computational time interval selected. The travel time can be computed as a function of reach length, velocity, slope, and depth, as well as inflow and outflow from equations. For this study, twelve routing reaches were used.

Model Calibration and Verification

The three hydrologic inputs parameters, soil cover complex number (CN), time to peak (t_p), and recession constant (k) were estimated for all the sub-basins. HYMO was calibrated and verified at the three hydrometric station sites based on rainfall and discharge data collected for the largest available event, which occurred during mid to late 1981. The model was calibrated for two antecedent moisture conditions (SCS: AMC I and AMC III) because no significant event corresponding to AMC II was available. For each antecedent moisture condition, three events were used for calibration, while one event was reserved for verification. It was noted that both k and t_p parameter values were high in comparison with those often encountered in studies elsewhere.

The best calibration results were obtained when the values of the model parameters k and t_p for each hydrologic unit (HU) were respectively set at 8 and 7 times that computed by the Version-1 equations (slope < 2%). In addition, the CN for each HU had to be increased by 10% over those calculated from land use statistics.

Calibrations were described as "*good*" for Kilbride, "*fair*" for Mount Pearl, and "*poor*" for Donovans. Flows were underpredicted at Mount Pearl and Donovans, despite the very high values of CN and adjustments to precipitation. This would seem to indicate an overall water balance problem caused by a need for better spatial resolution of rainfall (given the elevation differences in the basin), or underestimation of discharge at the streamflow gauging stations at Mount Pearl and Donovans.

Sensitivity Analysis

A sensitivity analysis of the calibrated watershed model was conducted to determine the sensitivity of simulated peak flows to changes in calibration parameters as well as rainfall and streamflow data. Results indicated that peak flows were not significantly affected by 10% changes in k, t_p, and Manning's *'n'*; but were sensitive to rainfall and CN. In particular a variation of 10% in CN caused a 40% variation in peak discharge. By assigning values near the upper limit to the CN parameter in the modelling, it can be seen that CN variation was the primary method used to calibrate the measured high basin yields.

3.3.3 HYMO Simulation of Urbanization Effects on Peak Flows

In order to assess the historic impact of urbanization on peak flows in the Waterford River Basin, two events which produced high flows in 1974 were simulated using the calibrated models based on 1981 land use conditions. The peak flow at Kilbride for August 28, 1974 was underestimated by 21% and time to peak was two hours late. For the event of September 18, 1974, the peak at Kilbride was overestimated by 10% while the time to peak was one hour early.

No comparison was made for Donovans and Mount Pearl since hydrometric stations were not operational at these sites in 1974.

3.3.4 HYMO Estimation of Peak Flows for Flooding Study

In the absence of adequate historical streamflow data for this basin, HYMO was used to generate the 1 in 20 year and 1:100 year peak flows, based on selected design storms, as input to HEC-2 model. For this purpose, precipitation data at St. John's airport were used to define the magnitude in terms of volume, time distribution and duration of the event using the standard statistical techniques. Design storms were then constructed using AES criteria (Ref. 10) for temporal distribution of rainfall. The amount of rainfall during a 6-hour duration storm for the 20 year return period was 78 mm. For the 100 year return period, the volume of rainfall was 94.4 mm for a duration of 12 hours.

The calibrated HYMO model was used to simulate peak flows for 1:20 year and 1:100 year return periods based on the design storms. It was based on the assumption that the T-year storm event will produce the T-year recurrence flood flow. This may not always be the case. The simulation was based on AMC III conditions. The results are shown in Table 3.14.

Table 3.14 **HYMO ESTIMATES OF PEAK FLOWS**

Station	Peak Flow (m^3/sec)	
	1:20 year	1:100 year
Kilbride	64.6	74.7
Mount Pearl	19.9	25.5
Donovans	11.5	14.7

3.3.5 HYMO Simulation of Future Urbanization Scenarios

During calibration, the average value of CN for AMC III was determined to be 95. In order to reflect new development in the watershed, the average value of CN would have to be increased so that the new value would be in the 95 to 100 range. Such a small increase in CN did not justify the examination of detailed development scenarios; however, projections of land use were made as the basis of land use changes from the period 1974 to 1981. It was estimated that the average value of CN in 1981 would be 97. The results of simulations of peak flows based on a CN of 97 are shown in Table 3.15.

Table 3.15 SUMMARY OF PEAK FLOWS FOR FUTURE DEVELOPMENT SCENARIOS USING HYMO

Return Period (years)	Peak Flow (m^3/s) (baseflow included)					
	Donovans		Mount Pearl		Kilbride	
	1981	1991	1981	1991	1981	1991
20	11.5	14.1	19.5	23.6	64.6	74.8
100	14.7	17.7	25.3	29.5	81.5	93.3

3.3.6 Application of HSPF

Continuous simulation is required to properly model such phenomena as low flows, seasonal variations in streamflow, effects of antecedent conditions on streamflow generation and water quality. To investigate these phenomena and meet the study objectives, it was recommended to simulate streamflow in the Waterford River Basin by means of the

Hydrologic Simulation Program - Fortran (HSPF) model distributed by the U.S. Environmental Protection Agency (U.S. EPA, 1980). The selection of this model was based on a literature survey of operational models available when formulating the modelling component plans (Ref. 12).

The actual modelling work (Ref. 3-12) was to be done by the Inland Waters Directorate (IWD), Atlantic Region. Because of other commitments, IWD could not undertake the HSPF modelling task and it was necessary to change the initially planned course of action. Having the choice of either cancelling this task or conducting it at a considerably reduced level of effort, the Technical Committee opted for the latter alternative and requested the National Water Research Institute (NWRI) to conduct the HSPF modelling task with considerably reduced objectives. In particular, such work was to be limited to streamflow quantity only, with emphasis on high flows and had to rely on the data base prepared by the IWD, Atlantic Region and the Newfoundland Department of Environment. It was felt that even with reduced objectives, listed below, this continuous modelling task would be useful and would demonstrate the feasibility of applying a complex and comprehensive model, like HSPF, to the Waterford River Basin.

Objectives

The newly defined objectives of this study task were:

1. *Simulate streamflow in the Waterford River by means of the HSPF model for the existing conditions, and*

2. *Simulate streamflow in the Waterford River for projected future land use reflecting continuing urbanization of the basin.*

In comparison to the initial objectives, the modelling of water quality, which would have required collection of additional supporting data, was excluded. It appears in retrospect that some aspects of the reduced task objectives could have been accomplished by means of simpler models, but without the benefit of having the water quantity components of the HSPF set up for possible future applications in the study area.

Calibration and Verification Procedures

The HSPF model was used in conjunction with the 37-month data base prepared for the Waterford River Basin by IWD, Atlantic Region, and Environment Newfoundland. As reported in the original task report (ref. 9-12), 29 months of data, which represented the maximum amount of data that could be stored by the computer used, were used to calibrate the model. The remaining eight months of data were used subsequently for verification.

The HSPF model is essentially a lumped model requiring calibration for successful application. In particular, calibration is required to estimate input parameter values that cannot be measured directly, which is the case of most of the HSPF parameters listed in Table 3.16, and it lends confidence to the modelling results.

Before starting calibration, it is required to establish goodness of fit criteria. Once these criteria are fulfilled, further calibration would be unproductive. Such criteria should reflect not only the study objectives, but also the accuracy of input and calibration data. In this connection, it should be recognized that, at best, streamflow discharges area measured with accuracies in the range from 5 to 15%. The upper values and even greater inaccuracies are encountered at gauging stations with shifting controls, as was the case in this study. Consequently, it would not be realistic to expect any model to reproduce the observed discharges with significantly better accuracies that 15 to 20%.

Calibration of the HSPF model comprised the estimation of the initial values of all HSPF parameters, and calibration of annual flows, seasonal/monthly flows, snowmelt parameters, and storm hydrographs. The values of the calibrated parameters and the initial values are listed in Table 3.16 and Table 3.17 respectively.

3.3.7 HSPF Simulation Results

The simulated annual streamflow volumes reproduced the observed ones within 1%. This was achieved by calibration of the evapotranspiration algorithms for the basin. The final adjustment employed the MFACT correction factor equal to 0.7. This was necessitated primarily by the catchment climatic and geologic conditions leading to very low evapotranspiration.

The monthly streamflows were reproduced, on the average, within ±15% of the observed ones as shown in Table 3.18 and Fig. 3.8.

Table 3.16 SUMMARY OF CALIBRATED HSPF PARAMETERS

Parameter	Range of Values Used In Calibration Runs	Final Calibrated Values
Meteorological Inputs		
Evaporation MFACT	0.04-1.0	0.70
General Hydrology		
LZSN	0.21-120	30.
INFILT	0.0025-120	0.5
AGWRC	0.001-1.0	0.98
UZSN	0.250-40	10.0
IRC	0.01-.5	0.5
INTFW	0.0-200	7.0
LZETP	0.0-1.00	0.01
FOREST	0.34-0.40	0.34
DEEPFR	0.0-0.20	0.0
SURSB	0.025	0.025
UZSB	0.025	0.025
IFWSB	0.025	0.025
UZS	2.0-35	35.
LZS	5.0-62	62.
CEPS	0.11-2	2.0
SURS	0.7-15	15.0
IFWS	0.0	0.0
AGWS	0.025-0.09	0.09
GWVS	0.025	0.025
TSNOW	0.0-2.0	0.0
SNOEVP	0.10	0.1
CCFACT	0.15-1.0	0.2
MWATER	0.01-1.0	0.01
MGMELT	0.15-5.0	1.5
COVIND	25-200	25.

Table 3.17 INITIAL WATER STORAGES USED IN HSPF SIMULATIONS

Initial Water Storage (mm)	Land Segment			
	PERLND1	PERLND2	IMPLD1	REMARK
UZS	35	35	-	
LZS	62	62	-	
CEPS	2	2	-	
SURS	15	15	-	
IFWS	0.0	0.0	-	DEFAULT
AHWS	0.09	0.09	-	
GWVS	0.025	0.025	-	
RETS	-	-	0.025	
SURS	-	-	0.025	DEFAULT

Table 3.18 OBSERVED PRECIPITATION AND STREAMFLOW, AND SIMULATED STREAMFLOW -- HSPF

		Mean Hourly Streamflow(mm/hr)											
Year	**Quantity**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1981	Precipitation	0.261	0.142	0.223	0.106	0.082	0.160	0.187	0.143	0.270	0.368	0.304	0.163
	Observed streamflow R_o	0.212	0.182	0.223	0.183	0.071	0.091	0.106	0.057	0.137	0.341	0.304	0.129
	Simulated streamflow R_s	0.185	0.164	0.212	0.164	0.055	0.094	0.113	0.061	0.156	0.316	0.293	0.127
	$(R_s-R_o)/R_o$	-12.7	-9.9	-4.9	-10.4	-22.5	3.3	6.6	7.0	13.9	-7.3	-3.6	-1.6
1982	Precipitation	0.337	0.245	0.150	0.131	0.218	0.250	0.074	0.145	0.274	0.208	0.151	0.187
	Observed streamflow R_o	0.104	0.119	0.212	0.293	0.246	0.131	0.066	0.042	0.182	0.217	0.071	0.207
	Simulated streamflow R_s	0.162	0.127	0.247	0.311	0.211	0.160	0.054	0.064	0.206	0.178	0.118	0.197
	$(R_s-R_o)/R_o$	55.8	6.7	16.5	6.1	-14.2	22.1	-18.2	54.4	13.2	-18.0	66.2	-4.8
1983	Precipitation	0.205	0.148	0.265	0.190	0.111							
	Observed streamflow R_o	0.183	0.088	0.334	0.195	0.082							
	Simulated streamflow R_s	0.196	0.109	0.295	0.192	0.080							
	$(R_s-R_o)/R_o$	7.1	23.9	-11.7	-1.5	-2.4							

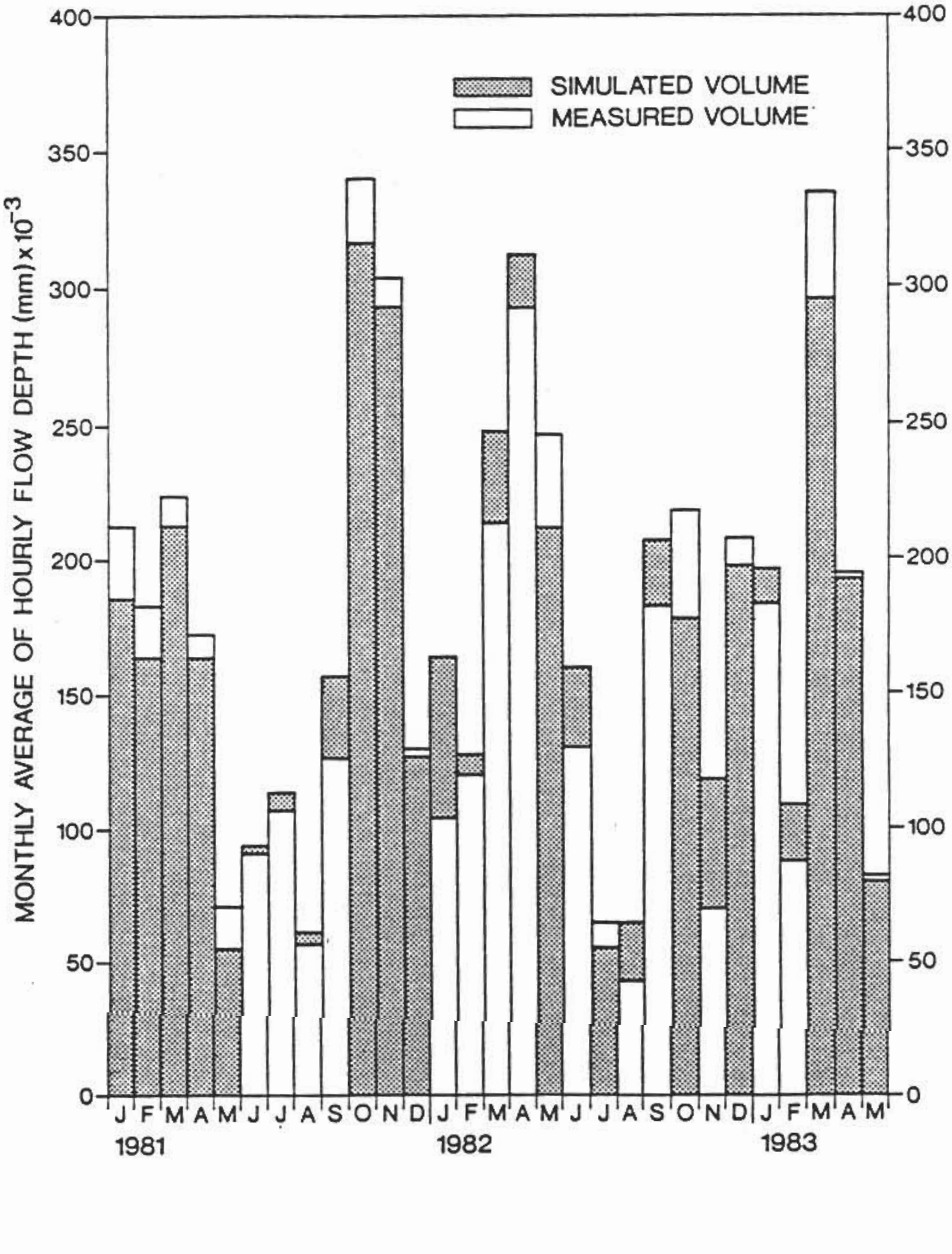


Figure 3.8 SIMULATED AND OBSERVED MONTHLY STREAMFLOW VOLUMES USING HSPF

In the calibration of storm hydrographs, the emphasis was placed on high flows, though the reproduction of low flows was also evaluated. The final calibration of hydrographs was primarily accomplished with the INTFW and IRC parameters as recommended in the HSPF manual (U.S. EPA, 1980). Hydraulic calibration of hydrographs with RCHRES parameters was not possible because of the lack of detailed cross-sectional data. This restriction was not significant considering the geometry and capacity of the Waterford River channel. The observed peak flows were reproduced, on the average, within ±20% for individual events for flows above 10 m^3/s. The results of comparison of simulated and observed peak flows, greater than 10 m^3/s, are shown in Table 3.19. For the 29 events listed, a very good match of observed and simulated peaks was achieved.

The low flows were somewhat underestimated in the initial simulations. The average simulated minimum hourly flows during individual months were smaller that those observed by 0.25 m^3/s. In subsequent runs, it was possible to reduce this difference to 0.1 m^3/s, but the mean absolute value of deviations for individual events was still about 0.3 m^3/s. Considering the eventual use of these modelling results in water management, the above underestimations are insignificant.

The degree of agreement between the simulated and observed hourly streamflows can be observed in Fig. 3.9 which shows the full 29 month records of simulated and observed streamflows.

Table 3.19 COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPH PEAKS USING HSPF

Event No.	Date (D/M/Y)	Q_{obs} (m^3/s)	Q_{sim} (m^3/s)	$(Q_{sim}-Q_{obs})/Q_{obs}$ (%)
1	15/03/81	12.7	13.5	6.3
2	18/03/81	17.1	17.5	2.3
3	09/07/81	13.5	14.4	6.7
4	25/09/81	12.4	12.4	0.0
5	05/10/81	10.1	8.5	-15.8
6	10/10/81	39.7	33.0	-16.9
7	12/10/81	34.1	26.6	-22.0
8	17/10/81	29.5	21.9	-25.8
9	08/11/81	27.6	28.8	2.5
10	26/11/81	62.1	62.5	0.6
11	08/03/82	31.8	21.8	-31.4
12	27/03/82	11.0	12.6	14.5
13	22/04/82	16.6	10.6	-36.1
14	13/05/82	34.0	27.0	-20.6
15	14/05/82	16.9	15.0	-11.2
16	21/06/82	37.0	50.4	36.2
17	01/07/82	12.0	10.7	-10.8
18	19/09/82	43.0	57.9	34.7
19	24/09/82	18.6	19.4	4.3
20	03/10/82	22.9	29.4	28.4
21	04/10/82	53.2	29.5	-45.0
22	30/11/82	10.7	11.6	8.4
23	07/01/82	15.8	16.0	1.3
24	15/01/83	12.9	8.9	-31.0
25	03/03/83	19.3	33.1	71.5
26	13/03/83	15.3	10.3	-32.7
27	15/03/83	10.7	6.8	-36.4
28	26/03/83	15.0	10.7	-28.7
29	20/04/84	11.9	11.2	-5.9
MEAN		23.0	21.8	5.2

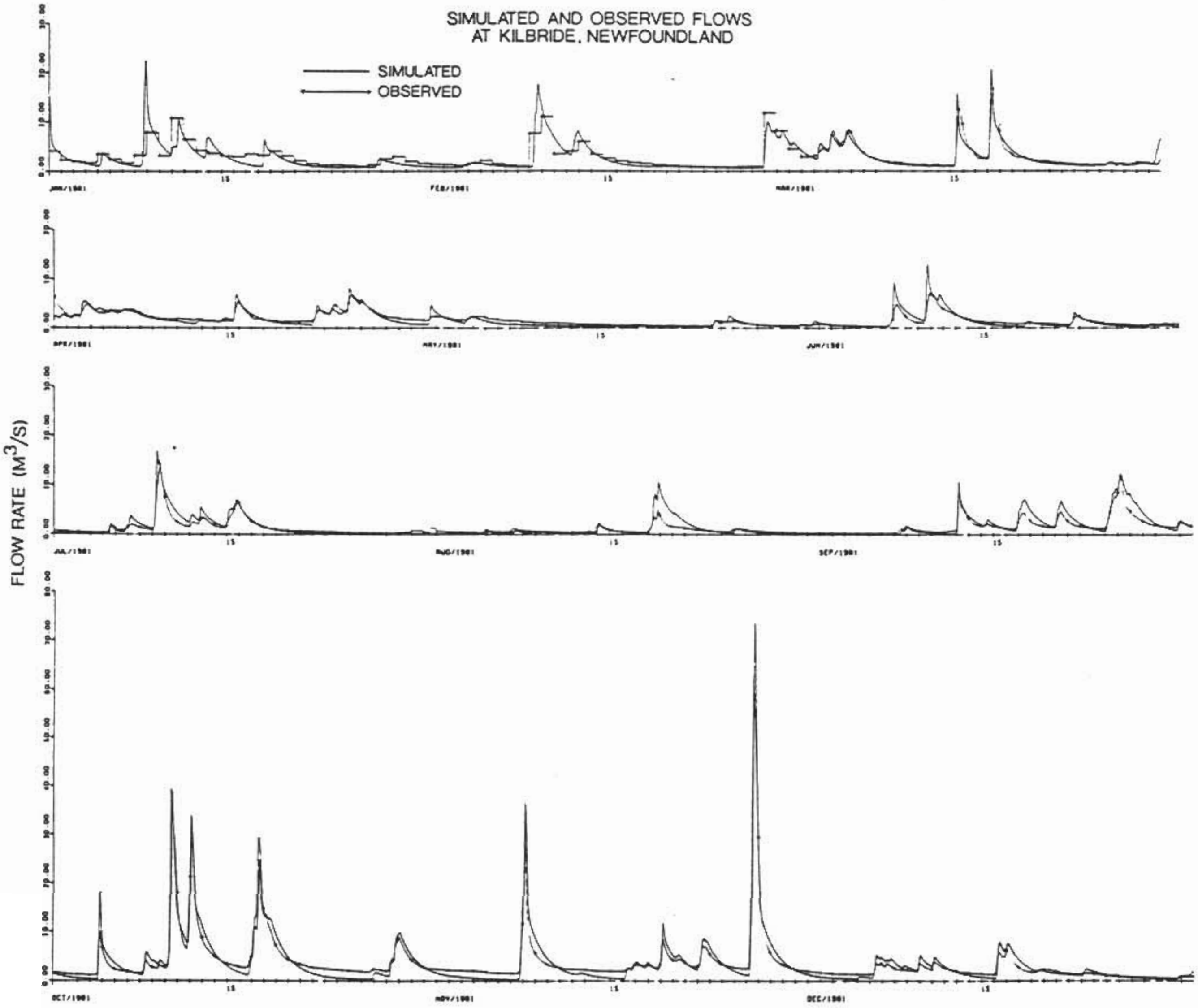


Figure 3.9 SIMULATED AND OBSERVED FLOW RECORDS AT KILBRIDE USING HSPF

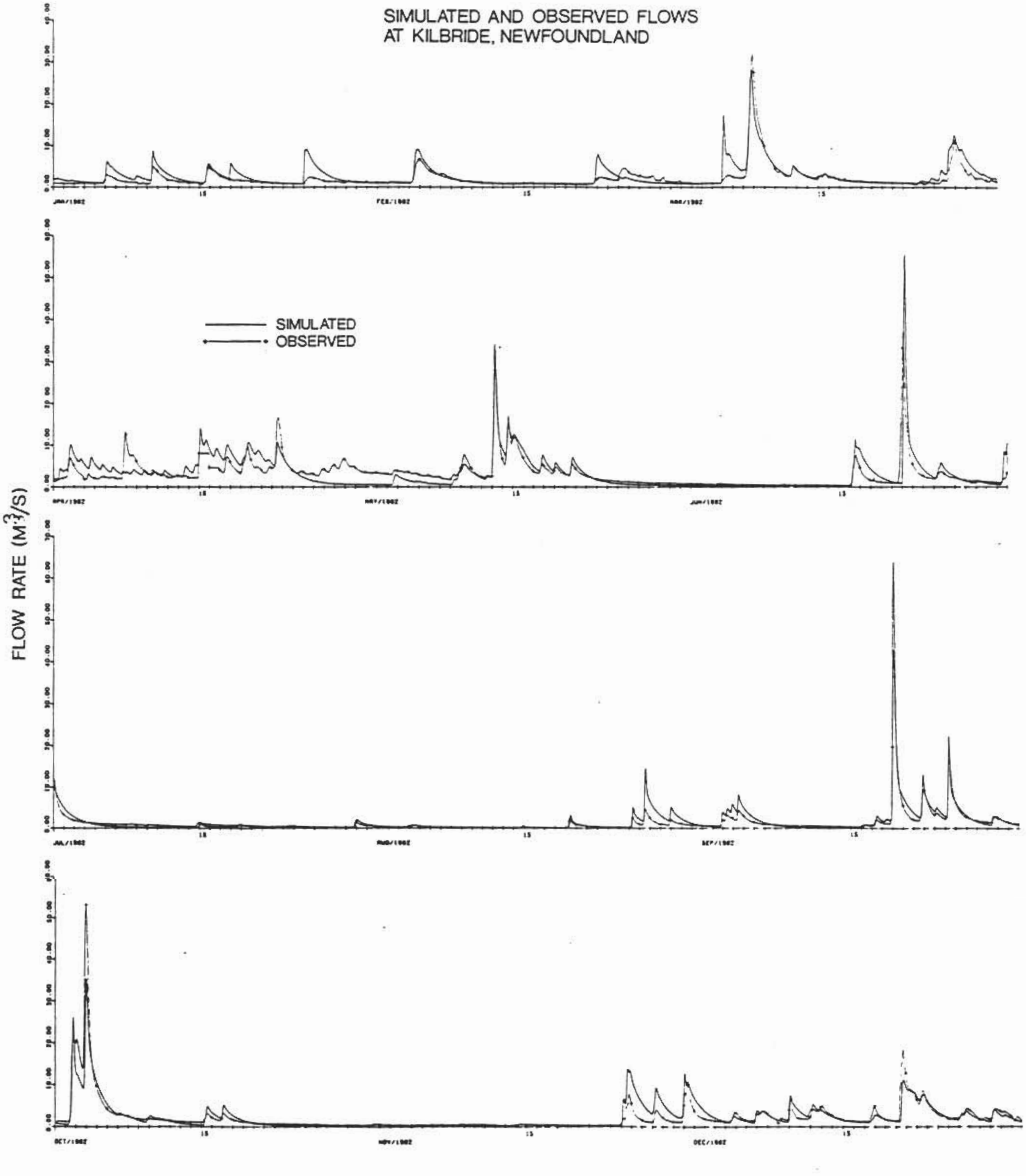


Figure 3.9 CONTINUATION (a)

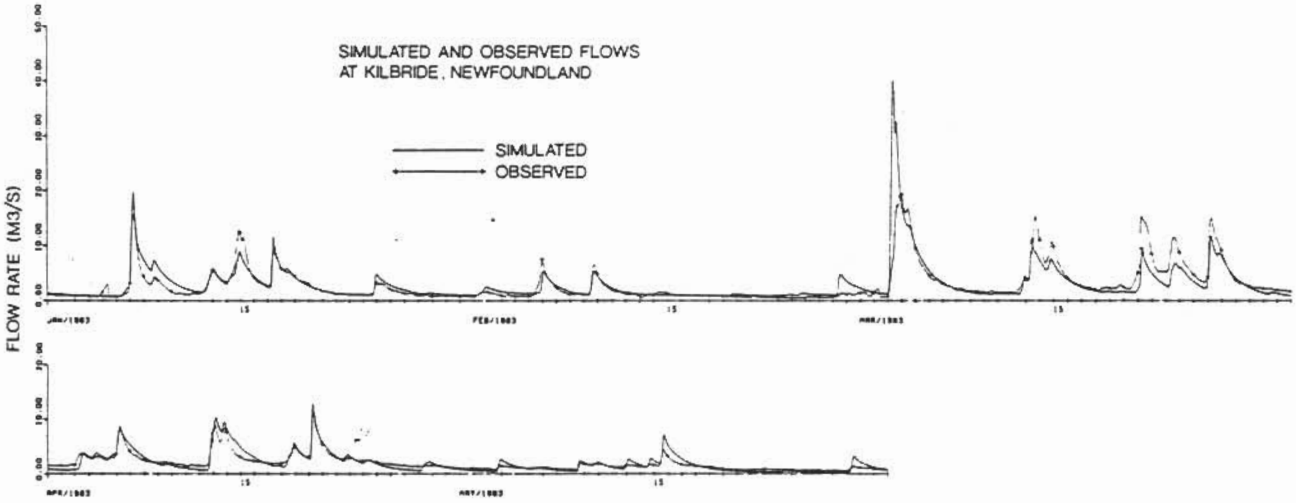


Figure 3.9 CONTINUATION (b)

The verification results, obtained for the remaining eight months of data, produced an agreement between the simulated and observed results comparable to that obtained in calibration.

3.3.8 Application of HSPF to Future Urbanization Scenarios

Following calibration, the HSPF model was used to simulate streamflows for future land use scenarios corresponding to increases in impervious areas by 50, 100 and 200 percent and referred to as scenarios F1, F2 and F3, respectively.

The annual and monthly streamflows simulated for the future scenarios are presented in Table 3.20. It can be inferred from this table that any future development in the study area will barely affect streamflow volumes. By tripling the current (1984) impervious area, the annual streamflow increases by only 1%. This follows from the fact that under the existing conditions, more than 80% of precipitation is converted into streamflow. This percentage is unusually high and leaves little room for further increases resulting from expanding impervious areas.

The simulation results for peak flows, given in Table 3.21, show more sensitivity to progressing development of the basin than volumes. For scenario F3, the peak flows increased by 20 to 25%. In evaluation of the effects of future development on low flows, a decline of low flows by 10% was noted for scenario F3. Such a reduction, though quantitatively insignificant, logically follows from reduced infiltration in the future land use scenario with a greater basin imperviousness.

Table 3.20 MONTHLY STREAMFLOW SIMULATED FOR VARIOUS LAND USE SCENARIOS USING HSPF

Mean Hourly Streamflow (mm/hr)														
Year	Land Use Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1981	E	0.185	0.164	0.212	0.164	0.055	0.094	0.113	0.061	0.156	0.316	0.293	0.127	1416
	F1	0.187	0.165	0.212	0.164	0.054	0.094	0.114	0.061	0.156	0.316	0.293	0.127	1418
	F2	0.186	0.166	0.212	0.164	0.054	0.094	0.115	0.063	0.159	0.316	0.293	0.127	1423
	F3	0.186	0.168	0.212	0.164	0.054	0.097	0.117	0.066	0.162	0.312	0.294	0.127	1430
1982	E	0.162	0.127	0.247	0.311	0.211	0.160	0.054	0.064	0.206	0.178	0.118	0.197	1486
	F1	0.162	0.126	0.247	0.310	0.210	0.160	0.054	0.065	0.206	0.178	0.118	0.197	1486
	F2	0.162	0.127	0.249	0.310	0.211	0.162	0.054	0.066	0.208	0.179	0.120	0.,196	1492
	F3	0.163	0.127	0.251	0.308	0.210	0.164	0.054	0.069	0.209	0.179	0.122	0.196	1498
1983	E	0.196	0.109	0.295	0.192	0.080								
	F1	0.196	0.109	0.295	0.192	0.079								
	F2	0.196	0.109	0.295	0.192	0.079								
	F3	0.196	0.109	0.295	0.192	0.079								

E - Existing
F1 - 50% more impervious cover than existing
F2 - 100% more impervious cover than existing
F3 - 200% more impervious cover than existing

Table 3.21 PEAK FLOWS SIMULATED FOR VARIOUS LAND USE SCENARIOS

Event No.	Q_p (m^3/s)			
	E	F1	F2	F3
1	13.5	13.8	17.6	19.5
2	17.5	17.8	23.0	25.3
3	14.4	15.0	19.5	22.1
4	12.4	12.3	13.2	14.0
5	8.5	8.4	11.4	12.5
6	33.0	33.1	42.1	45.2
7	26.6	26.5	34.3	36.4
8	21.9	22.0	27.0	29.2
9	28.3	28.4	39.0	41.4
10	62.5	61.0	76.9	80.2
11	21.8	21.8	29.9	31.8
12	12.6	12.4	13.3	14.1
13	10.6	10.6	11.6	12.4
14	27.0	27.2	35.9	38.6
15	15.0	14.9	16.7	17.9
16	50.4	49.6	58.7	62.3
17	10.4	10.9	11.7	12.7
18	57.9	57.1	68.9	73.9
19	19.4	19.7	24.2	26.3
20	29.4	29.2	29.2	32.1
21	29.5	30.2	37.8	40.0
22	11.6	12.1	14.6	16.3
23	16.0	16.4	22.0	24.2
24	8.9	8.8	9.6	10.3
25	33.1	32.9	42.4	45.2
26	10.3	10.6	12.9	14.1
27	6.8	6.4	6.7	8.4
28	10.7	11.1	13.5	14.9
29	11.2	11.6	14.4	15.8
MEAN	21.8	21.8	26.8	28.9

3.3.9 Flood Study Using HEC-2

Purpose

The primary purpose of this study (Ref. 3-11) was to determine 1:20 and 1:100 year return period open water flood profiles in selected areas along the Waterford River and plot them on existing topographic maps to determine the extent of flood prone areas. The study also assessed the suitability of various types of remedial measures for reducing flood damage. The reaches at Donovans, Mount Pearl, and Kilbride, which are shown on Figure 3.10, were chosen for the study because they were known to be flood-prone.

Methodology

The methodology adopted for this study is outlined as follows:

1. ***Review:*** *This consisted of a review of available information including existing data, previous reports and a site reconnaissance survey.*

2. ***Field Program:*** *A field program was designed to collect the relevant hydraulic and physical data required to develop the HEC-2 hydraulic computer model (Ref. 13). This included the collection of representative channel cross-sections and the measurement of water surface profiles and flows at selected points for model calibration/ verification.*

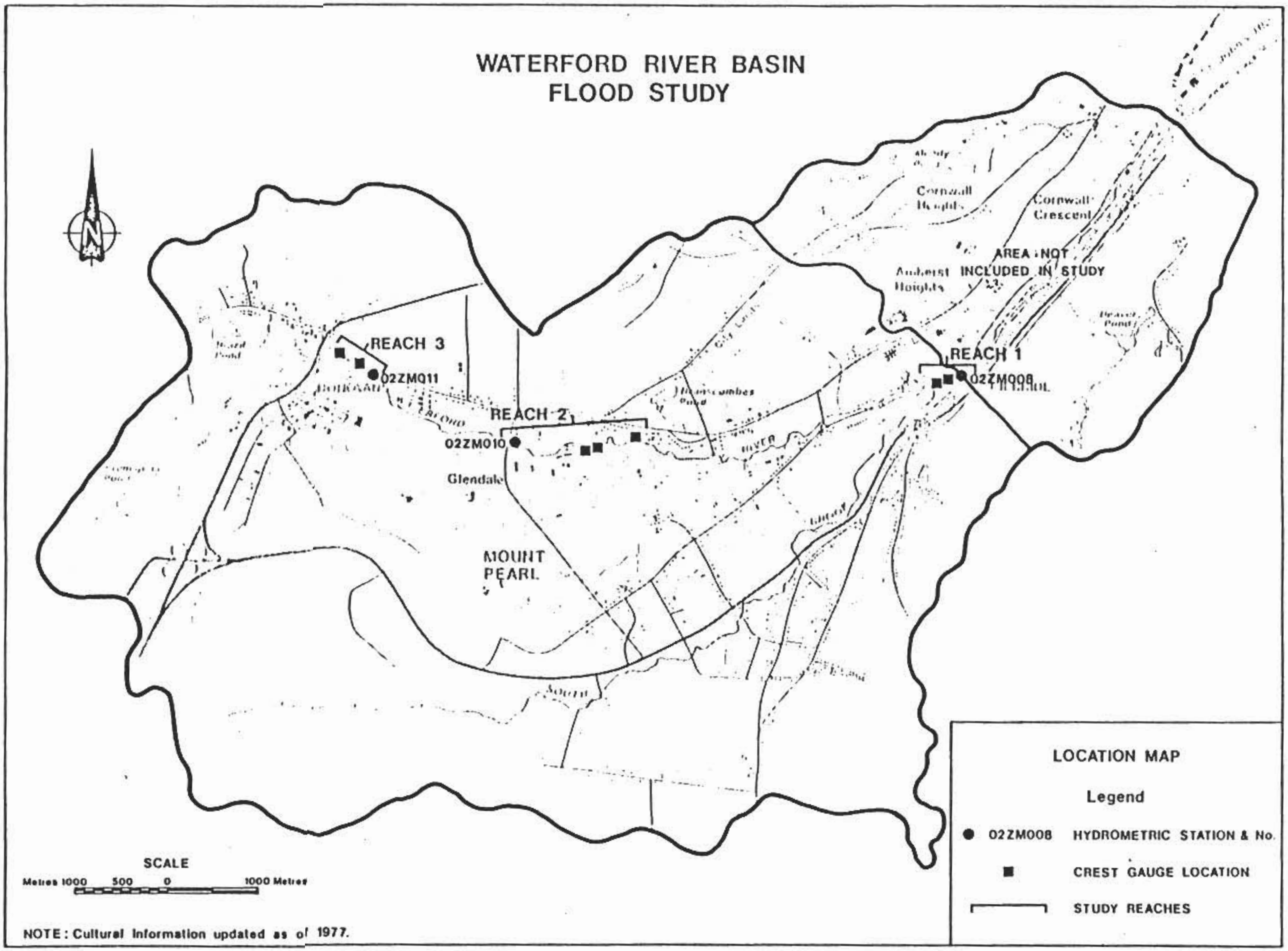


Figure 3.10 STUDY REACHES IN THE WATERFORD RIVER BASIN

3. ***Hydrology:*** *The 1:20 and 1:100 return period design flows as obtained by the HYMO model were used in this study.*

4. ***Hydraulics:*** *This portion of the study consisted of calibrating the HEC-2 model using the information gathered in steps 1 and 2. A sensitivity analysis was undertaken to determine the possible model error associated with individual parameter variance. The calibrated model then used the design floods developed in Step 3 to compute the flood profile. In establishing the model, a total of 49 cross sections, obtained from the three reaches, were used.*

5. ***Floodline Plotting:*** *Using the cross-sectional information and the derived flood profiles, the areal extent of flooding was plotted on existing topographical maps.*

6. ***Remedial Measures:*** *Suitable remedial measures were identified for the flood risk areas delineated on the maps. No attempt was made to recommend a particular remedial measure.*

Procedures for floodplain delineation established for the *Flood Damage Reduction Program* (Ref. 11) were used as basic guidelines for modelling.

Calibration and Verification

Two events (1982-83) were used for each of the Kilbride and Mount Pearl reaches, and three events were used for Donovans reach for calibration of the model. For verification of the model, two events were used at Kilbride, but because crest gauges had not been installed, only one event was used at Mount Pearl and none was modelled at Donovans. A trial and error procedure was used whereby Manning's *'n'* values, assigned to various sub-reaches, were gradually varied in a series of runs of the HEC-2 model until the simulated water surface profile adequately compared with the observed data.

Subsequent to calibration and verification, sensitivity analysis was carried out using the standard procedure to assess the sensitivity of the model to various physical factors used in the model. The factors considered for this analysis included elevation of the channel bottom, peak flow, downstream water level, Manning's *'n'* and contraction and expansion coefficients.

The calibrated model was then utilized to establish the flood profiles associated with the peak 1:20 and 1:100 year return period flows as determined with the HYMO model. From an interpretation of the design flood profiles, the areal extent of the 1:20 and 1:100 year return period floods was determined and are presented on large scale maps in Ref. 3-11.

When this study was initiated, it was expected that there would be considerable urbanization of the basin within the 5 year study period. This would possibly have provided the opportunity to examine the effect of urbanization on flood flows and flooding and to develop a flood management strategy. The anticipated development did not occur. However, it was assumed that further urbanization of the basin might increase peak flows by 30%. Thus, the model was run with an assumed increase of 30% to the design flood flows to determine the extent of increases in flooding.

3.4 Water Quality Study

3.4.1 Objectives

This study (Ref. 3-4) consisted of selecting eight water quality sampling stations downstream of various land use areas, collecting samples on a monthly basis and after significant precipitation events, and analyzing the samples for variables of interest to determine any temporal or spatial changes in water quality as a result of urbanization. That information and technology could then be used for water resource management, development of environmental protection guidelines, and transfer to agencies responsible for municipal planning and services in the Province. An additional objective was personnel training.

3.4.2 Methodology

Selection of Water Sampling Stations

The selection of water sampling sites for a time series must meet criteria such as accessibility, thorough mixing and stability of stream bed. For a combined area variability study, the sites must be located on the stream at sites downstream of the types of land use of interest. For this study the sites, shown on Fig. 3.11, were selected to represent the land use areas detailed in Table 3.22. A history of previous use was available for each of the land areas and the sites were designed to intercept runoff from any future urbanization activities.

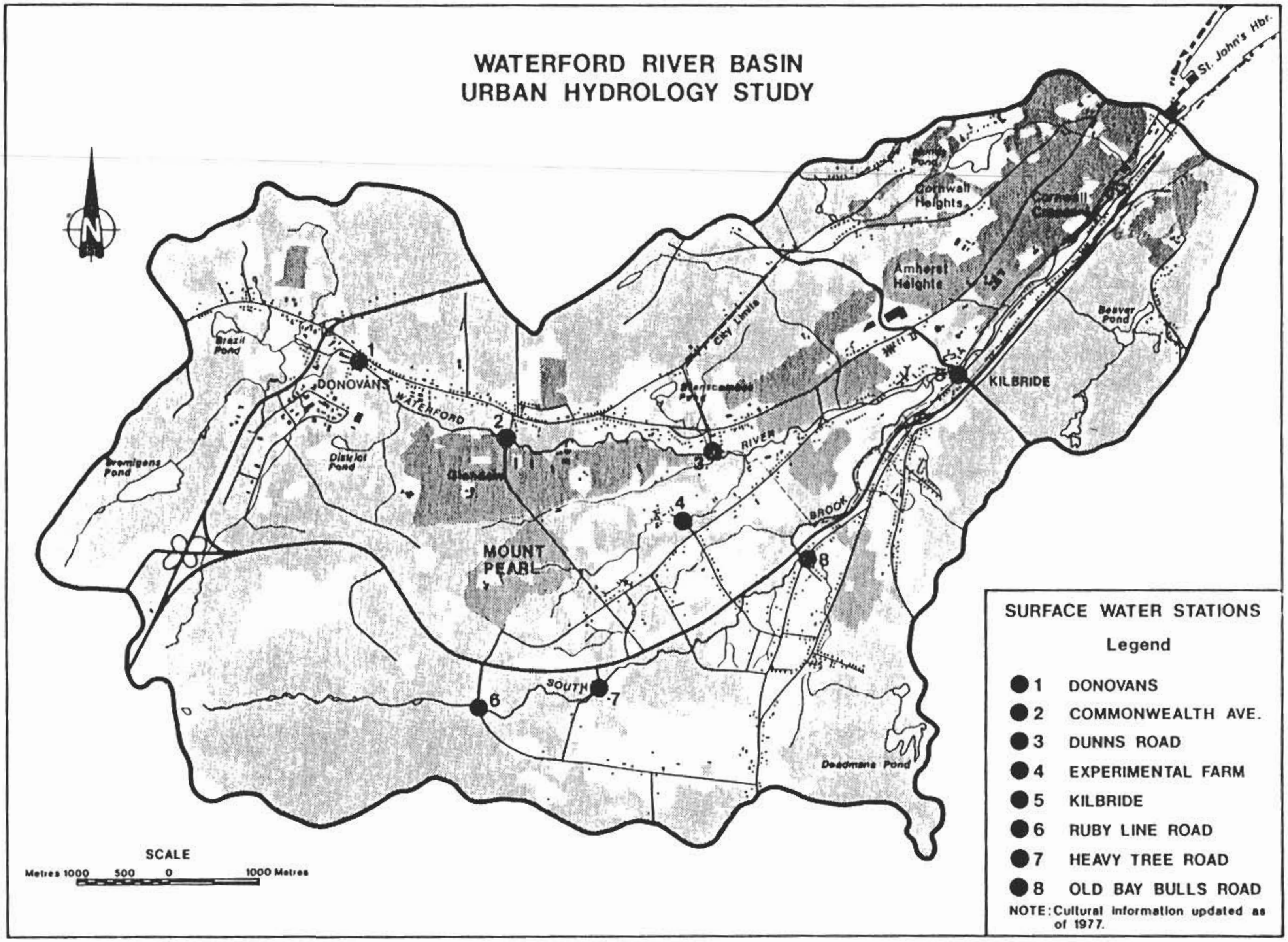


FIGURE 3.11 SURFACE WATER QUALITY SAMPLING STATIONS

Table 3.22 GEOGRAPHICAL INFORMATION
SURFACE WATER QUALITY STATIONS

Station No.	Description	Drainage Area (km^2)	Land Use
02ZM0009 #5	Waterford River at Kilbride	52.70	All uses
02ZM0008 #8	Tributary of South Brook at bridge on Old Bay Bulls Road	6.01	Suburban/ Agriculture
02ZM0007 #7	South Brook at Heavy Tree Road	7.40	Forest
02ZM0006 #4	Unnamed tributary at Agriculture Canada Farm (CDA)	3.16	Residential/ Agricultural
02ZM0004 #2	Waterford River at Commonwealth Avenue Bridge	16.60	Residential/ Commercial
02ZM0003 #1	Waterford River at Donovans (near the Industrial Park)	11.40	Light Industries
02ZM0012 #3	Waterford River at bridge on Dunns Road	21.10	Residential/ Commercial
02ZM0001 #6	South Brook at culvert on Ruby Line	5.41	Forest

Instrumentation and Data Collection

Each of the water quality stations was equipped with a flow measuring device; the most downstream site had a recording gauge while the other sites had staff gauges which were read at the time of sampling. In addition, the most downstream site had an automatic sampler which was triggered by stage height to sample every half hour for up to 40 samples.

The sample collection schedule had three levels of definition. Firstly, all stations were sampled monthly for physical, chemical and bacteriological parameters. Secondly, event samples were collected from the eight stations any time the predicted rainfall exceeded 15 mm. Thirdly, the automatic sampler at Kilbride sampled every half hour anytime the stage height was above 1.8 m (1.7 m during low flow periods). This sampling scheme provided data for interpretation on an annual, a seasonal and an event basis for water draining each of the different land uses. Data were collected by Newfoundland Department of Environment personnel.

The samples were analyzed for the water quality variables listed in Table 3.23 by the Government of Newfoundland and Labrador (bacteriological) and Environment Canada (physical) laboratories in St. John's, and by the Environment Canada (chemical) laboratory in Moncton. The data were entered in a minicomputer in Moncton and forwarded to Environment Canada's water quality data bank (NAQUADAT) in Ottawa for subsequent use by the participating agencies. Interpretation of the trends in water quality variables was facilitated by the RS/1 statistical package on the minicomputer in Moncton.

Table 3.23 LISTING OF SURFACE WATER QUALITY PARAMETERS

PARAMETERS	UNITS
Colour apparent -- A. COLOUR	Rel. Units
Specific conductance -- SP. COND.	uS/cm
Water Temperature -- H20 TEMP.	Deg. Cel.
Turbidity -- TURB.	J.T.U.
Total organic carbon -- T.O.C.	mg/L
Dissolved organic carbon -- D.O.C.	mg/L
Nitrite-nitrate -- NO2-NO3	mg/L as N
Nitrogen total -- N TOT.	mg/L
Oxygen dissolved -- DISS. O2	mg/L
Alkalinity total -- ALK. TOT.	mg/L as $CaCO_3$
pH	
Residue nonfilterable -- RES. N.F.	mg/L
Sodium dissolved -- Na DISS.	mg/L
Magnesium dissolved -- Mg DISS.	mg/L
Silica reactive -- SiO2	
Phosphorus total -- P TOT.	mg/L
Sulphate dissolved -- SO4 DISS.	mg/L
Chloride dissolved -- Cl DISS.	mg/L
Potassium dissolved -- K DISS.	mg/L
Calcium dissolved -- Ca DISS.	mg/L
Manganese extractable -- Mn EXT.	mg/L
Iron extractable -- Fe EXT.	mg/L
Alkalinity Gran -- ALK. GRAN	mg/L as $CaCO_3$
Copper extractable -- Cu EXT.	mg/L
Zinc extractable -- Zn EXT.	mg/L
Lead extractable -- Pb EXT.	mg/L
Total Coliforms -- TOT. COL.	/100 mL
Feçal Coliforms -- FEC. COL.	/100 mL
Instantaneous discharge	m^3/s

3.4.3 Results

A summary of the results of surface water quality analyses at the eight sampling stations is given Table 3.24. A synopsis of the ranges of the physical, chemical and bacteriological parameters is presented in the following sections.

3.4.3.1 Physical Parameters

The range of apparent water colour at all stations, except Donovans, varied between 5 and 70 Hazen units. At Donovans, the maximum observed value was 50 H.U.. There were no major differences observed in apparent water colour between the sampling sites located in the Waterford River Basin. The two stations on South Brook generally had higher apparent colour and higher dissolved organic carbon concentrations than the stations on the mainstem. This was possibly due to influences of the marshy headwaters.

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.

Dissolved oxygen generally ranged from 8 to 15 mg/l, with percent saturation usually over 90. The observed values reflect the quality of the river water as it tumbles over a series of small falls. 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.

Table 3.24 SUMMARY OF SURFACE WATER QUALITY RESULTS

	STATION																										
	02ZM0003			02ZM0004			02ZM0012			02ZM0006			02ZM0001			02ZM0007			02ZM0008			02ZM0009			02ZM0009 ***		
STATS	MIN	MED	MAX	MIN	MED	MAX	MIN	MED	MAX	MIN	MED	MAX	MIN	MED	MAX	MIN	MED	MAX	MIN	MED	MAX	MIN	MED	MAX	MIN	MED	MAX
PRMT.																											
pH	5.5	6.3	6.9	5.8	6.5	8.9	5.8	6.6	7.4	5.9	6.7	7.7	4.8	5.6	6.5	5.1	6.1	7.0	5.8	6.6	7.6	5.8	6.8	7.7	3.9	6.4	7.8
SO4 DISS.	4.5	6.4	10.0	4.5	6.6	14.5	4.8	6.7	11.2	5.4	7.8	11.8	2.1	2.8	5.0	2.2	3.2	5.2	2.8	4.0	13.1	4.5	6.7	29.5	4.5	7.3	18.2
ALK. TOT.	0.6	5.8	10.8	1.6	5.2	10.1	2.0	5.6	11.3	2.7	8.8	17.0	0.5	0.7	15.1	0.5	2.4	9.4	0.5	7.3	16.5	1.5	7.4	15.2	1.1	5.2	16.9
ALK. GRAN	-1.3	3.8	7.2	2.1	3.2	6.9	2.2	2.6	6.9	4.8	5.4	10.3	-0.1	0.4	2.4	0.4	0.6	2.2	2.4	3.2	7.5	4.2	4.7	9.3	-8.7	6.0	9.0
Na DISS.	6.0	19.5	58.0	5.3	19.0	102.0	6.1	21.0	130.0	4.8	18.9	76.0	2.2	4.4	10.7	3.5	7.2	15.0	3.9	10.0	120.0	8.1	20.0	210.0	5.3	18.3	114.0
Cl DISS.	7.0	35.0	100.0	6.4	32.5	170.0	7.8	37.5	178.0	6.2	32.5	130.0	4.4	7.0	27.0	4.8	11.8	33.0	5.6	17.0	170.0	12.5	36.0	350.0	7.0	31.0	180.0
Mg DISS.	0.52	1.20	1.90	0.20	1.20	1.80	0.65	1.20	1.90	0.30	1.50	2.70	0.20	0.60	2.10	0.39	0.80	2.10	0.40	1.20	2.00	0.17	1.36	2.30	0.70	1.10	1.90
K DISS.	0.4	0.7	2.3	0.4	0.7	1.1	0.5	0.7	1.2	0.4	0.8	1.4	0.1	0.3	2.5	0.1	0.4	1.2	0.4	0.8	1.7	0.5	0.9	1.6	0.6	1.0	3.2
Ca DISS.	1.90	4.80	7.80	1.90	4.60	9.40	2.10	5.00	7.50	2.10	7.00	11.00	0.42	0.90	6.35	0.72	1.80	6.60	1.70	3.50	7.70	2.80	5.80	17.00	2.00	4.60	9.00
SP. COND.	73	139	360	59	140	600	63	144	630	79	163	380	27	36	104	32	58	194	56	82	345	69	147	1100	61	120	657
A. COLOUR	5	20	50	5	20	70	5	15	70	5	15	70	5	20	70	5	20	70	10	30	70	5	20	70	5	20	70
TURB.	0.8	4.7	280.0	0.6	4.8	520.6	0.6	4.6	400.0	0.4	4.4	285.0	0.3	1.0	6.0	0.3	1.3	32.0	0.6	4.0	50.0	0.7	10.0	128.0	3.0	15.0	150.0
RES. N.F.	0.0	6.8	400.0	0.0	9.0	744.0	0.0	7.0	490.0	0.0	4.0	328.0	0.0	2.0	26.0	0.0	1.0	324.0	0.0	6.0	100.0	0.0	10.0	165.0	1.0	22.0	444.0
SIO2	1.7	4.0	6.1	0.1	3.9	6.2	0.1	3.8	6.0	0.1	4.4	6.9	0.3	3.3	6.1	0.1	3.4	5.7	0.1	3.0	6.3	0.1	3.8	6.2	2.0	3.3	6.1
D.O.C.	1.4	3.3	9.3	1.4	2.7	7.1	1.2	3.0	6.6	1.1	2.6	5.6	1.4	4.4	13.0	1.3	3.4	14.0	2.0	4.2	11.0	1.2	3.1	7.2	1.2	3.6	9.8
T.O.C.	3.5	6.5	31.5	2.5	6.5	65.0	3.0	6.5	49.0	2.5	6.4	85.0	2.5	7.1	15.4	3.0	7.5	15.0	4.0	9.5	20.0	2.5	7.0	22.5			
NO2-NO3	0.01	0.22	0.76	0.01	0.24	0.59	0.01	0.27	0.73	0.01	0.38	0.60	0.01	0.02	1.10	0.01	0.04	0.63	0.01	0.25	0.67	0.01	0.40	0.90	0.10	0.40	1.70
N TOT.	0.17	0.46	1.80	0.21	0.45	1.00	0.20	0.48	0.95	0.29	0.56	1.10	0.05	0.20	1.40	0.10	0.20	0.72	0.20	0.60	2.20	0.31	0.65	1.30	0.03	0.52	1.80
P TOT.	0.008	0.048	0.470	0.006	0.040	1.700	0.007	0.034	0.850	0.003	0.023	0.700	0.001	0.010	0.230	0.001	0.011	1.300	0.008	0.048	0.650	0.008	0.048	0.300	0.020	0.060	1.650
Fe EXT.	0.18	0.68	2.80	0.18	0.54	3.80	0.17	0.52	6.70	0.12	0.29	1.80	0.10	0.31	2.50	0.10	0.26	1.50	0.17	0.43	1.60	0.15	0.44	3.90	0.22	0.84	8.40
Mn EXT.	0.01	0.37	0.80	0.11	0.31	1.50	0.10	0.33	1.10	0.06	0.30	0.81	0.05	0.09	0.95	0.05	0.12	0.52	0.07	0.18	0.65	0.01	0.18	1.30	0.01	0.22	2.00
Cu EXT.	0.002	0.002	0.008	0.002	0.002	0.008	0.002	0.002	0.011	0.002	0.002	0.006	0.002	0.002	0.002	0.002	0.002	0.007	0.002	0.002	0.011	0.002	0.002	0.008			
Pb EXT.	0.002	0.002	0.019	0.002	0.002	0.020	0.002	0.002	0.038	0.002	0.002	0.014	0.002	0.002	0.005	0.002	0.002	0.003	0.002	0.002	0.015	0.002	0.002	0.037	0.002	0.015	0.300
Zn EXT.	0.01	0.02	0.07	0.01	0.02	0.07	0.01	0.03	0.10	0.01	0.03	0.08	0.00	0.01	0.01	0.01	0.01	0.03	0.01	0.02	0.04	0.01	0.03	0.10			
H2O TEMP.	0.0	6.9	18.0	0.0	7.0	18.5	0.0	6.7	18.5	0.0	7.8	19.1	0.0	7.5	19.3	0.0	7.2	20.0	0.0	8.2	21.6	0.0	7.4	19.8			
DISS. O2	6.8	11.0	14.4	8.8	11.1	14.8	8.8	11.0	15.6	8.7	11.0	14.8	8.3	10.8	14.7	8.6	11.0	14.6	8.6	10.6	15.6	8.8	10.5	16.8			
TOT. COL.	520	5300	560000	1300	4200	32000	200	3000	60000	200	1200	8600	0	120	5600	0	60	8600	80	12500	72000	1600	5800	110000			
FEC. COL.	30	700	22000	100	700	5000	50	600	10000	10	325	4400	0	10	1100	0	10	5200	60	4150	26000	200	2000	48000			

The parameters with their abbreviations and units are listed in Table 3.22.

The station numbers and their names are listed in Table 3.21.

*** Rain events monitoring data.

MIN : Minimum; MED : Median; MAX : Maximum.

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. 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" headwaters influence. 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 reflect a carbonic acid-bicarbonate buffering system.

Specific conductance ranged from 60 to 1100 uS/cm on the mainstem during the study period. Similar values were recorded at the Agriculture Canada farm station; the highest values were measured in winter and spring when road salting was performed (a measurement of 1100 uS/cm was made on 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. 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 reflect the dissimilarity in the ionic contents between the developed and undeveloped areas.

Turbidity was observed to be higher in the Waterford River than in South Brook. The South Brook generally had turbidity values lower than 2 JTU while at the other stations turbidity varied between 1 and 500 JTU, depending on flow conditions, seasons and development activities ongoing in the basin. The higher values in the mainstem can be related to human presence and activities in the Waterford River sub-basin, unlike the undeveloped and forested upper South Brook sub-basin.

The results collected during and over individual events showed several effects. Generally speaking, the physical parameters of specific conductance, pH and turbidity all tended to initially increase after the start of an event, reach a peak and then decrease if there was a prolonged rain event. These values did not parallel the hydrograph but rather they tended to peak before the discharge peaked. The height of the concentration peak was observed to be dependent on the time which had elapsed since the previous event. It was also a function of construction activity in the basin.

3.4.3.2 Chemical Parameters

High concentrations of sodium and chloride were observed in the waters of the main Waterford River, where the developed part of the basin is situated. Two known road salt depots, Donovans industrial park, major roads (road salting), urban and suburban development along the river, and sea spray inputs are thought to contribute to the high sodium and chloride concentrations. On the South Brook sub-basin, there was no known road salt depot or 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.

The basin surface waters were observed to be very soft as the computed hardness (Ca, Mg) was less than 30 mg/l as $CaCO_3$. The Agriculture Canada farm station presented the hardest surface waters (approximately 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.

Sulphate concentrations measured in the basin ranged between 2 and 10 mg/l. The highest sulphate concentrations were generally observed in winter and spring. These high sulphate values corresponded with the higher sodium chloride concentrations. It is possible that the road salt used contained some calcium sulphate.

Potassium concentrations were fairly constant throughout the year and were in the order of 0.3 - 0.8 mg/l. A few high values were observed at relatively high flows. Correspondingly high nutrients concentrations were also observed in those samples.

Silica concentrations in the Waterford River were typically between 3 and 5 mg/l, with the extreme values being 0.1 mg/l and 6.9 mg/l. Typical Canadian surface water exhibits a silica concentration of 3 to 4 mg/l.

The Waterford River water at the three 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 0.3 mg/l. Turbidity was generally much lower in the South Brook waters which may explain the lower iron concentration.

Manganese followed the same pattern as iron, presenting higher concentration at the three upstream stations on the Waterford River at typically 0.3 mg/l compared to 0.1 mg/l at the South Brook stations.

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 on the rising hydrograph. Lead concentrations higher than 0.03 mg/l were very seldom measured in the basin surface waters during this study. The highest lead value (0.30 mg/l) was recorded at the Kilbride station on a rising hydrograph, in September 1982. The major source of lead in the basin was suspected to be leaded gasoline.

Concentrations of zinc at all sites were generally lower than 0.05 mg/l, with the South Brook waters, similar to the other studied metals, having the lowest concentrations. In some cases, levels of zinc of about 0.10 mg/l were detected in the water at Kilbride, at high flows.

Nitrite-Nitrate concentrations were usually the lowest at the Ruby Line and Heavy Tree stations having a typical range of 0.02-0.05 mg/l as N. All the other sites had values usually greater than 0.2 but less than 1 mg/l as N. The total nitrogen content of the water samples was typically 0.5 mg/l in the Waterford River waters and 0.2 mg/l in the South Brook waters. The sites which generally had the highest nitrite-nitrate and total nitrogen values were the station at the Agriculture Canada farm (pasture lands) and the Kilbride station, which receives the waters from all tributaries.

Generally the total phosphorus concentrations were higher in the Waterford River waters than those of the South Brook. The total phosphorus concentrations in the stretches of rivers located in the developed parts of the Waterford River 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. 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. The Agriculture Canada farm station had a median phosphorus value of 0.023 mg/l; the extremes were 0.003 and 0.70 mg/l.

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 flows when the suspended matter content was also high.

Results collected during and over individual events showed several effects. For the major ions, the pattern was a general increase in values with early washoff followed by dilution with base flow until the event was over and values had reached their pre-event level. Nutrients showed the same trends during summer months but were restricted to dilution during the winter months. Because trace metals tend to be associated with particulate matter in the washoff, measured values were again greatest in the early stages of the event and were diluted as the rainstorm continued to add water to the system.

3.4.3.3 Bacteriological Parameters

The results of bacteriological analyses for the Waterford River sub-basin stations are as follows. The Donovans station showed highly fluctuating levels of bacterial density with no specific seasonal variation. Total coliform counts ranged from 220 to 160,000/100 ml. Fecal coliform counts were correspondingly high and fluctuating. The range of fecal streptococcus counts was from 80 to 3200/100 ml. Fecal coliform/fecal streptococcus (FC/FS) ratio showed mostly mixed human and animal pollution. At the Commonwealth Avenue station the total and fecal coliforms density ranged from 1800 to 32,000/100 ml and 230 to 9000/100 ml respectively. The Dunns Road station had low to moderate levels of bacteria counts; total coliform ranged from 200 to 14,000/100 ml and fecal coliform from 90 to 8000/100 ml. 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 streptococcus counts were correspondingly low. High bacterial counts were generally observed at the Kilbride station. The total coliform counts ranged from 1600 to 120,000/100 ml. Fecal coliform counts were also relatively high. Fecal streptococcus counts ranged from 0 to 2740/100 ml. At all the stations mentioned, high FC/FS ratios indicated that pollution was of human and animal origins.

The results of bacteriological analyses for the South Brook sub-basin stations are as follows. 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 Old Bay Bulls station consistently had high bacterial counts. Total coliform counts ranged from 6400/100 ml to 54,000/100 ml. Fecal coliform counts ranged from less than 3000/100 ml to 26,000/100 ml. The range for fecal streptococci was from 0 to 2320/100 ml. FC/FS ratio generally indicated human fecal pollution. A poorly placed and managed local septic tank system near this site is suspected to be responsible for the heavy pollution with bacteria of human origin.

The station located at the stormwater outfall in Mount Pearl had highly fluctuating bacterial density levels. FC/FS ratios indicated pollution from both human and animal sources. This leads to assumptions that there are cross-connections between storm and sanitary sewer systems in Mount Pearl.

Bacteriological analyses were limited to the last two years of the study, but certain trends did emerge from the data. Fecal coliform values, indicators of waste from warm blooded animals, were low during winter and summer from the undeveloped area of the basin. The values were elevated in the waters draining residential, commercial and light industrial areas of the basin. Highest values were recorded in the summer months of June, July and August and lowest in mid-winter. Fecal coliform to fecal streptococcus ratios indicated that the wastes were a mixture of human and animal wastes. Sources were ascribed to cross connections between storm and sanitary sewers, and animal pastures in the agricultural areas.

3.5 Biological Study

3.5.1 Objectives

A two-year study (1984 and 1985) was conducted to determine the effects of urban development, and its associated stresses, on the benthic invertebrate community structure as an indicator of biological environment of the Waterford River Basin (Ref. 3-8). Studies done on other river systems in North America indicate a direct correlation between poor water quality and reduced invertebrate diversity.

The objectives of this study were:

1. *To examine the benthic invertebrate community structure to determine the effects of water quality on the biological characteristics of the water.*

2. *To establish a dependable method for assessing the water quality of a river system using biological indicators.*

3. *To identify communities of invertebrates which are characteristic of "clean" and "unclean" water.*

4. *To identify problem areas, in terms of water quality and pollution, in the Waterford River Basin.*

5. *To establish baseline data, which can be used to monitor environmental changes in the future.*

3.5.2 Methodology

Site Selection

For the first year of the study, eight sampling sites were selected. The locations of these sites, shown in Fig. 3.12, approximately corresponded to where surface water quality was being monitored (Fig. 3.11). Note that the station numbers in Fig. 3.11 and 3.12 are different. Four sites were located on the Waterford River: Donovans Industrial Park (Site 6), Mount Pearl (Sites 5 and 7), and about 1 km below the Waterford River's confluence with South Brook (Site 1). One site was located on an unnamed tributary of the Waterford River, just downstream of a small man-made reservoir (Site 4), which runs through the Agriculture Canada Brookfield Research Station. For the second year of the study, an additional site was added to the unnamed Waterford River tributary about 20 m upstream of the reservoir (Site 4b) and Site 4 was renamed Site 4a. Two sampling sites were located on South Brook (Sites 3 and 8), with the upstream site (Site 8) acting as the control site for the study since it is located in an undisturbed area. The last site was located on an unnamed tributary of South Brook (Site 2).

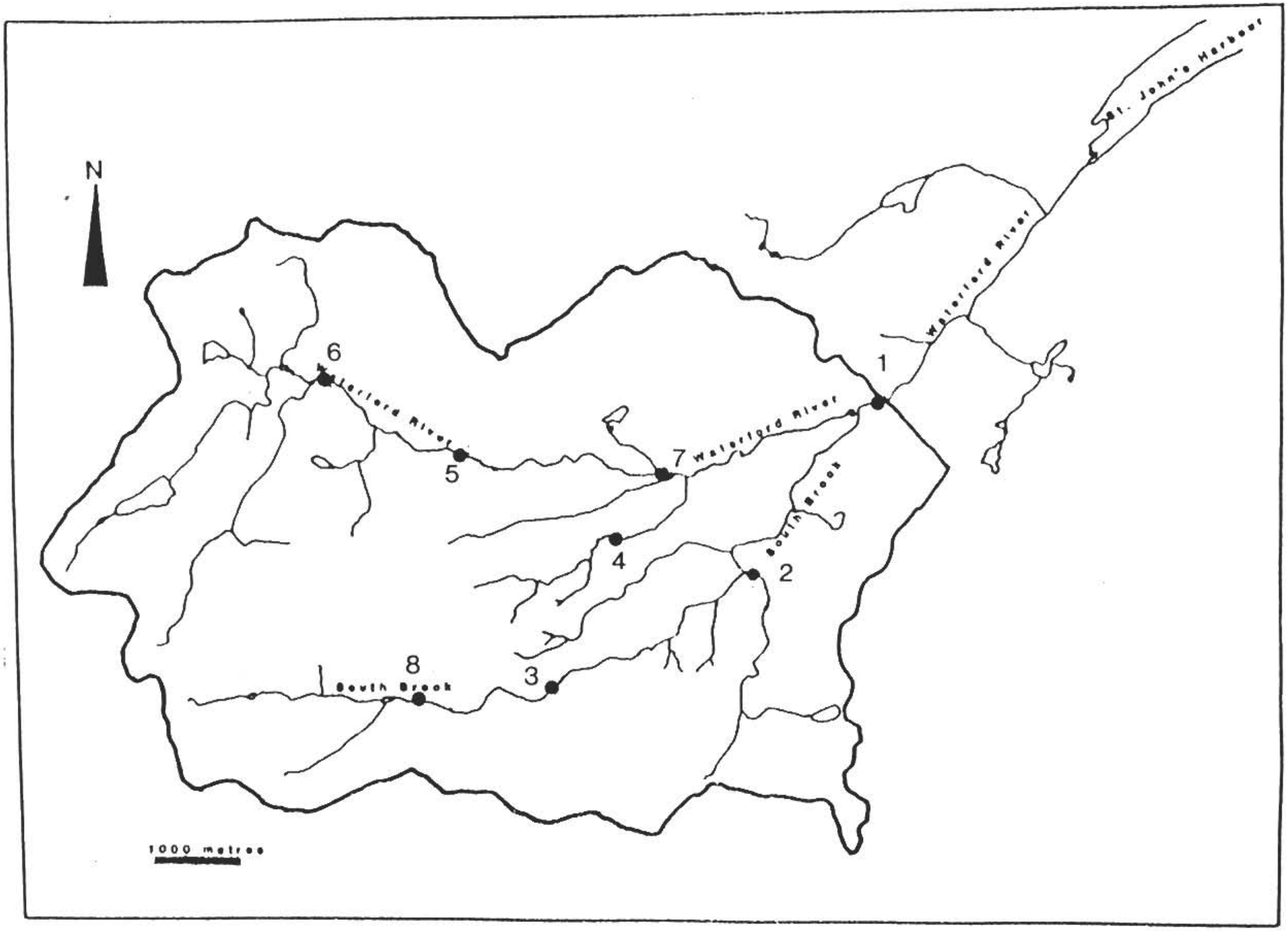


FIGURE 3.12 LOCATIONS OF THE BIOLOGICAL WATER QUALITY MONITORING SITES

Sampling Procedure

The sampling unit was an artificial substrate sampler, consisting of a bag made of 0.7 cm Vexar's nylon mesh tubing, filled with 1 kg crushed rock (1 to 3 cm in size), and tied at both ends. At least fifteen rock bags were placed in the river at each sampling site. A tether wire was firmly fastened to a tree, or a steel rod embedded in the river bank. The rock bags were attached to this wire, and placed into the river.

The bags were placed in the streams in such a way as to minimize the chances of being exposed during periods of low flow, and to maximize the potential of invertebrate colonization of each bag. In most cases they were placed in riffle areas with fast moving current.

Data Collection

The samplers were in the river for twelve months for the first year but for only four months for the second year to reduce or eliminate some problems encountered in the first year (eg., siltation of the substrates, dislodgement of substrates during spates, vandalism, etc.). Studies (Ref. 14) have shown that a four-month period is adequate for colonization by invertebrates.

In December, 1984 and again in December, 1985, the samplers were removed from the river and transported to the Environmental Protection Service (EPS) laboratory located in the Northwest Atlantic Fisheries Centre, St. John's. Here, each rock bag was individually scrubbed, the associated macroinvertebrates and debris were placed in a Mason jar, and preserved in Kahle's fluid. The contents of each jar constituted a sample for analysis. Ten samples from each site were cleaned and sorted for identification. Extra samples were preserved for later use, if necessary.

All the samples were cleaned, sorted, and analyzed at the Biology Department of Memorial University of Newfoundland (MUN). The individually preserved samples were placed in white enamel pans, and the associated benthic organisms were removed by hand, under a 2X illuminated magnifying glass. Identification of macroinvertebrates was completed by two students at the Department of Biology at MUN, and were checked by faculty members.

Analytical Procedures

The collected data was entered into computer files and analyzed with the objective of identifying *"clean water"* and *"unclean water"* communities of macroinvertebrates. The invertebrate data were examined on three levels: 1) intrasite variation, 2) intersite variation, and 3) between-year variation.

Faunal intrasite variation of samples was determined by calculating coefficients of variation for the number of taxa at each site, and the number of individuals in each taxon with a statistical mean of at least one individual per sample. The intersite sample variation in terms of taxon number, biomass, and number of individuals was examined by analysis of variance (ANOVA) statistics using the statistical package SPSS-X. Taxa which were determined to have a mean of at least one individual per sample for at least one site were included in the analysis.

The ANOVA results which showed a statistically significant difference in the mean number per sample were reanalysed by multiple comparison tests (Schiffe test and Tukey test) to determine where these differences occurred.

To examine between-year site-specific differences, taxa which yielded a significant ANOVA result were examined using a paired comparison t-test and also a Wilcoxon matched-pairs signed-ranks test.

Community structure was examined using two common methods; diversity indices and cluster analysis.

The diversity of the benthic fauna was examined at each site, by calculating the Shannon-Weaver diversity index for each sample. An ANOVA test was performed on the calculated diversity indices, with a Scheffe multiple comparison test to show which sites had significantly different diversity indices.

Community structure was also examined through a cluster analysis, procedure using the program Clustar-2. The results of a cluster analysis give an indication as to which samples (and therefore which sites) are similar to each other. By comparing these results with the water quality data, it is possible to specify communities of "*clean*" and "*unclean*" invertebrates.

The values of Pearson correlation coefficients were calculated, using statistical package MINITAB, for various combinations of stream characteristics, water quality, and the invertebrate data.

The total number of individuals, the number of taxa, diversity index, total biomass, stream order and drainage area were correlated with several water quality measurements to determine which parameters were significantly correlated with the distribution of the invertebrate fauna in the Waterford River system. Tests of association between stream order, drainage area and the invertebrate data were also performed.

Between-taxa correlations were also performed to determine whether any consistent grouping of taxa could be identified. Highly correlated species were then compared to water quality and diversity indices to determine whether there were any "*clean water*" and "*unclean water*" trends in invertebrate populations.

3.5.3 Results

A list of taxa collected from the watershed during the 2-year study is given in Table 3.25. Figures 3.13 and 3.14 graphically illustrate the values of mean biomass, number of taxa and number of individuals collected at each site in 1984 and 1985, respectively.

Correlations of benthos numbers and biomass with stream parameters are given in Table 3.26. Numbers of individuals correlated highly with stream size in 1984, but much less so in 1985. Biomass showed a small positive correlation with stream order. This might indicate that slight pollution provides sustenance for selected species. The number of taxa indicated very slight negative correlation with stream order.

The calculated results of (linear) correlation coefficients between stream size and invertebrate data (dependent) and water quality parameters (independent) are given in Table 3.27.

Table 3.25 LIST OF TAXA COLLECTED DURING THE TWO-YEAR STUDY

Taxon	Collected in 1984	Collected in 1985
Phylum Nematoda	+	+
Phylum Annelida		
Class Hirudinea	+	-
Class Oligochaeta		
Order Lumbriculda		
Family Lumbricidae		
Lumbricus sp.	+	+
Family Lumbriduligae		
Lumbriculus variegatus Muller	+	+
Order Haplotaxida		
Family Enchytraeida	+	+
Family Naididae	+	+
Nais communis		
Phylum Mollusca		
Class Gastropeda	+	+
Class Pelecypoda	+	+
Phylum Arthropod		
Class Arachnida		
Order Acarida		
Family Hydracarinidae	+	+
Class Crustacea		
Order Amphipoda	+	+
Hyalella azateca		
Order Copepoda		
Family Calanoida	-	+

Table 3.25 LIST OF TAXA COLLECTED DURING THE TWO-YEAR STUDY (Cont'd)

Taxon	Collected in 1984	Collected in 1985
Class Insecta		
Order Coleoptera		
Family Dytiscidae		
Hydroporus badiellus Fall	+	-
H. Paugus Fall	-	+
Family Elmidae		
Promoresia tardella Fall		
Stenelmis crenata Say.		
Family Hydrophilidae		
Hydrobia fuscus L.	-	+
Order Diptera		
Family Certopogonidae	+	+
Family Chironomidae	+	+
Family Empididae	+	+
Family Muscidae	+	+
Family Psychodidae	+	-
Family Simuliidae	+	+
Family Tabanidae	+	+
Family Tipulidae		
Antocha sp. Osten and Sacken	+	+
Limonia sp. Meighen	+	-
Tipula sp. L.	+	+
Order Ephemeroptera		
Family Baetidae		
Baetis flavistriga McD.	+	+

Table 3.25 LIST OF TAXA COLLECTED DURING THE TWO-YEAR STUDY (Cont'd)

Taxon	Collected in 1984	Collected in 1985
B. pygamaeus Hagen	+	+
B. tricaudatus Dodds	+	+
Centroptilum converxum Ide.	+	-
Family Ephemerellidae		
Ephemerella subvaris	+	+
Eurylophella sp. McD.	+	+
Family Leptophlebiidae		
Habrophlebia vibrans Needham	+	+
Leptophlebia cupida Say	+	+
Paraleptophlebia adoptiva McD.	+	+
Order Odonata		
Suborder Anisoptera		
Family Aeshnidae		
Aeshna sp. Walker	-	+
Order Plaecoptera		
Paracapnia opis Newman	+	+
Family Leuctridae		
Leuctra ferruginea Walker	+	+
Family Perlodidae		
Isogenus frontalis Newman	+	+
Isoperla transmarina Newman	+	+
Order Trichoptera		
Family Brachycentridae		
Micrasema wataga Ross	+	+
Family Glossosomatidae		
Glossosoma sp. Curtis	+	+
Family Hydropsychidae		
Arctosyche ladogensis Kolenati	+	+

Table 3.25 LIST OF TAXA COLLECTED DURING THE TWO-YEAR STUDY (Cont'd)

Taxon	Collected in 1984	Collected in 1985
Hydropsyche betteni Ross	+	+
H. Slossonae Banksptera	+	+
H. sparna Ross	+	+
Family Hydroptilidae		
Hydroptila metoeca Bickle and Morse	+	+
Oxyethira sp. Eaton	+	+
Family Lepidostomatidae		
Lepidostoma sp. Rambur	+	+
Family Leptoceridae		
Mystacides sepulchralis alker	-	+
Family Limnephilidae		
Hydatophylax argus Harris	-	+
Limnephilus sp. Leach	-	+
Pychnopsyche sp. Banks	-	+
Platycentropus sp. Ulmer	+	-
Family Philopotamidae		
Chimarra sterrima Hagen	+	+
Dolophiloides distinetus Walker	+	+
Wormaldia moesta Banksliidae	+	+
Family Phryganeidae		
Oligostomis sp. Kolenati	+	+
Ptilostomis sp. Kolenati	+	+
Family Polycentropodidae		
Neureclipsis sp. McLachlan	+	-
Polycentropus sp. Banks	+	+
Family Rhyacophilidae		
Rhyacophila carolina Banksidae	+	+
R. fuscula Walker	+	+

Table 3.25 LIST OF TAXA COLLECTED DURING THE TWO-YEAR STUDY (Cont'd)

Taxon	Collected in 1984	Collected in 1985
R. invaria Walker	+	+
R. melita Ross	-	+
R. minora Banks	+	+
R. nigrita Banks	-	+
R. torva Hagen	+	+
R. vibox Milne	+	+

Note: + collected
- not collected

Table 3.26 CORRELATIONS OF BENTHOS NUMBERS & BIOMASS WITH STREAM PARAMETERS

Invertebrate Data				
Stream Parameter	**Diversity Indices**	**Biomass**	**Number of Individuals**	**Number of Taxa**
1984				
Stream Order	0.031	0.550	0.720	-0.033
Drainage Area	0.131	0.356	0.820	0.092
1985				
Stream Order	-0.233	0.323	0.331	-0.218
Drainage Area	-0.075	0.361	0.399	-0.035

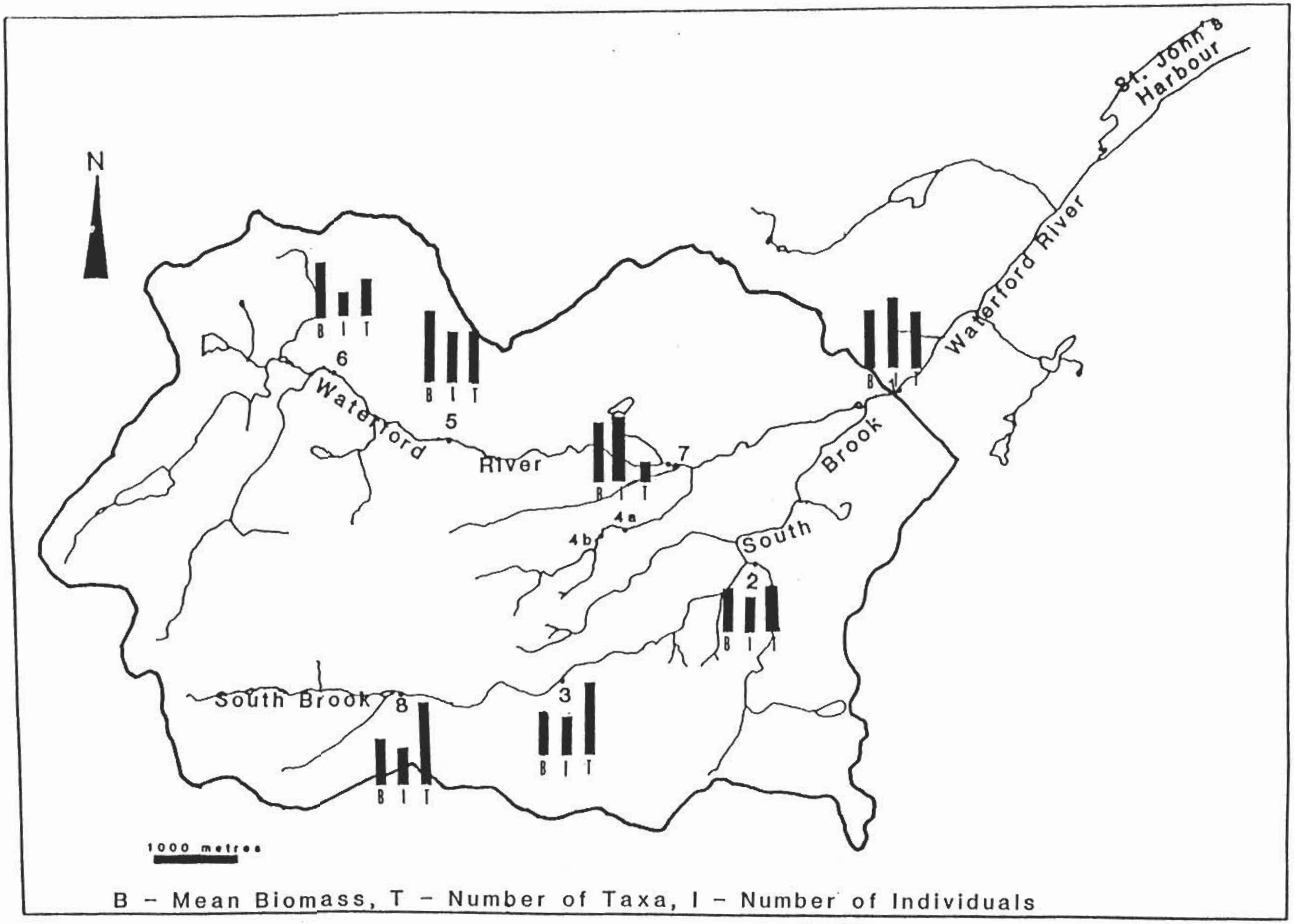


Figure 3.13 RELATIVE DISTRIBUTION OF BIOMASS, NUMBER OF INDIVIDUALS AND NUMBER OF TAXA, 1984

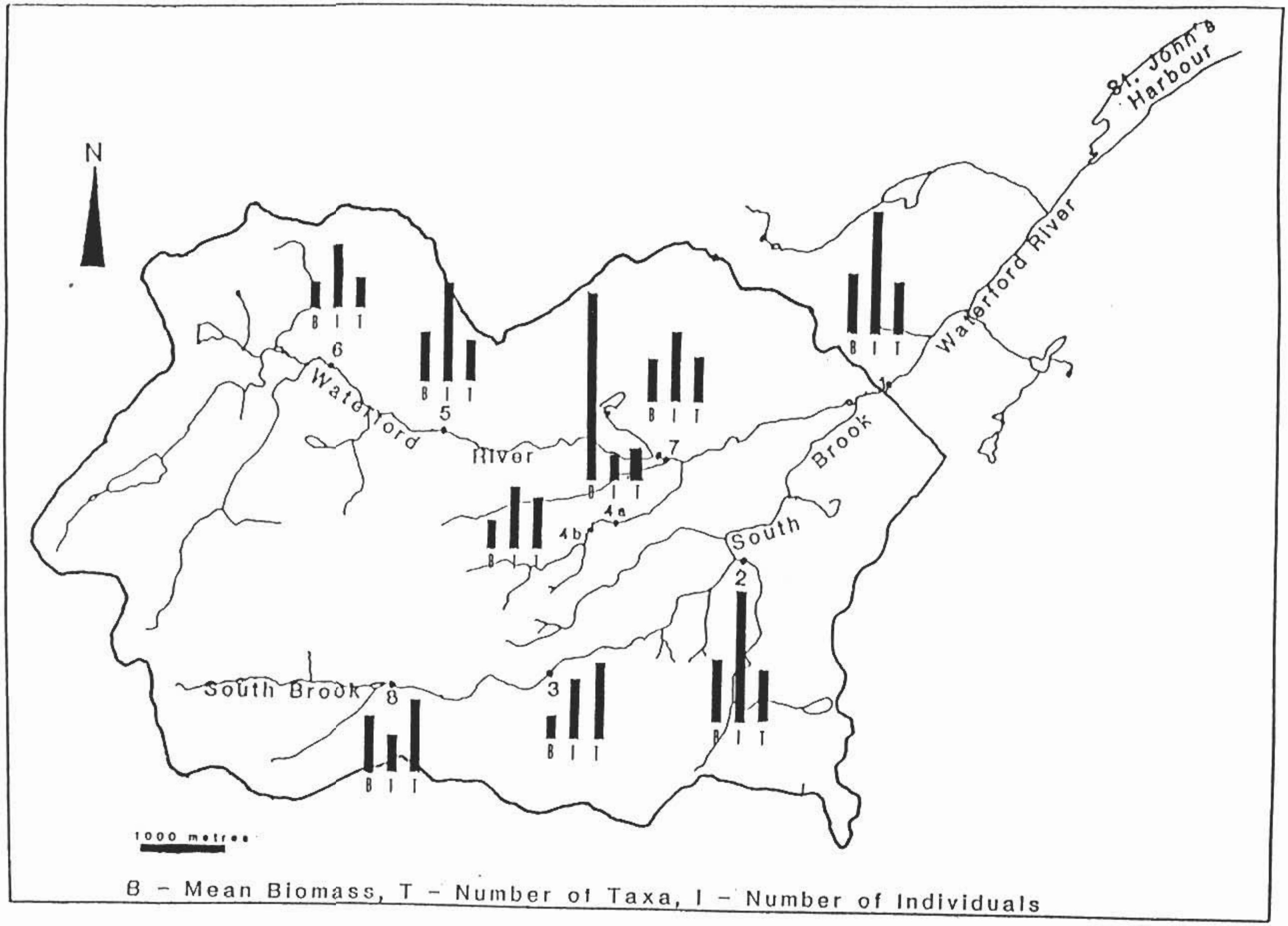


Figure 3.14 RELATIVE DISTRIBUTION OF BIOMASS, NUMBER OF INDIVIDUALS AND NUMBER OF TAXA, 1985

Table 3.27

CORRELATION COEFFICIENTS BETWEEN SELECTED STREAM CHARACTERISTICS, INVERTEBRATE NUMBERS, BIOMASS AND WATER QUALITY DATA

Source	pH	Specific Conductivity	Temperature	Turbidity	Flow Rate	Organic Carbon	Nitrate-Nitrite	Dissolved Nitrogen	Dissolved Phosphorus	Dissolved Oxygen	Total Alkalinity	Dissolved Chloride	Total Coliforms
Stream Order	0.466	0.583	-0.082	0.565	0.875*	0.206	0.551	0.479	0.513	0.115	0.271	0.756**	0.550
Drainage Order	0.466	0.541	0.180	0.340	0.959*	-0.040	0.496	0.422	0.368	0.297	0.281	0.627**	0.391
Diversity Indices	-0.733	-0.642	-0.361	-0.303	-0.021	0.383	-0.715**	-0.707	-0.324	0.154	-0.859*	-0.572	-0.269
Biomass	0.460	0.737	-0.232	0.945*	0.495*	0.671	0.559	0.315	0.562	0.543	0.316	0.729	-0.056
Number of Individuals	0.158	0.205	0.053	0.355	0.726	0.051	0.109	0.058	0.390	0.525	-0.121	0.289	0.049
Number of Taxa	-0.730	-0.687	-0.337	-0.358	-0.061	-0.434	-0.766	-0.753	-0.348	0.172	-0.874	-0.623	-0.411

** Significant at $\alpha = .05$

* $r^2 \geq 0.64$

3.6 Groundwater Study

3.6.1 Objectives

The original objectives of the study (Ref. 3-6, 3-7) were as follows:

1. *To define the major aquifers in the basin both in the bedrock and in the overburden materials in terms of depth, quantity of water available, quality of water, spatial distribution, and vulnerability to contamination or depletion,*

2. *To assess the impact of urbanization on the groundwater in the bedrock and overburden materials in terms of quality and quantity,*

3. *To quantify the groundwater component of the hydrologic cycle in the Waterford Basin, and*

4. *To investigate the physical and chemical processes that lead to changes in the groundwater.*

Despite the large number of wells in the basin, virtually no information was available concerning their construction or yield characteristics. In addition, for the most part, they were concentrated in one developed area. Because of this, most of the resources that were available to accomplish the objectives were expended for the construction of monitoring wells. It became obvious very early in the study that the emphasis would have to be placed on the water quality effects of urban development. This imposed a severe limitation on the attainment of objectives 1 and 4. The definition of major aquifers could only be accomplished insofar as information was available from wells drilled for the purpose of monitoring the various land use activities in the basin. The determination of the groundwater component of the hydrologic budget was limited to an annual estimate of baseflow for the years 1974-1983.

In addition, no independent study of physical and chemical processes that operate in the basin was possible because of the resource and time restraints.

3.6.2 Methodology

Literature Review

As groundwater is predominantly influenced by geology, a thorough review of existing knowledge of the local bedrock geology, surficial geology and hydrogeology was undertaken to assist in developing a study plan including the groundwater monitoring well network.

A) Bedrock Geology

All rocks within the Waterford River Basin are of latest Precambrian age (circa 700-600 Ma). Bimodal volcanic rocks of the Harbour Main Group occur west of the watershed and are overlain within the basin by three contrasting clastic sedimentary assemblages, which, in order of decreasing age, are the Conception, St.John's and

Signal Hill Groups. These groups are subdivided into nine formations, which have been traced throughout the area.

The rocks provide evidence of two phases of deformation. The first phase is assumed to be related to the Precambrian Avalonian Orogeny and the second to a major Siluro-Devonian (circa 395 Ma) disturbance - the Acadian Orogeny.

The most significant features influencing groundwater movement in the basin are major plunging folds and fracture zones in low porosity rocks of the Drook Formation which generally slope toward the Waterford and South Brook Rivers. Tuffaceous siltstones (Mistaken Point Formation) and black shales (St. John's Group) conformably overlie the Drook Formation in the Mount Pearl area. Both rock units show fractures and slaty cleavage which provide conduits for groundwater movement. Secondary growths of pyrite and pyrolusite are commonly altered to iron and manganese precipitates along fractures, particularly in the cherts of the Drook Formation and the thinly bedded sandstones of the Renews Head Formation, and are known to have an adverse effect on water quality. (Ref. 3-2).

B) Surficial Geology

The overburden in the Waterford River Basin is generally thin (0-5 m), and is composed of a very compact, poorly sorted lodgement till with high (10%) silt-clay content overlain by a till deposit that is looser, coarser and more permeable in nature, derived by supraglacial or melt-out processes. Water movement is largely determined by the overburden mantle, so the surficial geology is an important component of any hydrological study (Ref. 3-1).

C) **Hydrogeology**

In general, the primary permeability of bedrocks is low. The bedrock is well cemented and the glacial till is characteristically overconsolidated, thus the porosity of each is reduced. The assessment of hydrogeology characteristic becomes complicated because of the existence of secondary permeability due to joints, fracture zones and shear zones. It is not enough to examine only the matrix of bedrock or overburden materials, as even those with seemingly dense, massive textures can have high values of permeability if sufficiently fractured or jointed. These fractures and joints are the primary conduits for groundwater movement. On the basis of the available information, a preliminary map of bedrock hydrostratigraphic units was prepared and is presented herein as Figure 3.15.

Throughout the study area, the overburden is unfractured and its thickness extremely variable, averaging less than 3 m in depth. In addition, being predominantly of glacial origin, it contains a relatively high percentage of fine material and is extensively overconsolidated. As such, the overburden materials of the Waterford River Basin are not very significant aquifers in terms of high yield.

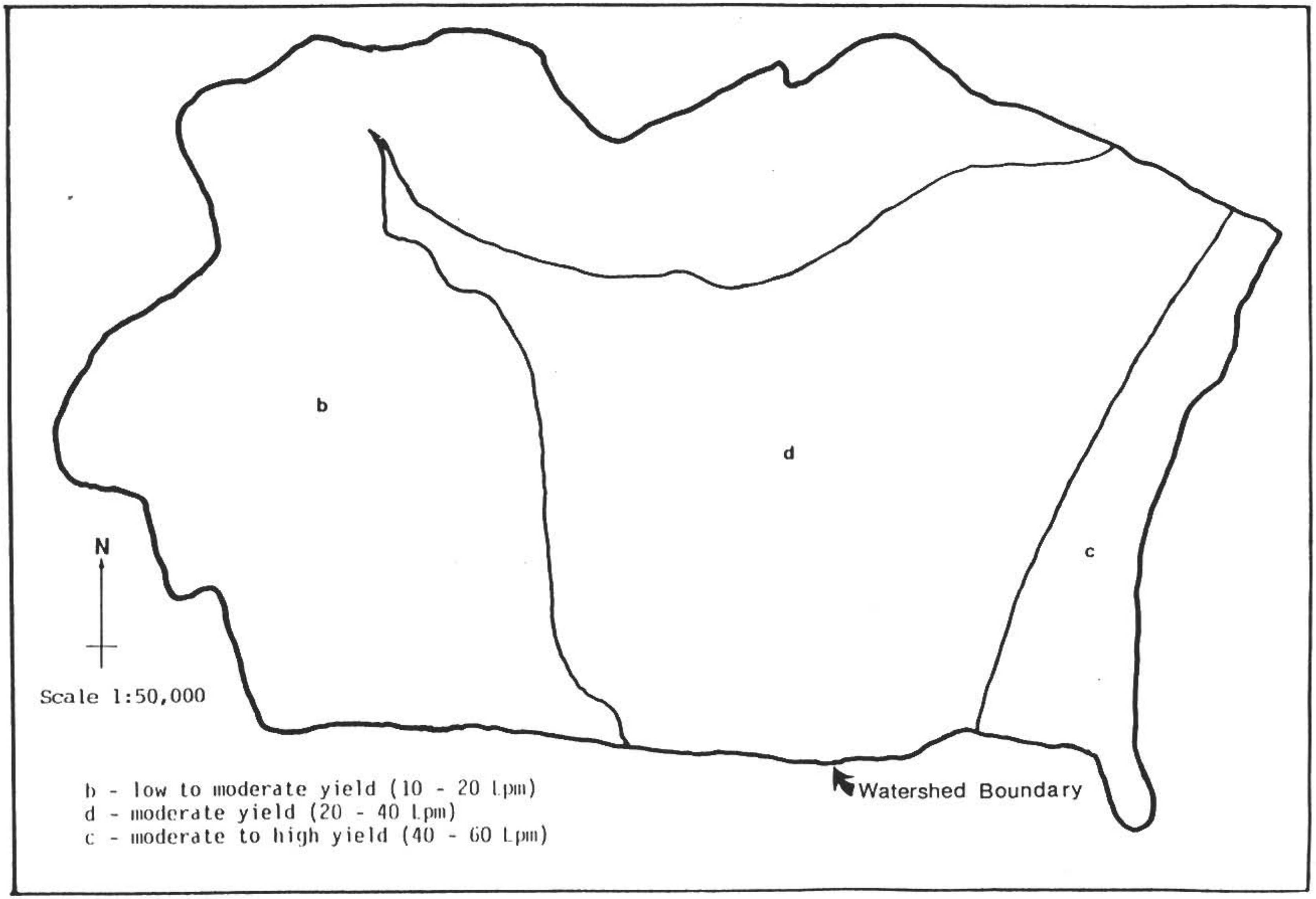


Figure 3.15 BEDROCK HYDROSTRATIGRAPHIC UNITS

Because of its importance to domestic users and its role as a reservoir supplying the deeper systems, the areal variability of the overburden with regard to groundwater movement was assessed using information on grain size analysis contained in the Report on Surficial Geology (Ref 9-1). The distribution of two hydrostratigraphic units is shown on Fig. 3.16.

In general, it is accepted that topographic highs are areas of groundwater recharge and topographic lows are areas of groundwater discharge. This is supported by the direction of flow indicated by the water table contours shown in Fig 3.17. Since the overburden is thin and of low permeability in the study area, it is not a major conduit of subsurface water. It is probable that the bedrock exerts critical control over the movement of water in the basin. Since the bedrock has generally low matrix porosity, the fracture systems control the movement and storage of groundwater. Fractured reservoirs, however, are not well understood. Treatment of the system as a continuum is not generally acceptable, and yet, in order to consider treatment on a discrete basis very detailed structural analyses are necessary. Since this kind of information was not available for this study, only a general assessment could be made.

A particularly interesting and important finding was the high baseflow component of riverflow, which implies a correspondingly high recharge rate exists. The water budget was analyzed for 10 years of data, 1974 - 1983, and the average baseflow component was calculated to be 43%.

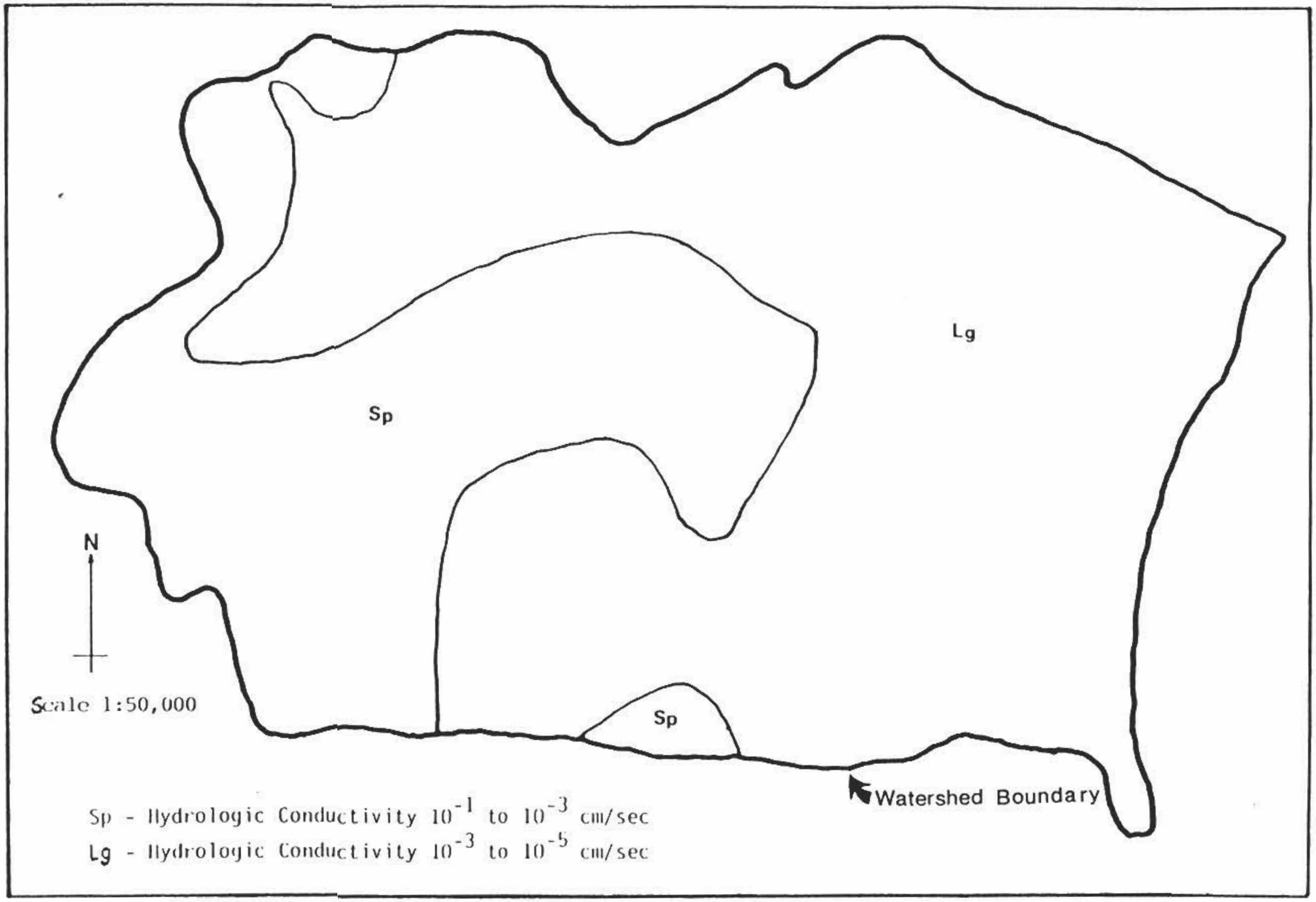


Figure 3.16 **OVERBURDEN HYDROSTRATIGRAPHIC UNITS**

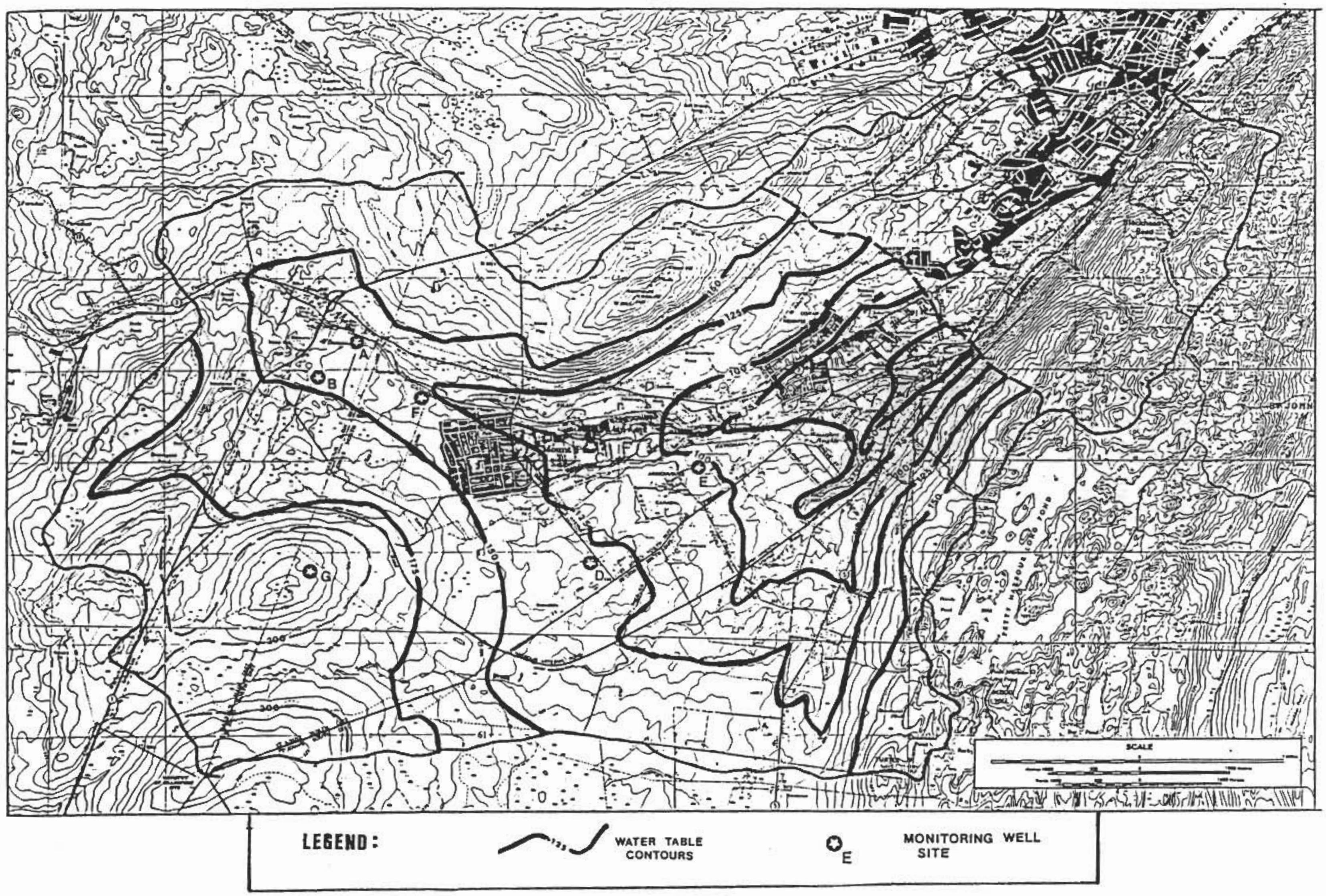


Figure 3.17 WATER TABLE CONFIGURATION AND MONITORING WELL LOCATIONS

Placement of Monitoring Wells

The purpose of the monitoring well network was to provide sampling stations from which representative groundwater samples could be obtained to reflect the effects of each of the major land use categories found in the study area. In order to determine the impact that a particular land use had on the groundwater quality, water samples had to be obtained both upstream and downstream of the activity in question in the direction of groundwater flow which was determined from the available information shown in Figure 3.17. It was assumed that the piezometric level was represented by the water table. This assumption was confirmed during the aquifer testing. Pumping the deeper wells caused measurable drawdown in the nearby shallow wells, thus demonstrating some degree of hydraulic connection.

The locations of wells are shown in Figure 3.17. Sites A and B were positioned to monitor industrial land use. Sites C, D, and F were located to reflect urban land use. Site E was situated to indicate the effects of agricultural activity and site G was chosen to represent the undeveloped area.

At each of the seven sites, two wells were constructed using an air hammer rotary drilling rig. One well was used to sample the water table aquifer; the other was used to sample the artesian aquifer, beneath the site. Site A was an exception to this rule, as a suitable abandoned water table well was available for sampling. Bentonite and casings were used to isolate the surficial and deep aquifers. In the absence of shallow water bearing zones in the bedrock, the casing was set a minimum of 0.6 m below the overburden bedrock contact.

3.6.3 Results of Pumping Tests and Water Level Monitoring

Bedrock Wells - Pumping Tests

The long-term pumping tests were performed to determine the transmissivity of the fracture zone and where possible, its areal extent to determine the degree of hydraulic connection between the overburden well and the bedrock well. The values of transmissivity are given in Table 3.28.

A step test was conducted on each of the artesian monitoring wells to estimate the optimal rate of pumping for the longer term aquifer test. The long term pumping rates determined from the step tests are listed in Table 3.29. The optimum flow rate from G was too small to conduct a long term test on the well.

Adequate pumping tests could not be performed on the shallow wells due to the low yield characteristics of the overburden materials. In order to obtain some information on the hydraulic characteristics of these materials a slug test was used. The values of hydraulic conductivity for the 4 wells tested are summarized in Table 3.30.

Table 3.28 ARTESIAN WELL TRANSMISSIVITY VALUES

Well #	Site	Transmissivity (m^2/s)
1526	A	5.6E-5
1529	B	3.5E-7
1527	C	2.0E-5
1531	D	3.8E-7
1522	E	2.0E-5
1521	F	2.8E-7

Table 3.29 LONG TERM PUMPING RATES FOR ARTESIAN AQUIFERS*

Well #	Well Site	Pumping Rate for 24 Hour Test (L/S)
1526	A	.16
1529	B	.05
1527	C	.17
1531	D	.14
1522	E	.16
1521	F	.35

* As determined by a step test Note: 1 litre = .001 m^3

Table 3.30 HYDRAULIC CONDUCTIVITY OF OVERBURDEN DETERMINED BY SLUG TEST

Well #	Site	Hydraulic Conductivity m/sec
1530	B	1.31×10^{-6}
1532	D	3.81×10^{-5}
1535	E	1.62×10^{-6}
1533	G	2.27×10^{-6}

Water Level Monitoring

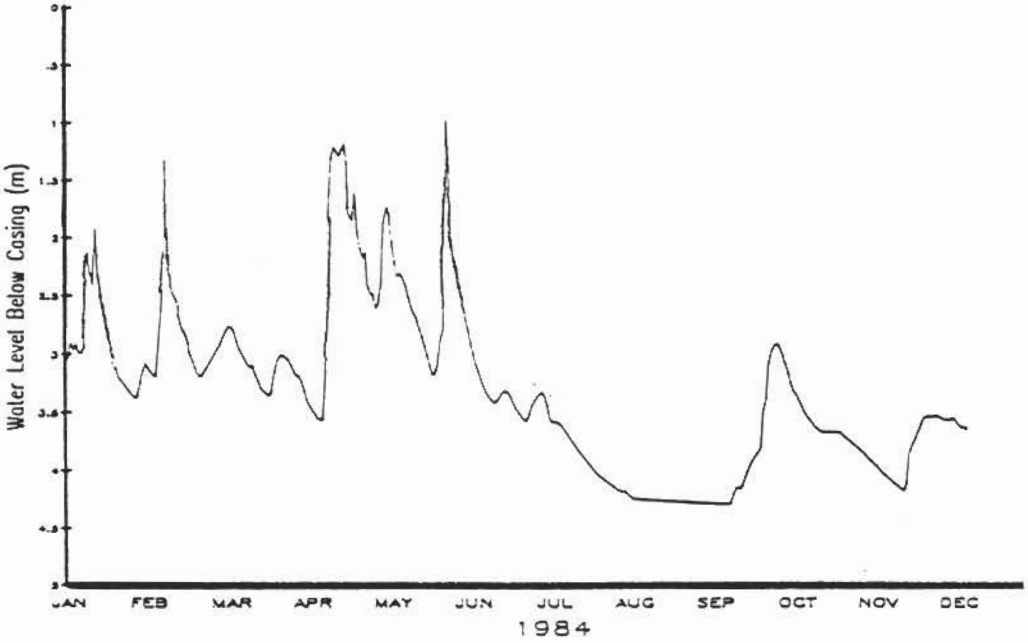
The water level in both shallow and deep wells at all sites was monitored to document the seasonal fluctuations of the water table and the piezometric level to determine the change in groundwater storage and to examine the response time of the water table and piezometric level to precipitation events. To establish the response to precipitation events two wells, one shallow and one deep, at site H were monitored continuously using a water level recorder. The wells at the other 7 sites were monitored on a monthly basis.

No general analysis of the piezometric levels of the monitoring well network was undertaken. Piezometric hydrographs for wells #1026 and #1028 at site H for 1984 are shown in Figure 3.18.

3.6.4 Groundwater Quality

The parameters sampled are listed in Table 3.31. Sampling was done quarterly in order to detect seasonal variations in water quality.

SITE H, WELL # 1028



SITE H, WELL #1026

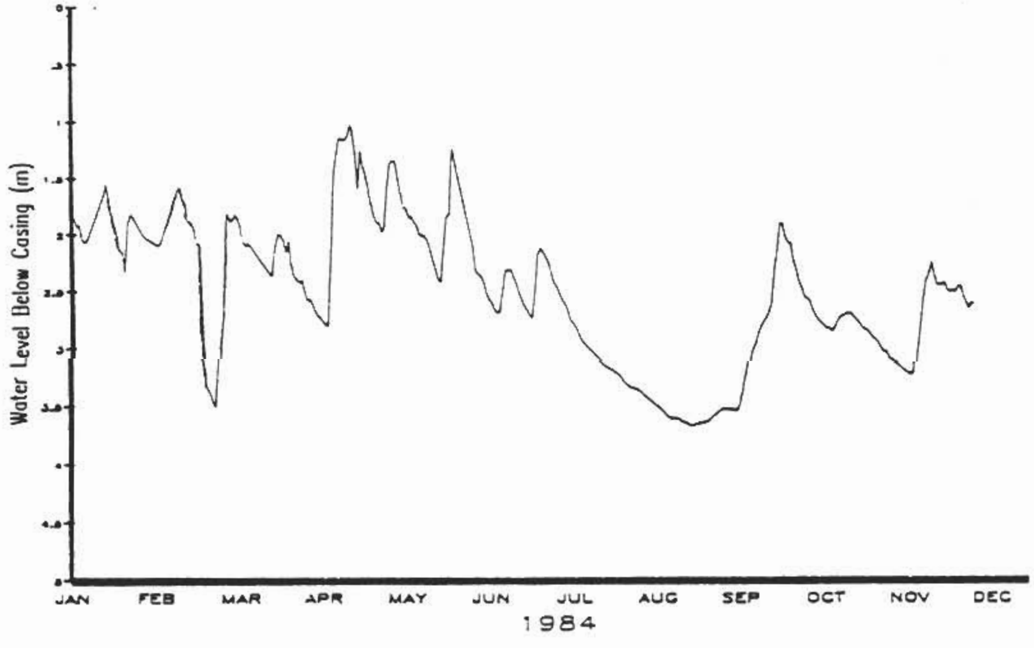


Figure 3.18 PIEZOMETRIC HYDROGRAPHS AT SITE H, 1984

Table 3.31 WATER QUALITY PARAMETERS SAMPLED FOR THE GROUNDWATER STUDY

Calcium	*Bacteria
Magnesium	Total Nitrogen
Sodium	Nitrate and Nitrite
Potassium	Ammonia
Chloride	Total Phosphorous
Sulphate	Orthophosphorous
Total Dissolved Solids	Total Organic Carbon
Turbidity	Copper
Colour	Lead
Dissolved Oxygen	Specific Conductance
Temperature	Zinc
Iron	Alkalinity
Manganese	

* total and fecal coliforms

The specific sampling procedures were revised and improved over the course of the study. The final routine sampling procedure was as follows:

1. *The static water level was measured.*
2. *The specific conductance and temperature were measured at the water bearing zone.*
3. *The peristaltic pump inlet or Kemmerer tube was lowered to the water bearing zone.*
4. *The sample bottles were rinsed 3 times with well water.*
5. *The sample was filtered using a 0.2 to 40 micron filter.*
6. *The sample used for metal analysis was preserved with 1 ml of nitric acid* HNO_3.

In artesian wells samples were taken as over the depths of the well to determine the variations in water quality. An example from Site E is presented herein as Figure 3.19.

Chemical analyses were done by the Water Quality Branch, Inland Waters Directorate, Environment Canada, in Moncton, New Brunswick.

Physical parameter analyses were conducted by the Environmental Protection Service, Environment Canada, in St. John's.

3.6.5 Characterization of Groundwater Quality

In general, geology influences the quality of groundwater by the mineralogical make-up of the earth media through which the groundwater is moving. The other major influence is the length of time the groundwater is in contact with the earth media. This is a function of the length of the flow system between the recharge and discharge area and the velocity of groundwater flow.

Bedrock Hydrogeochemistry

The seven bedrock wells used in the study area are located in late Precambrian clastic sedimentary rocks. Wells designated B and G (Figure 3.17) are in the Conception Group, which generally consists of green-grey and red greywacke, siltstone shale, chert and minor tuff. This is generally reflected in the stratigraphic borehole logs for wells B and G. The other five

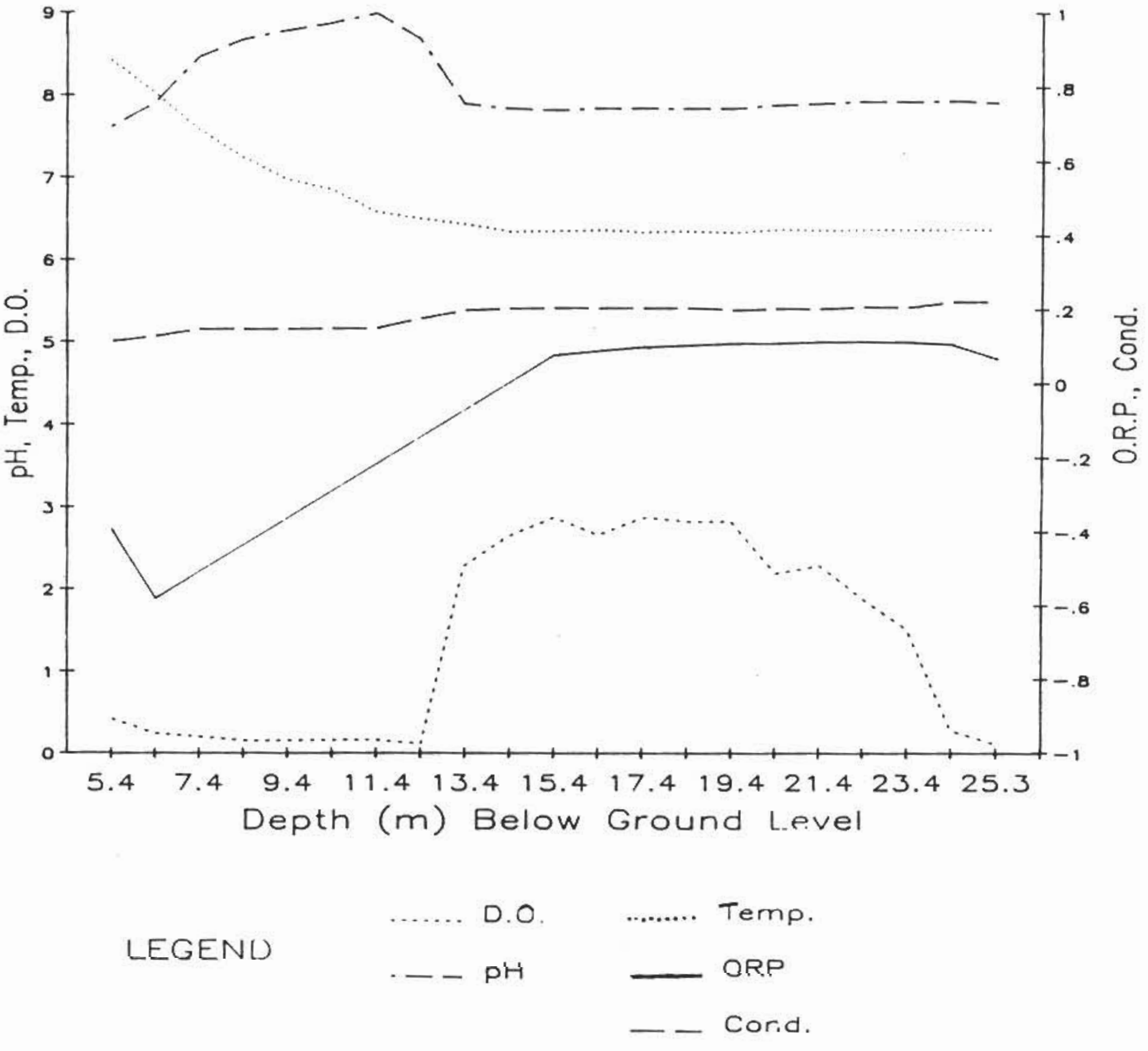


Figure 3.19 CHEMICAL PROFILES AT SITE E, NOVEMBER 5, 1984

wells (A,C,D,E and F) are completed in the Fermeuse Formation of the St. John's Group (Ref. 3-2), which consists mainly of black slates and minor sandstone, with traces of calcite, dolomite, pyrite, magnetite and apatite. As for the Conception group, the stratigraphic logs of the wells in the Fermeuse Formation generally reflect this description, including one report of pyrite and several of calcite veins.

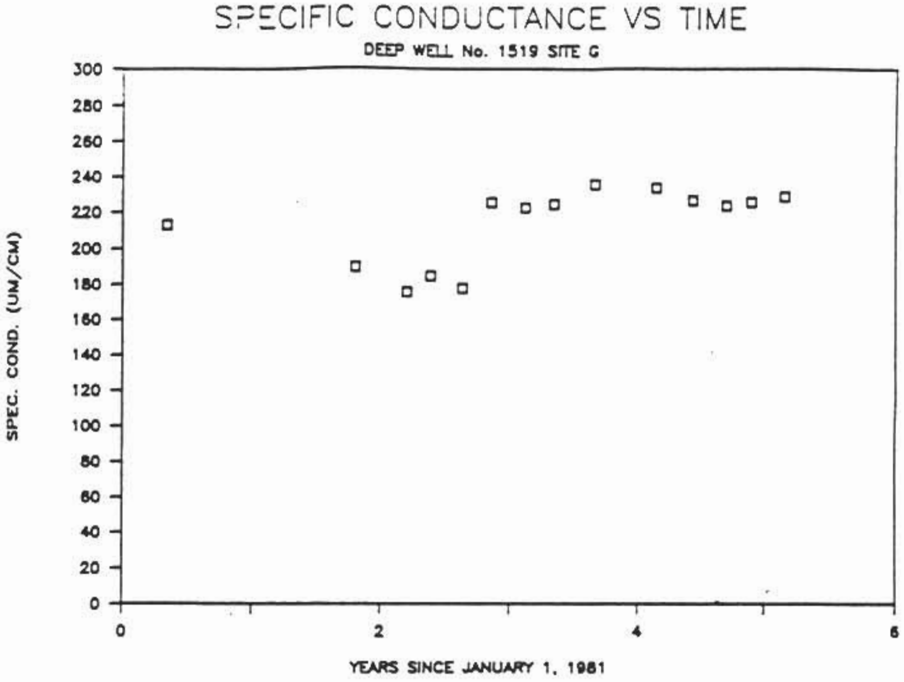
There are overall similarities in the water quality at sites A, B and G. All are dominantly calcium bicarbonate waters. In addition, total dissolved solids are generally similar. Wells B and G are in the Conception Group, while well A is in the Fermeuse Shales. However well A is close to and downstream from the Conception Group, and would be dominated by waters of similar quality.

The other wells, all in the Fermeuse formation, show waters of a somewhat different chemical character. Although calcium is still the dominant cation, sodium exerts more of an influence. More noticeable, the sulphate and chloride influence significantly lessens the bicarbonate character of these waters. Wells C, D and F all tend to have higher TDS values than wells A, B and G. Well E, is most similar to the first three, although higher sulphate tends to offset the bicarbonate content. Well C shows some similarity to Well E although it is higher in TDS. Well D displays water of a predominantly calcium chloride character, with chloride values in the 150-180 mg/L range, significantly higher than values of sodium (ranging from 25 to 30 mg/L). Well F, on the other hand, is a calcium, sodium sulphate water, with sulphate in the 90 to 115 mg/L range. The common feature of groundwaters in both bedrock units is the pH, which generally falls in the slightly alkaline range of 7 to 8.

Overburden Hydrogeochemistry

Overburden in the area consists mainly of three till units - lodgement till, supraglacial till and supraglacial melt-out till - derived from local bedrock material (Ref. 3-1). The overburden wells are all completed in the lodgement till, except for the well at site G. This well is completed in the badly-broken near surface zone of the bedrock, but the groundwater effectively represents that of the lodgement till (Ref. 3-7). Locations of well sites are shown on Figure 3.17.

The susceptibility of these shallow wells to influences resulting from activities on the surface often tends to mask natural groundwater quality. The well at Site G, however, was located as a control well. The waters tend to be bicarbonate, although less predominantly so than in the deeper groundwater. Calcium predominance gives way much more to sodium than in the bedrock hydrogeochemistry. Total dissolved solids are significantly lower in the shallow groundwater, as indicated by a comparison of the specific conductance values, in Figure 3.20. The groundwater at site A closely reflects the character of the control well at site G. Prior to the end of 1982, well B tended to be largely calcium bicarbonate with less sodium influence than at site A and G. Road salt severely influenced water quality after 1982. Further downstream in the basin, at site F, the waters show a variation from strongly calcium bicarbonate in 1982 and 1983 to more calcium, sodium bicarbonate in 1984. Total dissolved solids were up to twice as high, however (the well at site C is contaminated by de-icing salt). Shallow groundwater at site D is similar to site A, but with a slightly greater sulphate tendency in 1982 and chloride in 1983 and 1984. Specific conductance tends to be somewhat



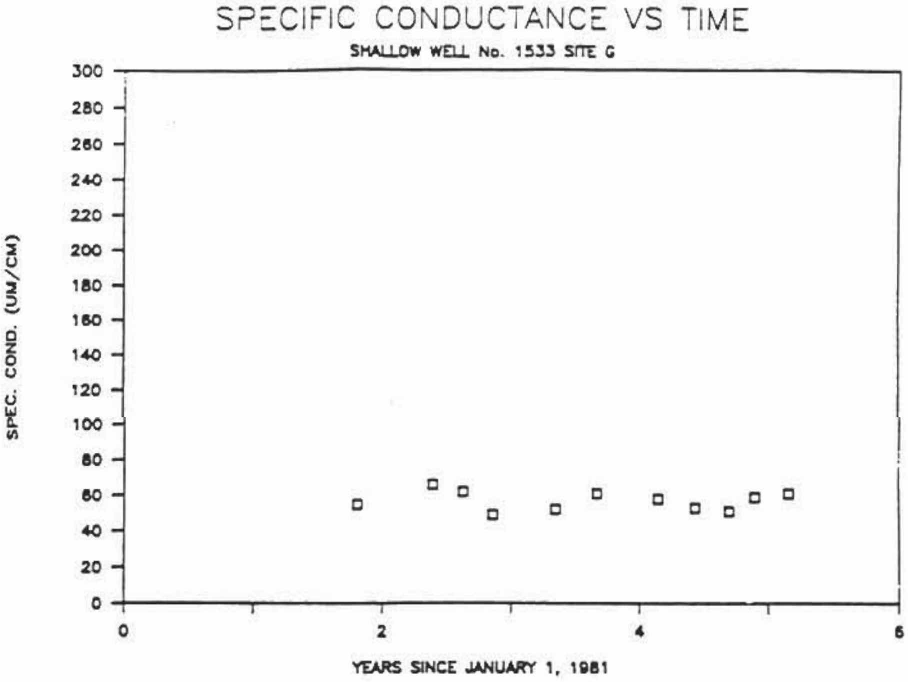


Figure 3.20 SPECIFIC CONDUCTANCE VS TIME AT SITE G DEEP AND SHALLOW WELLS

higher. Site E closely resembles the background station, with a tendency towards a slightly higher calcium influence. Total dissolved solids are somewhat higher.

Nitrate concentrations are well below the recommended limit of 10 mg/L as nitrogen but occasionally exceed the values found in the background wells at site G, which average 0.01 mg/L in the deep well and about 0.03 mg/L in the shallow well (with a 0.8 mg/L anomaly). The concentration of nitrate increased during 1981 in the deep well at site A. Higher nitrate values were observed in the deep well at site E and the shallow wells at sites C and D. Coliform and iron values tend to fluctuate severely with time.

4 DISCUSSION OF RESULTS

4.1 Introduction

The main objectives of the Waterford River Basin Urban Hydrology Study were to identify the effects of urbanization on the hydrologic regime of the Waterford River Basin, to model the hydrologic processes involved, and to recommend solutions to specific water management problems in this and other similar basins in the province. A systematic and detailed examination of several components of urban hydrology including geology, land use, storm drainage, hydrologic modelling, flooding, water quality, biological assessment, and groundwater was necessary to meet the objectives of the study. The objectives, methodologies, and results of the various components of the study have been published in a series of accompanying reports (Ref. 3-1 to 3-12) and are summarized in Chapter 3 of this report. In this chapter the results of the component studies are discussed in light of the main objectives of the Waterford River Basin Urban Hydrology Study.

4.2 Geology

The amount of water that is stored in and eventually leaves a watershed depends upon the nature of the constituent soils and rocks. The chemical character of the water is also conditioned by these factors. Analysis, interpretation, and prediction of the hydrological characteristics of a watershed should therefore consider the effects of geological controls and geochemistry as fully as possible. The surficial and bedrock geology of the Waterford River Basin was determined as part of the study.

4.2.1 Bedrock Geology

Hydrologically, the most significant bedrock features influencing groundwater movement in the basin are the major plunging folds and fractures in the low porosity rocks of the Drook Formation. These folds and fractures generally slope toward the Waterford and South Brook Rivers. Open fracture zones, defined as closely spaced and highly interconnected discrete fractures, are characteristic of the siliceous Drook Formation. Iron and manganese stains along fracture surfaces indicate that the fracture zones and, to a lesser extent, bedding surfaces are the primary conduits for groundwater movement in these otherwise well-cemented, low matrix porosity rocks. The iron and manganese precipitates along the fractures are known to have an adverse effect on water quality.

4.2.2 Surficial Geology

The overburden in the Waterford River Basin is generally thin (0-5 m), and is composed of a very compact, poorly sorted lodgement till with high (10%) silt-clay content overlain by a till deposit that is looser, coarser, and more permeable in nature. This upper layer is often only 50 cm thick.

Hydrologically, the most significant features of the surficial mantle are its thinness, the slow percolation and discharge of water through the compacted lodgement till, and the influence of bedrock upon drainage. Percolation into and through the upper less compacted layer, with its coarse texture and low silt-clay content (average 4%), would be relatively fast compared with percolation through the lower lodgement till unit. Pore spaces in the lower till are small due to the higher silt-clay content and overconsolidation, and water movement in this till is seriously restricted. Discharge is therefore slow, but is probably continuous even through long periods of drought. The lodgement till contains no fractures through which rapid discharge may be facilitated.

Due to the thinness of the overburden mantle, the bedrock exerts a critical control over the movement of water throughout the basin. During precipitation, the upper supraglacial unit is rapidly saturated, developing a perched water table, often with surface ponding of water. The hydrological response of the drainage basin to precipitation events is therefore expected to be rapid.

During urbanization vegetation is removed and the critical supraglacial layer is disturbed with the result that the overall storage capacity of the groundwater environment is reduced and surface flow into storm sewer systems is faster. Runoff and flooding potential therefore increases. In addition, the geochemistry of the runoff will change since the filtering effect of the till is removed.

4.3 Land Use

Land use has a significant influence on the runoff characteristics of watersheds. Many hydrologic models use land cover information to simulate precipitation-runoff events. Land use information is also useful in the interpretation of data on the physical, chemical, and biological quality of surface water and groundwater. The results of the land use component study are given in Section 3.1.

In 1984, land classified as Forest made up 33% of the basin's area with Unproductive and Agricultural lands, respectively, accounting for 29% and 11% of the total. Commercial, Industrial, Institutional, and Residential together accounted for 20% of the total area of the basin. An analysis of the changes in land use from 1973 to 1984 shows that urbanization during this period proceeded more slowly than had been initially thought. For example, the basin above Kilbride, as a whole remains largely un-urbanized despite development of Mount Pearl and Donovans. Most of the land required for urbanization came from the forestry land base. The short term trends indicate that with the gradual decrease in forest area, the land classified as Unproductive will become the dominant land use in the basin. The agricultural land base will also continue to decrease, albeit at a slower rate than in previous years.

4.4 Storm Runoff Study of the Newtown Urban Catchment

A common factor to all urbanization is that a significant portion of the land surface becomes impermeable. The impacts on the hydrological cycle include increased magnitude of peak flows and a decrease in river water quality. It is important to be able to model the hydrologic processes involved in an urban environment so that mitigative measures can be devised and implemented. One objective of this study was to evaluate the applicability of various computational procedures including urban hydrologic models to simulate the effects of urbanization on the hydrology of the Waterford River Basin. In the current drainage practice, peak flows are computed by means of empirical formulae, such as the Rational method, or by hydrological synthesis models such as SWMM and ILLUDAS. Both approaches have been investigated in this study and the results are presented in Section 3.2.8.2.

4.4.1 Input Data and Calibration of Hydrologic Simulation Models

The level of detail of physiographic data extracted for the study area was found to be sufficient for runoff modelling. On the other hand, the quality of the hydrometeorological data, particularly the rainfall data, should be improved for future applications of the hydrologic models. For this study, rainfall data for a number of rainfall events were not available because the tipping-bucket rain gauge occasionally malfunctioned. Other problems were encountered in the synchronization of rainfall and runoff records. Such difficulties may be avoided in the future by operator training and close supervision, and/or by adding another tipping bucket raingauge to the observation network.

Flow data seemed to be of fairly good quality with only rare instances of recorder malfunctions.

Applications of urban runoff models require, besides hydrometeorological and physiographic data, hydrological process parameters. In urban hydrology overland flow, detention storage, and infiltration parameters are important. In applications of the SWMM and ILLUDAS models, overland flow parameters include the overland flow plane roughness (in both models), the overland flow plane width (in SWMM), and the inlet time (in ILLUDAS). A sensitivity analysis of simulation runs indicate that the results are barely sensitive to overland flow plane roughness within the practical range of values such as 0.013 for impervious areas and 0.20 for pervious areas.

The width of the overland flow plane is in principle a physiographic parameter defined as the sub-catchment area divided by twice the length of the sewers in the sub-catchment. It is advisable to use this parameter as defined and not as a calibration parameter.

The specification of an inlet time is one of two options in the overland flow calculations with the ILLUDAS model. It is preferable to avoid this option and specify the length, slope, and roughness of the flow route and let the model calculate the inlet time.

The values used as surface detention storage parameters were 1.5 mm for impervious areas and 5 mm for pervious areas and followed recommendations in the SWMM manual. While the value for impervious areas was tested and found to be satisfactory in the study area, the pervious area value was not adequately tested. Detention storage on pervious areas becomes important only during severe storms. Only two such storms were observed during the study period and, therefore, did not provide a sufficient database for verifying the detention storage values for the pervious areas.

4.4.2 Runoff Computations by Hydrologic Simulation Models

Using the available hydrometeorologic and physiographic data, simulation results indicate that runoff events observed in the Newtown catchment were reproduced fairly well both by the SWMM and ILLUDAS urban runoff models.

For smaller storms (rainfall < 50 mm), the contributions of pervious areas to runoff were relatively small and, without much calibration, both SWMM and ILLUDAS reproduced the mean observed runoff volume within 10%. Both models performed equally well; this follows from similar formulations of losses in the two models. For individual events, the differences between observed and simulated volumes varied from -25% to 13% at the 95% level of confidence. When heavy storms (with rainfall > 50 mm) were included in the test data, it became desirable to properly simulate runoff contributions from pervious areas. This meant that infiltration rates needed to be calibrated in simulations of runoff volumes from large storms. Although this can be done with both models, the ILLUDAS model, which accepts the soil group and antecedent moisture conditions as input, was found to be easier to apply.

For the adjustment of infiltration rates, the ILLUDAS model offered more convenience and flexibility, because the user can select the appropriate rates by specifying the soil type and the antecedent moisture conditions for the 5-day antecedent rainfall. It should be noted that the same effect could be achieved with the SWMM model by calculating infiltration rates for various AMC conditions and then substituting them into the model.

The accuracy of runoff volume simulations was adversely affected by the presence of baseflow in the stormwater sewer system which was contributed by foundation drains and infiltration of groundwater into the sewers. The required separation of baseflow from flow hydrographs did not eliminate all uncertainties in the observed runoff volumes. It is therefore difficult to determine to what extent discrepancies in runoff volumes were caused by the uncertainties in hydrometeorological data as opposed to the ability of the models to reproduce the observed events.

Peak flows, particularly those from small to medium events, were reproduced fairly well by both models, although uncertainties in runoff volume simulations, as discussed earlier, were also reflected in simulated runoff peaks. The mean value of the difference between observed and simulated peaks varied from 0.000 to 0.009 m^3/s for the best three simulation series. Simulation run S1 of SWMM used only the sewers as transport elements while simulation run S2 of SWMM also employed street gutters which fed into sewers. The almost identical results between S1 and S2 suggest that a detailed modelling of transport elements within sub-catchments is unimportant as long as the correct length of travel is preserved.

When considering both runoff volumes and peaks, the best five simulation series produced comparable results for small to medium events. For events with large rainfall and runoff, it was desirable to account for an increased contribution of pervious areas. This was best achieved in two runs with the ILLUDAS model, in which the soil group B and 5-day antecedent rainfall were considered. Similar conditions could be reproduced by the SWMM model.

4.4.3 Comparison of Runoff Computational Methods

The choice of the computational methods depends more on the general requirements on the calculated results than on their perceived accuracy. When comparing the Rational, ILLUDAS, and SWMM methods, the differences in the scope of their applications are quite important.

The Rational method is applicable to relatively small catchments where no runoff control or water quality considerations are contemplated. Under such conditions, drainage design is limited to sewer sizing for the peak flows which can be produced by the Rational method. The method is particularly well applicable to the catchments with intermediate-to-high imperviousness where runoff is controlled by impervious areas. In all other cases, it is recommended to use runoff models. Hydrologic models provide better results for runoff computations for pervious areas and also provide entire hydrographs which may be required in runoff control considerations. Among various models, it is recommended to proceed in the selection process from the simplest models toward the more complex ones. In this sense, the ILLUDAS model represents the next level of sophistication above the empirical formulae. It is suitable for design of sewer systems with free flow in sewers and runoff storage considerations. Where runoff quality and/or flow routing through surcharged sewers or special hydraulic structures are needed, a complex model, such as SWMM, need to be used.

4.5 Urbanizing Watershed Study

In order to provide an indication of any significant change in the response of the Waterford River Basin to snowmelt and/or storm rainfalls since streamflow records were first collected in 1974, two hydrologic models of the watershed were calibrated. The HYMO model, a single event deterministic hydrologic model, simulated the short term response of the catchment to individual storm events. The HYMO model was also used to provide an indication of the change in direct storm runoff which can be anticipated as a result of future urbanization as well as to estimate peak flows of given return periods which can occur based on the existing level of urbanization in the Waterford River Basin. The HSPF model, a large continuous simulation deterministic model, was applied as well. The results are presented in Section 3.3.

4.5.1 HYMO Modelling

4.5.1.1 Input Data and Calibration of Model

HYMO requires three hydrologic input parameters, namely, the hydrologic soil cover complex number (CN), and the time to peak (t_p) and the recession constant (K) of the unit hydrographs.

During calibration the average value of CN for AMC III was determined to be 95. This value is almost 10% over that calculated from land use statistics. For AMC I, the adjustment required was almost 30%. The high CN values needed to match observed and simulated hydrographs indicate a high runoff potential. As discussed in Sections 4.2.1 and 4.2.2, the presence of relatively thin and impermeable surficial materials and exposed bedrock conditions in the watershed results in a large portion of storm rainfall contributing to direct runoff and it accounts for the relatively high CN values needed for calibration.

The HYMO program provides empirical equations for the estimation of the parameters k and t_p. For best calibration results, the parameters k and t_p had to be set at, respectively, 8 and 7 times that computed by HYMO. It was initially believed that the large adjustments required to the parameters k and t_p were also related to the characteristics of the overburden. It was felt that the overlying, more permeable till deposit, in association with the relatively impermeable lodgement till and bedrock, may be producing a large amount of flow just under the surface (interflow). A subsequent simulation of one event using the entire study area as one hydrologic unit, however, indicated that values of k and t_p, only approximately two times those provided by the HYMO program (used as initial estimates) were required to obtain a good match to the observed flows. It was concluded then that a possible explanation for the large adjustments required to the initial estimates of k and t_p might be related to the size of the Hydrologic Units (HU) used for running HYMO. The drainage areas of the HUs into which the study area was divided were about the size of the smallest ones used in the derivation of the equations used internally by HYMO.

Precipitation and streamflow data were required for the calibration of the HYMO model. At six of the seven locations within the study area at which rainfall data were collected, there was an apparent undercatch problem. The recorded rainfall amounts had to be adjusted to be, on average, not less than those recorded at the CDA permanent standard gauge. A network of seven gauging stations in the basin was considered reasonably good considering the size of the basin. It was felt, however, that the network did not adequately represent the higher topographic areas, located at the drainage basin boundaries.

The modelling work indicated that significant problems were encountered in the simulation of streamflows. The problem may be related to the undercatch problem in the rain gauges as described in the previous paragraph or, which is more likely, to a poorly defined streamflow rating curve for high flows. The river channels in the basin are generally gravel-lined with some areas being cobble-paved, where bedrock controls the channel. Where the channel bed is movable, gravel bars are formed and are scoured out during high flow events.

It is therefore not unreasonable to expect a significant amount of error in the recorded high flows since the relationships between water level and streamflow are likely to be poorly defined for high flows. In fact, during the course of the study, the rating curve for Kilbride was adjusted downward by the Water Survey of Canada by as much as 30 percent for high flows, as a result of field measurements. This type of uncertainty in rating curves is not unreasonable when peak flows, of the magnitude used in the modelling exercise, have not been measured in the field and when the metering section contains shifting gravel beds. This implies then that it is not unreasonable to conclude that the peak streamflow data for Donovans and Mount Pearl may be in error, and low, by the amount by which simulated and observed streamflows differed at the two sites (25 percent and 10 percent respectively).

4.5.1.2 Impacts of Present Level of Urbanization

In order to assess the historic impact of urbanization on peak flows in the Waterford River Basin, two events which produced high streamflows in 1974 were simulated using the calibrated model based on 1981 land conditions. One event generated a peak flow lower by 21% while the other produced a flow higher by 10%. Thus, it was concluded that any urbanization which occurred between 1974 and 1981 had no significant impact (i.e. greater than the error range associated with model calibration) on high streamflows at Kilbride. However, it must also be realized that the amount of developed land increased from just 12 percent to 17 percent from 1974 to 1981.

4.5.1.3 Impacts of Future Urbanization

In order to evaluate the effects of various development scenarios on peak flows and water levels, HYMO was applied by varying the lag times, recession characteristics, and direct runoff volumes. To adequately simulate the future conditions in the watershed, the curve numbers (CN), the time to peak (t_p), and the recession constants (k) for each hydrologic unit were modified in accordance with the development predictions.

As discussed previously, the average runoff curve number (CN) for the study area is 95 for wet antecedent conditions. This implies that, under wet conditions, almost all storm rainfall contributes to direct runoff. Even under dry antecedent conditions, the average CN is 87. Assuming that the calibration of the watershed model HYMO to the Kilbride hydrometric station is based on reliable data and hence the CN values are accurately estimated, then these high CN values imply that there is not likely to be much increase in storm runoff volume at the outlet of the study area, even with complete development.

Flow simulations for projected development indicated hypothetical increases in peak flows varying from 14 percent at Kilbride to 23 percent at Donovans. As would be expected, a greater relative increase was projected for the less developed areas.

It was therefore concluded that since the amount of urbanized land in the study area is not great (as of 1981, approximately 17 percent), and because the overburden material in the basin is very thin, it is unlikely that urbanization has had, or could result in, a very significant (greater than 20 percent) increase in direct runoff associated with high streamflow peaks. Projections of the change in high peak flows for a fairly complete level of development in the basin suggest the possibility of an increase of no more than 23 percent. This is due to the unusually high proportion of impervious areas in the Waterford River Basin.

4.5.1.4 Estimation of the 20 and 100-year Floods using HYMO

The procedure used to estimate the design floods began with the determination of storm parameters, which include the time distribution, the rainfall amount and the storm duration. Then, using the calibrated watershed model and an appropriate antecedent moisture condition, the peak flows were simulated. These peak flows were then compared with peak flow estimates obtained from a single station (at Kilbride) flood frequency analysis. At Kilbride the simulated design floods were within the 95% confidence limits of the frequency estimates of the design floods.

4.5.2 HSPF Modelling

Continuous simulation is required to properly model low flows, seasonal variations in streamflow, effects of antecedent conditions on streamflow generation, and water quality. To investigate these phenomena and meet the study objectives, streamflow in the Waterford River Basin was simulated by means of the Hydrologic Simulation Program - Fortran (HSPF) model.

4.5.2.1 Calibration of Model

Calibration of the HSPF model was comprised of the estimation of the initial values of all HSPF parameters, and the simulation of annual flows, seasonal/monthly flows, snowmelt parameters, and storm hydrographs.

In assessing the goodness of fit between simulated and observed results, it should be recognized that, at best, streamflow discharges are measured with accuracies in the range from 5% to 15%. Even greater inaccuracies are encountered at gauging stations with shifting controls, as was the case in this study. Consequently, it would not be realistic to expect any model to reproduce the observed discharges with significantly better accuracies than 15 - 20%.

4.5.2.2 Simulation Results

It is believed that better modelling results could have been obtained with better precipitation data. The available precipitation data were obtained from a single gauge and their representativeness for the whole basin could be questioned. Although the basin is relatively small, the distribution of precipitation could be influenced by orographic effects. Another area of possible improvement would be the description of dimensions of the flow routing channels. For simulated discharges, it is necessary to know the channel geometry and channel rating curve. Without such data, it is impossible to identify the bank-full discharge and to consider channel overflows with significant impacts on flow routing.

Considering the above limitations, the simulation results obtained are fairly good. In fact, the agreement between the simulated and observed flows is about as good as the accuracy of the observed flow data. The simulated streamflow matches the observed one for annual and monthly flow volumes, as well as for peak and low flows. The actual application of the HSPF model to the Waterford River Basin led to numerous practical findings which are summarized below and should be useful in future applications of this model.

The HSPF model is a lumped model and this feature strongly affects the application procedures for this model. It should be applied only in conjunction with calibration data that should cover a period of two to three years. Such calibration data are used to establish the values of numerous model parameters which represent lumped values. Without distributed calibration data, it is pointless to discretize the study area into a large number of land segments. This was the main reason for the basin discretization used in this study in which the basin was divided into three land elements, the impervious part, and two pervious segments.

The size of land segments also affects the selection of the computational time step. For rational utilization of the input data base, the computational time step has to reflect the discretization time interval in the input data series. In this study, the data base contained hourly data and this limits the minimum size of the land segments. Finally, the computational time step affects the length (and therefore the number) of the flow routing reaches. For hourly data and slopes found in the study basin, the best routing results should be obtained for reach lengths of about 4.7 km, or somewhat less. It follows that the modelled section of the Waterford River can be realistically divided into two flow routing reaches only.

There is a close connection between the detail of input and calibration data and the way the HSPF model can be used in conjunction with such data. Considering the Waterford HSPF database with a single continuous flow record and hourly data, this database can realistically support only HSPF applications with relatively low numbers of land and flow routing elements. The discretization used, with three land segments and two flow routing reaches, was quite appropriate as obvious from the modelling results which reproduced the observed flows fairly well. More detailed discretization would require more detailed input data. There is a general need for better coordination between data collection efforts and modelling activities in future studies with the HSPF model, focusing in particular on high quality continuous hydrologic data collection.

4.5.2.3 Simulations of Future Land Use Scenarios

The impact of urbanization on the hydrologic regime is generally manifested by an increased volume of runoff, due to the increased drainage imperviousness, and the increased speed of runoff, due to the increased drainage density and hydraulic improvements of transport elements. Both factors may then contribute to the increased incidence of flooding in the receiving waters.

The impact of urbanization on the hydrological regime of the Waterford River was studied by applying the HSPF model to hypothetical future land use scenarios. The basin response was fairly insensitive to the changes in land use, mostly because of the special physiographic and climatic basin characteristics. A very high percentage of precipitation in the basin is converted into streamflow because of relatively low basin evapotranspiration.

Consequently, any future development does not seem to affect the volume of streamflow much. On the other hand, the temporal distribution of the runoff volume is affected resulting in increased peak flows.

Increases in runoff volume are typically evaluated in hydrologic studies by increasing the basin imperviousness. In this study, the unusual basin characteristics led to somewhat rare results indicating that the streamflow volume should remain practically unchanged regardless of future urban development. The basin geology, characterized by a solid bedrock and poorly drained soils, and low evapotranspiration contribute to a very high basin yield which does not seem to be affected by further increases in imperviousness.

It should be emphasized that streamflow simulations for future land use scenarios employed an increased watershed imperviousness as the main factor for investigating the impact of urbanization on runoff volumes and peaks. Additional increases in runoff peaks may be caused by the increased speed of runoff in new developments which follows from increased drainage density and replacement of natural rough surfaces by smooth man-made channels and conduits. Simulations of such effects, by means of physically based models capable of reflecting basin changes, would require detailed characterization of the future development in terms of imperviousness, drainage density, and roughness and connectivity of drainage elements. This information is generally not available during the planning of hydrologic studies.

It is conceivable that future peak flow increases resulting from both increased volume and speed of runoff would exceed those due to changes in the watershed imperviousness alone. It should, however, be recognized that increases in the speed of runoff can be effectively counteracted by application of stormwater management techniques. Such techniques include runoff detention and retention, preservation of natural surface cover and drainage, and restricted drainage density. Applications of these techniques would minimize the impact of future development on streamflow in the Waterford River Basin.

The HYMO modelling efforts focused mostly on changes in runoff volumes and, consequently, did not indicate any significant increases in runoff peaks. In this regard, the HSPF results are more realistic.

4.5.3 HEC-2 Modelling

The designed 20-year and 100-year peak flows used for the HEC-2 modelling were derived from using the HYMO model as discussed in Section 5.5.1.4. When this study was initiated, it was expected that there would be considerable urbanization of the Waterford River Basin within the 5-year study period. This would possibly have provided the opportunity to examine the effect of flooding due to urbanization and to develop a flood management strategy. The anticipated development did not occur. However, it was assumed urbanization might increase peak flows by 30%. Thus the HEC-2 model was run with an assumed increase of 30% to the design flood flows to simulate the potential effects of future urbanization. The results are presented in Section 3.3.9.

4.6 Water Quality Study

4.6.1 Storm Runoff Quality in the Newtown Urban Catchment

Stormwater quality in the Newtown catchment shows the typical signs of pollution associated with urban runoff. In comparison to data from other urban areas, however, the Newtown catchment shows a relatively low degree of pollution. This may follow from the relatively low density of urban development, a low level of land-use activities, and the absence of large industrial complexes in the catchment. It is conceivable that some improvement in the Newtown stormwater quality could be achieved by disconnecting the remaining source of sanitary sewage from the storm sewer system. While this single connection does not represent a particularly strong source which would continuously affect the composition of stormwater, it may contribute to some very high concentrations of nitrogen and bacteria occasionally observed at the outfall. Brief discussions on the results of monitoring selected parameters follow.

Dissolved oxygen values were relatively high, varying from 7.2 to 12.0 mg/l. The critical low value for aquatic organisms is 4.0 mg/l. Such fairly high values, therefore, indicate that the stormwater discharges studied do not induce any stress on dissolved oxygen in the receiving waters.

Values of specific conductance were high relative to those from background (rural) surface water stations in the basin and reflect the effects of urban activities and pollution.

The highest values were observed during the winter months and reflect the effects of road salt applications.

Suspended solids were found in concentrations typical for clean urban catchments, ranging from 2 to 366 mg/l with a mean of 52 mg/l. Such a low range of values indicates a somewhat lower production of suspended solids than is usually encountered in residential areas and is probably due to the relatively lower density of urban development.

Among the major ions, dissolved sodium, chloride, sulphate, and calcium were found in somewhat elevated concentrations. The main sources of sodium and chloride were marine aerosol deposits and road salt. The highest reported values of sodium and chloride were clearly associated with road salting in winter months and exceeded significantly the highest values reported for surface waters in the basin. Road salt was also thought to be the main source of sulphate and calcium.

Among metals, only zinc and lead occurred in concentrations which may cause some concerns because they exceeded safe guideline limits for aquatic life. The true toxic potential of these metals, however, could not be properly evaluated, because the data produced in this study represented extractable metals and thus included those metal quantities which were originally adsorbed on the particulate matter and were not readily available to the aquatic biota as dissociated toxic forms. The main sources of zinc include galvanized sewer pipes, tires, and soils. Because of low traffic density in the area, lead concentrations in Newtown were low relative to those in other urban areas.

Nutrient levels in Newtown stormwater were also fairly low and did not cause any special concerns. The relatively low values of total nitrogen, phosphorus, and carbon may be explained by the relatively lower fertility of the Newtown soil.

Finally, although the bacteria densities were also low, they indicated a presence of significant sources of bacteria. Pollution from total coliforms and fecal coliforms was probably caused, to a large extent, by the remaining connection of sanitary sewers to storm sewers in the drainage system.

4.6.2 Surface Water Quality in the Waterford River Basin

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. Many factors have, therefore, to be taken into account to explain the variation in the physical and chemical characteristics of river water. The discussion that follows is limited to the physical, chemical, and bacteriological quality of the water collected from the eight stream sampling stations in the Waterford River Basin.

4.6.2.1 Variation of Water Quality Parameters with Discharge

Most of the physical water quality parameters had irregular relationships with flow rates during rain events. Turbidity and suspended solids often peaked before the actual hydrograph peak, suggesting that the retention capacity of the drainage basin is low.

The parameters most affected by rain events and resulting runoff were the metals which in some cases had very high concentrations. However, it is believed that these metals were not totally readily available as dissolved species to the aquatic biota. In addition, soon after an event, all metal parameters rapidly attained their lower "typical" levels in river water.

The general effect on 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.

Nutrient concentration variations also had irregular patterns with discharges. 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.

4.6.2.2 Surface Water Quality Characteristics

This study has shown that urban and industrial development in 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. In the undeveloped area of the basin, generally speaking, the water is soft with low dissolved and suspended solids concentrations. In the upper reaches the coliform counts are at or close to detection limits for the test. More specifically, the monthly data for physical parameters at the headwaters stations are consistently low for specific conductance, highly coloured, and acidic, as are the majority of Newfoundland rivers draining a mix of coniferous forests and bogs. In contrast, the stations downstream from the developed areas have higher values for specific conductance, turbidity, and pH. The latter are all indicators of removal of forest cover and disturbance of surface soils. Seasonally one sees the effects of de-icing salts reflected in higher specific conductance in the winter and the results of applications of lawn and agricultural fertilizers and/or lime reflected in higher pH's during late spring and early summer.

Similar seasonal trends are observed for the chemical parameters such as nutrients, major ions, and metals. The headwaters site is nutrient poor, low in major ions concentrations, and the levels in trace metals is limited to iron which is ubiquitous in acidic bogs. At the sampling stations which are downstream, summer levels of nutrients, from lawn and farm fertilizers or a feed mill in the light industrial area, are higher than winter values when the ground is frozen. High levels of nutrients could lead to extreme autotrophic productivity under certain conditions of low river discharge. However, the very high nutrients concentrations were generally observed during high river discharge periods when the water turbidity was high and these periods did not prevail for a long time in the river; their pollution effects are therefore limited.

The major ions values were dominated by sodium chloride which came from both marine aerosol and de-icing activities. The combination of these sources served to keep levels in the developed part of the basin quite constant year round. The high levels of these ions exceeded by far the typical concentrations observed in "*natural*" Newfoundland waters.

Trace metals such as lead and zinc were present at levels just above the detection limit but tended to be quite variable. Some instances of very high concentrations of trace metals in the river were observed; these could have potentially toxic effects on some of the aquatic biota. These episodes of high concentrations, however, occurred most often during high river discharge periods and did not prevail for a long period of time. Their pollution effects may therefore be limited. It can be concluded that contributions of trace metals to the water column are sporadic as might be expected in the absence of any heavy industry in the basin.

Bacteriological analyses were limited to the last two years of the study but certain trends did emerge from the data. Obtaining precise and accurate estimates of bacterial populations in river water is complicated by their highly non-random distribution. 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. Fecal coliform values, indicators of waste from warm blooded animals, were low during winter and summer from the undeveloped area of the basin. The values were elevated in the waters draining residential, commercial, and light industrial areas of the basin. Highest values were recorded in the summer months and lowest in mid-winter. Fecal coliform to fecal streptococcus ratios indicated that the wastes were a mixture of human and animal wastes.

The high bacterial counts and FC/FS ratios 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 high FC/FS ratios indicating 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.

4.6.2.3 Water Quality Sampling Methodologies

The location of the surface water quality stations was planned to observe the water quality from the 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 water quality, before it passes through the industrial park, on a regular basis during the study period.

The automatic river water event sampling program at Kilbride was very useful to further illustrate the importance of runoff loadings on the surface water quality. Section 4.6.2.1 of this report provided a general discussion of the behaviour of the water quality parameters in relation to flow rates monitored during rain events on the basin. 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 climatic and flow event conditions, for a period of more than three years. The major drawback in this program was the copper and zinc contamination problem from the automatic sampler.

4.6.2.4 General Discussion

Although there are obvious physical, chemical, and bacteriological water quality problems (most of these seem to originate from sanitary and storm sewer 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 stations in the basin and most of the peak concentrations of suspended solids, nutrients, and metals were observed during periods of high flows and were the results of the washing effect of rain events and related runoff.

4.7 Biological Study

The biological study was conducted to determine the effects of urban development, and its associated stresses on the biological environment of the Waterford River Basin. Generally, there is a direct correlation between poor water quality and reduced invertebrate diversity. Thus, the benthic community structure can be taken as a general indicator of total water quality condition. A well-balanced benthic community is an indication of undisturbed environmental conditions while a community that is dominated by one or a few taxa is an indication of a disturbed environment.

4.7.1 Invertebrate Sampling

The ensuing discussion is primarily based on a site-by-site comparison. Clean water and unclean water sites are identified, as well as which taxa tend to be found in clean and unclean water.

The sites were divided into four categories on the basis of the faunal data;

1.	"Clean" Sites	3 and 8
2.	"Fair" Sites	1, 4b, and 5
3.	"Poor" Sites	2, 6, and 7
4.	"Extremely Poor" Site	4a.

Site 1 contained many individuals of a few taxa, namely chironomids and hydropsychid species, although small numbers of other taxa were collected.

Sites 2, 5, 6, and 7 all had a similar pattern of a few species dominating both biomass and number of individuals.

Site 4a contained very low numbers of individuals and few taxa, with terrestrial earthworms and tipulids dominating the site in large numbers. The numbers of mayflies, stoneflies, caddisflies, and water beatles collected were far below that of any other station. The poor water quality of this site, and the observed poor fauna, is most likely a result of the combination of runoff from the pasture, with its high fecal content, and the entrapment of invertebrates in the reservoir. A flock of geese is maintained at the reservoir, which is also undoubtedly affecting the quality of the water immediately downstream. It is unlikely that the poor water quality is a result of any upstream perturbation or input, as Site 4b showed a much higher diversity, and supported a much more "healthy" community, indicating a cleaner environment.

Site 4b, located just upstream above the small dam showed a much higher diversity of invertebrates than Site 4a. Some invertebrates can be depleted in streams below dams since insect drift from upstream areas is unavailable to replenish the individuals lost from the stream segment below the dam.

Although Sites 3 and 8 had low sample biomass, the number of individuals was fairly high and more importantly the diversity indices were the highest of the different sites sampled during the two-year study.

Removal of vegetation along streams can result in ecological conditions that originally characterized lower reaches of rivers (e.g., nutrient levels) but have now been shifted upstream. In addition, because downstream conditions are dependent upon upstream functions, alteration of the riparian habitats of headwaters streams can be reflected in lower reaches. Shading can affect the occurrence and abundance of certain species. The poor diversity of Site 1 could be a reflection of the lack of vegetation upstream of the site. Other sites that were not shaded include Sites 1, 2, and 4a.

Dominant populations of chironomids and annelids are often characteristic of polluted conditions, however, in this study the distribution of these taxa did not reveal that pattern. It is possible that artificial substrate samplers did not collect these organisms or the cleaning and sorting techniques used resulted in the loss of the smaller chironomids and annelids from the samples.

Stoneflies (Plecoptera), although not too sensitive to high pH, are sensitive to most other water quality parameters. The distribution pattern of the stoneflies indicates that they are "**clean water**" organisms since most specimens were found at Sites 3 and 8.

The water beetle (Coleoptera) is usually associated with aquatic mosses which are generally characteristic of clean water. The water beetle was found in large numbers at Sites

3 and 8, and in smaller numbers at Site 1. The presence of "**clean water**" taxa, such as stoneflies and water beetles at Site 1 indicated that the site was fairly clean, probably due to the mixing of South Brook water with the Waterford River water.

Most of the caddisflies (Trichoptera) seem to prefer "**clean water**", but some species appear to be more pollution tolerant. Hydroprychid species tend to favour some degree of pollution since the populations were found at the "**fair**" and "**poor**" water sites.

4.7.2 Water Quality and Benthos Distribution

In the discussion which follows, the statistical correlations between stream characteristics, water quality data, and invertebrate data do not necessarily imply cause and effect relationships, they are simply measures of association between them.

4.7.2.1 Correlations between Stream Characteristics and Invertebrate Data

The number of individuals collected at a site had a significant positive correlation with stream order, drainage area, and flow rates but diversity and biomass were not significantly correlated with the stream characteristics. The Waterford River Basin is probably too small to permit detection of major natural changes in fauna due to changes in the stream order.

4.7.2.2 Correlations between Stream Characteristics and Water Quality

The one water quality parameter which correlated significantly with the stream characteristics was dissolved chloride. All other water quality parameters examined did not correlate significantly with the stream characteristics. Salty air, due to the Waterford River's proximity to the ocean, along with runoff from winter application of road-salts could explain the positive significant correlation of chloride observed in the river systems: downstream areas contained higher levels of dissolved chloride than upstream areas.

The lack of significant correlations of the other water quality parameters with stream characteristics indicates that the river is probably suffering from environmental stress. Natural rivers usually show a general pattern of changes in the stream characteristics, both chemical and physical, from headwaters streams to the higher order downstream reaches. Inorganic nutrients (e.g., nitrates and phosphates) and suspended solids usually show an increasing trend over the course of a river system. Soluble organic compounds are generally found with high concentrations at headwaters streams because it is here that maximum interface with the terrestrial environment takes place.

The Waterford River does not show the above-noted patterns of high organic carbon levels in headwaters areas and decreased levels downstream or an increased level of inorganic nutrients in higher order streams. Site 8 did show the physical characteristics and a diverse community typical of a headwaters tributary; the typical downstream patterns, however, were not observed. Because of this, the river can be assumed to be under environmental stress. Pollution has probably caused a shift in the water quality parameters.

4.7.2.3 Correlations between Water Quality and Invertebrate Data

The diversity indices and the number of taxa were significantly negatively correlated with nitrate-nitrite and total alkalinity. An increase in these water quality parameters will result in a decrease in diversity and the number of taxa.

One of the possible main sources of nitrates is human and animal wastes; high concentrations of which may reflect unsanitary conditions. As the Waterford River system drains large areas of unserviced residential development and pasture land, it is likely that the increased nitrate-nitrite levels observed are due to waste material. Increased pollution usually results in decreased diversity in the fauna and thus the negative correlation between diversity and nitrate-nitrite and dissolved nitrogen could be expected.

As the hardness of water decreases, worms, shrimp, molluscs and finally chironomids tend to decline in importance to the functioning of the ecosystem, and are replaced by various insects, particularly mayflies and stoneflies. The results of this study indicated a decrease in diversity and number of taxa as the alkalinity increased, however, few worms, shrimp, and molluscs were collected and definite conclusions on the effects of alkalinity on diversity can not be made. The source of alkalinity (given that there are no large geological deposits of calcite or dolomite in the basin) is not known.

Biomass was significantly positively correlated with turbidity. High turbidity values can often be related to urbanization and other human activities. As turbidity increased, so did biomass, probably due to the elimination of sensitive taxa and the enhancement of more resistant taxa. Site 6, which runs through an industrial area, was highly turbid and its fauna was characterized by a large number of Hydropsyche spp., and few of anything else. Site 8, on the other hand, had very clear water, and the community was diverse, not dominated by any one taxa. Siltation and turbidity from inorganic sedimentation is perhaps the greatest single cause of water quality degradation.

The negative correlation between diversity indices and nitrate-nitrite and concomitant positive correlation between biomass and turbidity, may indicate the stream is nutrient-poor.

If decreased water quality had any effect on total biomass, it could not be detected in this study. The low biomass at Site 4a in 1985 could probably be directly attributable to the combined effects of the dam just upstream, and the pollutants and/or fertilizers from the sheep pasture.

4.7.2.4 General Discussion

Habitat changes and pollution in the Waterford River system from its many and varied sources resulted in a trend of decreasing faunal diversity, and increasing faunal biomass due to functional changes over the course of the river. Further, it was observed that the pollution eliminated the sensitive taxa while enhancing the more pollution resistant taxa. South Brook was determined to be in much better condition than the Waterford River. The two sites identified as "clean" sites were both on South Brook. The upstream reaches of the Waterford River were determined to have poor water quality, as did the tributary of South Brook in which Site 2 was located. Sites 1 and 5, both on the Waterford River, and Site 4b, upstream of the reservoir at the CDA farm, were judged to have fair water quality, and Site 4a, downstream of the reservoir and the sheep pasture at the CDA farm was determined to have the worst quality.

4.8 Groundwater Study

Groundwater is the major portion of water that is retained in any watershed. As part of the overall study of the effects of urbanization on the water resources of the Waterford River Basin, seven well sites were chosen to monitor the impacts of the various land uses in the basin on the quality of groundwater. The lack of information on the yield characteristics of wells in the basin limited the efforts to quantify the groundwater resources in the basin.

4.8.1 Monitoring Well Network

At each of the seven monitoring sites, a deep well and a shallow water table well were constructed. Overburden depths in the basin are generally thin, ranging from about 1.5 to 6.0 m below surface. This fact and the general lack of extensive confining layers within the overburden required that all artesian wells be constructed in the bedrock.

In all cases, except at Sites A and B, a positive boundary condition was encountered during the aquifer tests. This indicates that the aquifer was receiving recharge from some source as the cone of the depression extended further and further away from the well. The most likely source of recharge is the overburden. At Sites A and B the overburden is much thinner than at the other sites.

Different methods of obtaining representative water samples for water quality testing were used in the course of this study. Analyses of the various sampling methods show that they have little effect on the value of most parameters; the parameter that was influenced the most was turbidity. The slight differences in chemistry from one method to another were attributed to turbidity. Only at Site D were the differences more pronounced, but were significant only with respect to calcium, magnesium, sodium, chloride, and sulphate. Possible causes include the proximity of the well to a stream draining a subdivision and man-made disturbance through proximity of a playground.

The limited effects of surface exposure in the artesian wells on water quality parameters was demonstrated by depth profiles of dissolved oxygen, pH, temperature, oxidation-reduction potential, and conductivity. The profiles of these parameters with depth indicate that there is very little effect, at depth, of surface exposure in the well. For deep wells, at least, then the Kemmere sampling method is an adequate method of obtaining representative groundwater samples.

The hydraulic conductivity values determined during pumping tests indicate that yearly samples would be adequate to detect changes in water quality. To determine seasonal quality fluctuations, however, a quarterly sampling schedule would be required. This schedule should be maintained until these are determined and then an annual sampling will be sufficient to detect any water quality changes that may occur.

4.8.2 Groundwater Flow Systems

The original objectives of the groundwater study included (1) a definition of the major aquifers in the basin both in the bedrock and in the overburden materials in terms of depth, quantity of water available, quality of water, spatial distribution, and vulnerability to contamination or depletion, and (2) investigation of the physical and chemical processes that lead to changes in groundwater.

Because of limited resources, more emphasis was placed on the water quality effects of urban development at the expense of groundwater quantity studies. The definition of major aquifers could only be accomplished insofar as information was available from wells drilled for the purpose of monitoring the various land use activities in the basin. The determination of the groundwater component of the hydrologic budget was limited to an annual estimate of baseflow for the years 1974-83. In addition, no independent study of the physical and chemical processes that operate in the basin was possible.

The overburden in the study area is unfractured and its thickness is extremely variable, averaging less than 3 m in depth. The overburden materials of the Waterford River Basin are not very significant aquifers in terms of high yield; however, numerous dug wells constructed in this material have provided, and still provide, an adequate amount of water for domestic purposes. Their ability to do so is primarily due to their relatively large storage capacity, rather than high transmissivity. Seasonal fluctuations are likely though, because of the large water table fluctuations.

The overburden materials form an extensive recharge reservoir for the deeper bedrock aquifers. Precipitation readily infiltrates the topsoil and is held for slow percolation into the bedrock fractures. That there is some hydraulic connection between the overburden and the bedrock reservoirs is indicated by the results of the pumping tests. At each site where the shallow well was close to the deeper well, some response was noted in the shallow well when the bedrock well was pumped.

Since the overburden is thin and of low permeability in the study area, it is not a major conduit of subsurface water. It is probable that the bedrock exerts critical control over the movement of water in the basin. Since the bedrock has generally low matrix porosity, groundwater flow in the bedrock materials of the study area is primarily through fractures, at least in the near surface environment. The Signal Hill Group reported relatively higher yields; this is probably due to the numerous, well-developed joint sets in the Group.

Another function of the overburden materials is that of protection of the deeper groundwater. For this it is very well suited. Having a relatively high silt-clay content, it provides a filter and an exchange medium for waters percolating through it.

The analysis of the yearly water budget for the years 1974-1983 indicated that the average baseflow component to the Waterford River was 43 percent.

4.8.3 Groundwater Quality

Groundwater quality can be affected by geological as well as anthropogenic influences. Geological influences include the mineralogical make-up of the earth media and the length of the contact time between the groundwater and the earth media. Anthropogenic activities include urbanization, vegetation removal, agriculture, and industrialization.

4.8.3.1 Bedrock Hydrogeochemistry

Bedrock mineralogy is a significant contributor to natural groundwater quality. Consideration of contact time between groundwater and earth materials is not expected to be significant in determining groundwater quality differences between sampling points in the study area because the flow systems are very short and groundwater flows are similar, reflecting fracture flow conditions.

Groundwater quality at Sites A, B, and G are very similar; all are dominantly calcium bicarbonate waters and have similar levels of total dissolved solids. Wells B and G are in the Conception Group. Although Well A is in the Fermuse Group, it is close to the Conception Group and can be expected to have characteristics similar to those in the Conception Group.

The other wells, all in the Fermuse Formation, show waters of a somewhat different chemical character. Although calcium is still the dominant cation, sodium exerts more of an influence. More noticeably, the sulphate and chloride influence significantly lessens the bicarbonate character of these waters. Well D displays water of a predominantly calcium chloride character.

The common feature of groundwaters in the Fermuse and Conception Groups is the pH, which generally falls in the slightly alkaline range of 7 to 8.

The general dominance of the calcium cation in the water and the slightly alkaline pH are attributed to the reported calcite and dolomite mineralization. A possible source of increased sulphate in the Fermuse Group is the reported pyrite mineralization. The relatively high sulphate content in the water from well F is puzzling. The high level of calcium chloride in well D is unlikely to be naturally occurring; it is speculated that the use of calcium chloride as a dust control agent may be responsible.

4.8.3.2 Overburden Hydrogeochemistry

The susceptibility of the shallow monitoring wells to influences resulting from activities on the surface often tends to mask natural groundwater quality. The well at Site G, however, was located as a control well. The waters tend to be bicarbonate, although less predominantly so than in the deeper groundwater. Calcium predominance gives way much more to sodium than in the bedrock hydrogeochemistry. Total dissolved solids are significantly lower in the shallow groundwater. Prior to the end of 1982, Well B tended to be largely calcium bicarbonate with less sodium influence than at sites A and G. Road salt severely influenced water quality after 1982.

4.8.3.3 Anthropogenic Influences

The objective of the monitoring well network was to determine the effects of the various major land use categories in the basin - industrial, urban, agricultural, and for background information, undeveloped land. The study cannot be considered to have been exhaustive in its approach because of the limited number of wells installed and, possibly of more significance, the period of monitoring was relatively short, making it difficult to define trends.

The most obvious impact on groundwater quality from anthropogenic activities is that of road de-icing salt application. The shallow well at monitoring Site C in Mount Pearl shows high levels of sodium and chloride, but with a notable decreasing trend since the removal of the depot in 1982. Sodium chloride concentration increased dramatically in the shallow well at Site B in the Donovan's Industrial Park in 1983, reflecting the move of the depot to this site. The strong sodium chloride presence is not reflected in the deeper wells at Sites B and C. This could result from a strong component of lateral movement in the overburden near the bedrock surface (note the relatively high overburden hydraulic conductivities listed in Table 3.29).

As mentioned in Section 4.8.3.1, the high level of calcium chloride in the bedrock well at Site D could possibly be due to the use of this chemical as a dust control agent. There may be an indication of increasing calcium chloride in the shallow well at Site C.

Nitrate concentrations were well below the recommended limit of 10 mg/L as nitrogen, but occasionally exceeded the values in the background wells at Site G. Higher nitrate values were observed in the deep well at Site E and the shallow wells at Sites C and D, perhaps reflecting the release of nitrate, resulting from the removal of vegetation, or possible from human waste.

4.8.3.4 Impacts of Urbanization on Groundwater Quality

At present, with one exception, no effects on groundwater quality can be clearly attributed to the impacts of industrial, agricultural, and urban activities. The only serious effect on groundwater quality to be noted is that of road salt stockpiling and application. Dust control operations with calcium chloride may be affecting groundwater quality at one site. Higher nitrate values may result from vegetation removal or animal wastes and chemical fertilizers, but agricultural activities are not at present affecting groundwater quality at site E. It may be that the length of time that was allotted to the groundwater portion of the study was not sufficient to show the effects of development in measurable concentrations.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Discussions of the results specific to each of the component studies were presented in Chapter 4. In this section general conclusions are drawn from the results and discussions.

This study differed from most of the projects carried out by the Water Resources Division of the Department of Environment in three major respects: the focus was geographically intensive (being centred on the Waterford River basin uniquely) rather than the extensive monitoring programs normally conducted by the Division; conversely, the approach was extensive from a scientific viewpoint, and purposefully multidisciplinary. Finally, a significant development and training component existed. Therefore the results and conclusions of this study must be assessed in terms of both its objectives and the special nature of the project itself.

The first objective of the study was:

> *"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."*

A general but significant conclusion that can be drawn from the results of the study is that water quality and flooding problems in the Waterford River basin are, as yet, not too serious. The quality of water in the river is not as poor as was initially hypothesized, and it is not deteriorating (because of urbanization) as quickly as was feared. The most serious water quality problem encountered, high fecal coliform levels, is in effect a point source one which can be readily corrected if desired. While localized flooding remains a recurrent problem, particularly in the low gradient reach near Mount Pearl, it will probably not become notably worse because of urbanization of the basin. This results from the already high runoff/rainfall ratio (81%) of the basin which is due to (1) high annual precipitation occurring almost uniformly through the year, (2) thin impermeable till soils, (3) small depths to bedrock, and (4) low evapotranspiration. Flooding damage will likely only be significantly exacerbated if structural development in the floodplain occurs, or storm sewer installation without runoff detention facilities increases the rates of inflow into the river. In the first case, potential flooding damage can be prevented by proper planning and zoning. The second case was not examined explicitly in the basin hydrologic modelling exercises for this study, but standard practices requiring post-development peak runoff rates not to exceed pre-development conditions will mitigate adverse flooding effects from urbanization.

Another significant conclusion of the study is that both the percent of basin land currently urbanized and the rate of increase of this land use sector are smaller than had been assumed or expected at the outset of the study. Thus, even Newfoundland's fastest growing suburban area remains surprisingly rural.

The general conclusion is that there is no need for extraordinary measures to be taken for water management in the basin; rather, water quantity and quality concerns may be handled through deliberate planning and regulation in the normal course of growth. Pertinent conclusions of each component study are presented in the following subsections.

5.1.1 Geology

Bedrock in the Waterford River basin consists largely of Precambrian materials, mostly sedimentary in origin but with some volcanic deposits. The most significant features which influence the river course in the basin are major plunging folds and fracture zones in low porosity rocks which generally slope toward the Waterford River and South Brook.

Most of the study area is covered by materials of glacial origin which range in depth from 0 to 5 metres. The overburden is composed of a very compact, poorly sorted lodgement till with high silt-clay content overlain by a till deposit that is loose, coarser, and more permeable. Water movement is largely determined by the overburden mantle.

5.1.2 Land Use

The study area has not experienced any significant change in land uses during the period under study. There was only a small increase (2.1%) in urban land use. There has been sustained decrease in forestry and agricultural uses. This decline contributed mostly to unproductive land areas (cleared and open areas) which generally is a transitional stage between forest and developed land. These changes were observed to be generally similar in all sub-basins. The extent of urbanized area in any of the sub-basins did not exceed 20 to 25%.

5.1.3 Storm Runoff from the Newtown Urban Catchment

Water Quantity - Flow Simulations using ILLUDAS and SWMM

Runoff events observed in the Newtown urban catchment were successfully reproduced by the two simulations models used - the ILLUDAS and the SWMM urban runoff models. For relatively smaller storms (rainfall < 50 mm), the contributions of pervious areas were rather small and without much calibration, both models reproduced the mean observed runoff volume within 10% of the mean value. For individual events, the differences between observed and simulated volumes varied from -25% to 13%.

Runoff peak flows were reproduced fairly well by both models. The mean value of the difference between observed and simulated peaks varied from 0.000 to 0.009 m^3/s for the best three simulation series.

For events with large rainfall and runoff, it was desirable to account for an increased contribution of pervious areas by assuming the soil group B and the antecedent moisture conditions based on the 5-day antecedent rainfall.

Water Quality

The composition of Newtown stormwater shows typical signs of urban pollution arising from characteristic land-use activities. In comparison to other urban areas, the Newtown stormwater is relatively unpolluted and this may follow from a relatively low density of the development, low levels of urban activities (e.g., light traffic), and absence of industrial complexes within the catchment.

5.1.4 Urbanizing Watershed Study

Three significant results about the hydrologic regime of the basin came from this study. The first is that, on a 10-year average basis, about 81% of the precipitation eventually appears as streamflow. This is a higher than anticipated value. The second is that about 43% of the Waterford River flow is contributed by baseflow. Thus, during an average year, 46% of the precipitation is "*immediate*" runoff, 35% goes into the ground and appears as baseflow, and 19% is lost through evapotranspiration. The third interesting general hydrologic finding is that the lower bedrock aquifer is hydraulically connected to the surficial one, and probably carries an appreciable flow through fracture and joint systems.

Watershed Modelling using HYMO

No significant change in the time of concentration could be discerned between 1973 and 1981 by applying the HYMO model calibrated to 1981 land use conditions in conjunction with rainfall and streamflow data for two events in 1974. Based on these two simulations, it would appear that the urbanization which occurred between 1974 and 1981 has probably had no significant impact (i.e., greater than the error range associated with model calibration) on peak streamflows at Kilbride. However, it must be realized that the amount of developed land increased from just 12 to 17 percent between 1974 and 1981. It is also unlikely that urbanization had a very significant (e.g., perhaps greater than 20 percent) increase in the volume of direct runoff associated with high streamflows.

Watershed Modelling using HSPF

Streamflow in the Waterford River basin has been reproduced fairly well by means of the calibrated HSPF model. Good to very-good match between the observed and simulated data was obtained for annual and monthly streamflow, and for low and peak hourly flows.

The calibrated HSPF model was applied to three hypothetical future land use scenarios representing increases in the basin imperviousness area by 50%, 100% and 200%. It was noted that any future developments in the basin will not greatly affect the annual or monthly streamflow volumes, but it will lead to higher flow peaks and increased incidence of flooding. By tripling the impervious area existing in 1984, the annual streamflow volume increases by only 1%. This follows from the fact that under the existing conditions about 81% of precipitation is converted into streamflow. Such percentage is unusually high and there is not much room for further increases resulting from expanding impervious areas. The doubling of the impervious area would result in increases of the largest peak flows by up to 25%.

5.1.5 Surface Water Quality

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. While some higher "*first-flush*" concentrations of nitrite-nitrate, total nitrogen, total phosphorus and extractable metals were observed following precipitation events, these diminished quickly. In general the quality of the surface waters of the river is good, except for fecal coliform contamination at a few locations. Autotrophic productivity, due to high nutrient loadings, was not a problem, except for the lowest flow events at some sites. Higher values of chlorides were observed closer to the sea (as expected), and downstream of a salt depot at Donovans. The fair to good physical, chemical and bacteriological conditions of the water in the river corresponded to the analogous results obtained during the biological study of the river.

5.1.6 Biological Study

The biological survey showed that the Waterford River was, overall, in acceptable condition. It was possible though, through statistical analyses, to identify reaches with less than desirable biological indices. These reaches were near Donovans, the Agriculture Station, and downstream of Mount Pearl. The latter reach was the least affected of the three. South Brook was in good condition and improved the Waterford River quality below the confluence through mixing. The relatively inexpensive biological water quality assessment techniques used for this study show promise for generic application in the rivers of the Province, and further development work is warranted.

5.1.7 Groundwater

The groundwater results are preliminary because of the very limited number of wells and the short duration of the study in comparison with the time scale of groundwater flow processes. This indicates a need to obtain a better understanding of this valuable, but hidden, resource. Basin groundwater quality is, in general, good with the surficial aquifer having somewhat better water quality than the deep one. The two aquifers are hydraulically connected, likely through extensive fracture and joint zones, so that piezometric response at depth is almost as volatile as in the surface aquifer. Substantial recharge (about 35% of precipitation) occurs.

5.1.8 Modelling of Hydrologic Processes

The second objective of the study was:

> *"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 Waterford River Basin."*

Several hydrologic and hydraulic models including ILLUDAS, SWMM, HYMO, HSPF and HEC-2 were applied during the study. During the applications of these models, emphasis was placed on higher flows, both peaks and volumes.

The urban hydrology models, SWMM and ILLUDAS, were used to simulate precipitation-runoff events from an urbanized catchment with a storm-sewer system. Volumes of runoff as well as peak flows for smaller storms (< 50 mm) were reproduced well by both models. For heavier storms (> 50 mm), infiltration rates needed to be calibrated to properly simulate runoff contributions from pervious areas. In this respect, the ILLUDAS model offered more convenience and flexibility than the SWMM model because the user can select the appropriate rates by specifying the soil type and the antecedent moisture conditions for the 5-day antecedent rainfall. The same effect could be achieved with the SWMM model by calculating infiltration rates for various AMC conditions and substituting them into the model. The SWMM model has some distinguishing features which are of importance when dealing with runoff quality, storage and treatment, and when analyzing receiving waters. Making use of these features was outside the scope of the study. In conclusion, the ILLUDAS model represents the next level of sophistication above the empirical methods such as the Rational Method and is suitable for design of sewer systems with free flow in sewers. Where flow routing through surcharged sewers or special hydraulic structures and/or runoff quality are needed, a more complex model, such as SWMM, must be considered.

The hydrologic models, HYMO and HSPF, were used to simulate precipitation-runoff events in the Waterford River Basin. Difficulties were encountered in the calibration and verification of HYMO because CN numbers close to the limit of 100% were required. This was due, in part, to the known high values of yield (about 81%) in the basin. The results of the application of HYMO indicate that volumes of runoff and peak flows were not significantly being affected by the urbanization of the watershed. Although the HSPF application was limited by the available data, computational capability, and scope, fairly good calibration results were obtained for both peak flows and volumes of runoff. Also, increases in peak flows due to urbanization were more significant with applications of HSPF than with HYMO. The HSPF model has significantly more "*calibration*" parameters than HYMO and is, therefore, more flexible. A further advantage of HSPF over HYMO is that while HYMO is a single-event simulation model, HSPF is a continuous simulation model. Single-event models are generally unsuitable for investigations of low flows, seasonal variations in streamflow, and the effects of antecedent conditions on streamflow generation. In conclusion, if the quantity and quality of data available are reasonable, the HSPF model is preferable to HYMO in basins where the yield is relatively high, and simulation of low and seasonal flows is necessary.

HEC-2 was the only hydraulic model used to simulate flood levels in the Waterford River. HYMO results were used as inputs to HEC-2. Given that no other hydraulic model was used, the imprecision of the HYMO input data, and incomplete channel cross-sectional field data, a conclusion on the hierarchy of models for simulating flood levels cannot be made.

A very important benefit of the modelling studies was training of personnel. It provided an opportunity for Federal and Provincial staff to learn and test these common hydrologic and hydraulic models.

5.1.9 Solutions to Water Management Problems in the Watershed

The final objective of the study was:

> *"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 urban development which are related to the environmental protection of the affected water resources."*

The Waterford River Basin study was a success in that a great amount of useful information encompassing several disciplines was collected for a specific basin of concern. This information base can permit regulatory agencies to make reasoned decisions with regard to planning and environmental regulation in this (relatively) rapidly-growing area and provide a basis for judgement for water management in similar basins in other parts of the Province.

Recommendations on the management of urban water resources are given in the next section. To date though, general guidelines and planning and management criteria still need to be developed. Such work is logically subsequent to this study.

5.2 Recommendations

General recommendations can be offered in both the technical and regulatory areas of urban water resources management. Five years have elapsed since the end of this study and the issuance of this report, and several recommendations made in the reports on the component studies (such as continued monitoring) have been implemented. Thus, due to the passage of time, recommendations in this section are few.

5.2.1 Technical

1. *Further hydrologic studies should be done to better define and confirm the high basin yield and recharge rates found in this basin. An assessment of the generic nature of these findings is required.*

2. *Precipitation data for modelling precipitation-runoff events needs to be more reliable by improving data collection procedures. Equipment redundancy and higher levels of operational support (including modeller participation) are required.*

3. *For the application of the hydrologic model HYMO in basins with very little precipitation and streamflow data, detailed surficial geology information should be provided for accurate estimation of the runoff coefficients (CN).*

4. *The water quality part of the HSPF model should be set up and calibrated.*

5. *The biological techniques used for this study show promise for low-cost general application. Further development and testing is warranted.*

6. *Because of the time scale involved in groundwater flow processes, the groundwater monitoring should be continued for a longer time to develop a better understanding of the groundwater regime.*

5.2.2 Regulatory

1. *The cross-connections causing high values of fecal coliforms in the Waterford River need to be removed and further cross-connections discouraged.*

2. *While the risk of flooding due to urbanization does not appear to be increasing, it is prudent to ensure that regulations requiring stormwater runoff detention capability for new drainage systems be strictly enforced.*

3. *Further to (2), infilling of the floodplain, or major modifications to it, should not be permitted or acquiesced to. The portion filled in near Donovans should be re-excavated to return the floodplain to its former dimensions.*

4. *Pollution generated by the Agricultural Station should be reduced by treatment on-site.*

5. *Construction-related turbidity should be minimized by strict enforcement of water quality regulations.*

5.2.3 Further studies

Further studies of a similar nature on this basin are not recommended as the results of this study satisfy near term information requirements. However, similar intensive studies on other basins in the Province should continue to be undertaken to supplement the extensive monitoring work normally conducted by the Water Resources Division, and to provide experience and training to staff.

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