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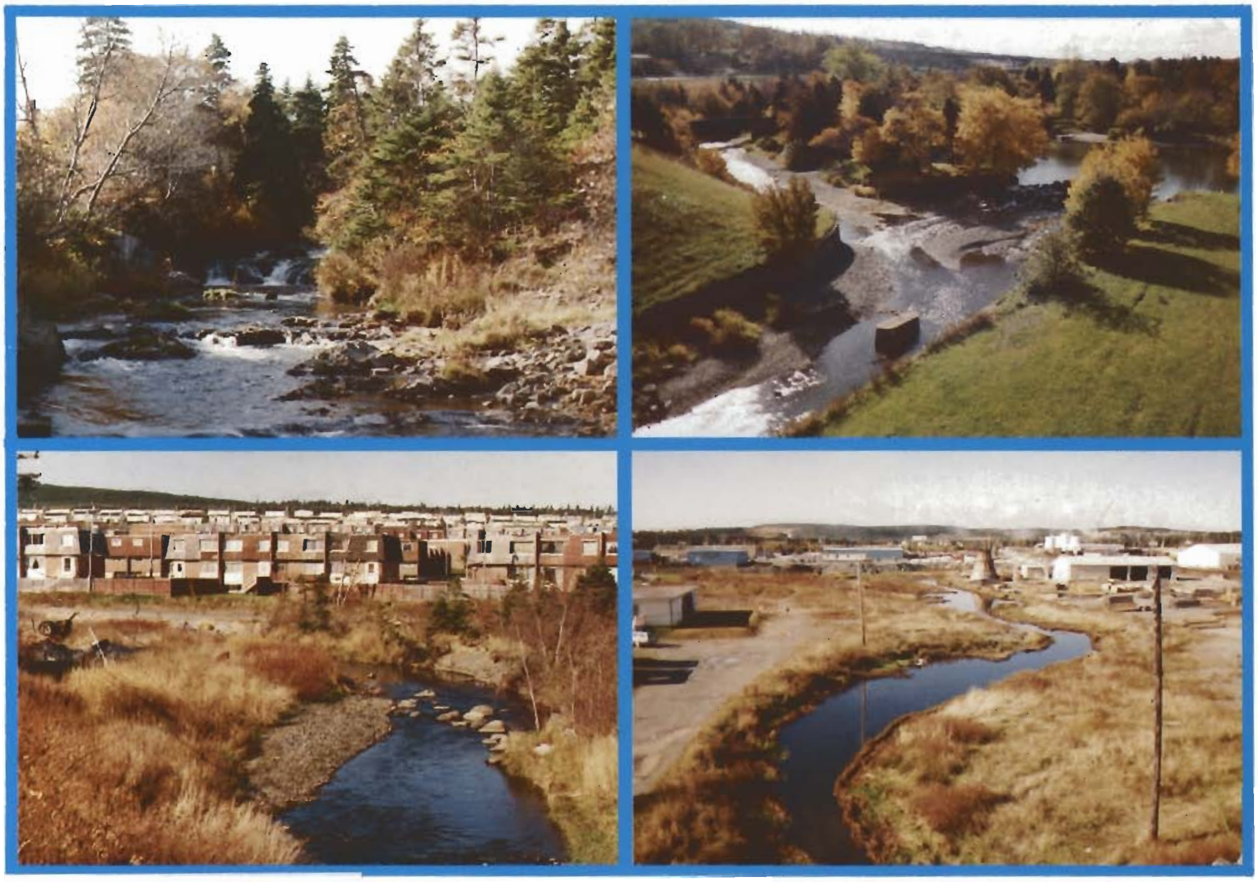
STREAMFLOW MODELLING USING HSPF



Urban Hydrology Study of the Waterford River Basin

TECHNICAL REPORT No.
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STREAMFLOW MODELLING IN THE WATERFORD RIVER BASIN USING THE HSPF MODEL

by

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ABSTRACT

The hydrologic modelling of streamflow in the Waterford River Basin has been conducted as part of comprehensive investigations of the effects of urbanization on water resources in the basin. Using a detailed input data base, continuous simulation of streamflow in the study area has been done by means of the HSPF model distributed by the U.S. Environmental Protection Agency. The model has been calibrated using 29 months of data from the input data base. Model calibration against such data has been done in three stages for the annual water balance, seasonal/monthly streamflows, and peak flows from individual large storm events. On the average, the differences between the observed and simulated results were less than 15% and such an agreement was classified as good to very good.

The calibrated HSPF model has been applied to several future land use scenarios. It was noted that future urban development in the study basin is unlikely to increase the annual volume of streamflow, but would contribute to increases in peak flows and the incidence of flooding. If the impervious area in the basin is doubled, the peak flows may increase by about 20%. The calibrated HSPF model may be retained for future analysis of water resources in the Waterford River Basin.

PREFACE

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

The five-year study, begun in 1980, was completed in 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 processes in the Province. The specific objectives of the study, as outlined in the report "Waterford River Basin - Urban Hydrology Study Plan", were as follows:

(i) 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.

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

(iii) To recommend solutions to specific water management problems in the studied basin and to develop guidelines for implementation of similar solutions elsewhere in Newfoundland. Furthermore, planning and management criteria should be developed for those aspects of the urban development which 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, land use, and socio-economic analyses.

The study was administered by a Steering Committee appointed by the governments of Newfoundland and Canada. To implement the study plan, a Technical Committee consisting of three representatives, one from each participating agency, was established. Subsequently, the Technical Committee appointed sub-committees and working groups to prepare and carry out the work plans for the various components of the study.

The report that follows deals with one such component.

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1.0 INTRODUCTION

Urbanization of the Waterford River Basin is adversely affecting water resources in the basin (5). The reported adverse effects of urbanization include increased runoff and incidence of flooding, the lowering of groundwater level and deterioration of surface water quality. It is conceivable that further development of the basin will aggravate the conditions of water resources in the basin, unless proper control measures are adopted for future urban developments.

In reponse to the concerns about the state of water resources in the Waterford River Basin, the Department of Environment of the Province of Newfoundland proposed to study the hydrology of the basin (5). This proposal was modified in cooperation with Environment Canada and, eventually, a joint hydrologic study of the basin was started in 1980.

One of the components of this joint study was to simulate streamflow in the Waterford River. The objectives of this study component can be summarized as follows:

(i) Simulate streamflow in the Waterford River by means of a continuous simulation model for the existing watershed conditions.

(ii) Simulate streamflow in the Waterford River for a projected future land use reflecting continuing urbanization of the basin.

The initial planning of this study component has been done by the Working Group on Modelling chaired by Mr. David Smith (IWD, Halifax). This working group and the Water Planning and Management Branch (WPMB), Environment Canada, have initiated the streamflow modelling task by selecting the HSPF model as the most appropriate model for this task, acquiring the HSPF model and setting it up for the CYBER computer system, and preparing the data base for application of the HSPF model for the Waterford River Basin (3, 4). After the completion of the above tasks, the Hydraulics Division of the National Water Research Institute (NWRI) has been requested to take over this study component and finish the final tasks by limiting its contribution to setting up the water quantity parts of the HSPF model for the Waterford River Basin and conducting the simulation runs. Such a division of responsibilities was necessitated by limited resources available for this study at both WPMB and NWRI and had some unfavourable impacts on the study. In particular, the resources available at NWRI did not allow further work on the input data base.

For completeness, the contributions of all federal and provincial government agencies involved in the streamflow modelling study are summarized below. In particular, the contributions of the following agencies and their staff are gratefully acknowledged.

Department of Environment, the Government of Newfoundland and Labrador, St. John's, Newfoundland - Selection of monitoring sites, the collection and processing of some input data, catchment documentation, and assistance in the preparation of the final report.

Water Resources Branch, Environment Canada, Dartmouth, Nova Scotia - Design of the flow monitoring stations and collection of streamflow data.

Water Planning and Management Branch, Environment Canada, Dartmouth, Nova Scotia - Collection of some physiographic data, preparation of a three-year input data series for the HSPF model, and preparation of a water-quantity-only version of the HSPF model.

Hydraulics Division, National Water Research Institute, Environment Canada, Burlington, Ontario - Streamflow modelling for the existing and future land use, and the preparation of the study report.

The material presented in the report that follows starts with a description of the study area, followed by descriptions of the model used, input data base, model calibration, simulation results, and conclusions and recommendations.

2.0 WATERFORD RIVER BASIN

Under the terms of reference of the Urban Hydrology Study of the Waterford River Basin, it was required to simulate the basin hydrological response using both single event and continuous simulation models. Single-event simulations have been conducted using the HYMO model and reported elsewhere (12). The main purpose of such simulations was to study high flows in the basin and to use such information in the flooding component of the study. Single-event models are generally unsuitable for investigations of low flows, seasonal variations in streamflow, and the effects of anticedent conditions on streamflow generation. To provide such information, it was proposed by the Modelling Work Group to use the HSPF continuous hydrologic model. The report that follows, deals only with continuous simulation of streamflow by the HSPF model. In collection of physiographic data, it was possible to use much information collected for the modelling with the HYMO model and frequent references to that task (12) are made. It should also be noted that some single-event simulations for a fully sewered small urban catchment in the basin have been done using the ILLUDAS and SWMM models and reported elsewhere (9).

2.1 Study Area

The Waterford River Basin is located near St. John's, Newfoundland as shown in Fig. 1. The map of the whole basin and of the study area representing the sub-basin upstream of the hydrometric station at Kilbride is shown in Fig. 2.

The Waterford River originates upstream of Bremigens pond at about 168 m above the sea level. The river flows in the northeasterly direction over a distance of about 14 kilometres with its outlet in St. John's harbour. Among the river tributaries, South Brook originating in a swampy area in the upper region of the watershed is the largest one.

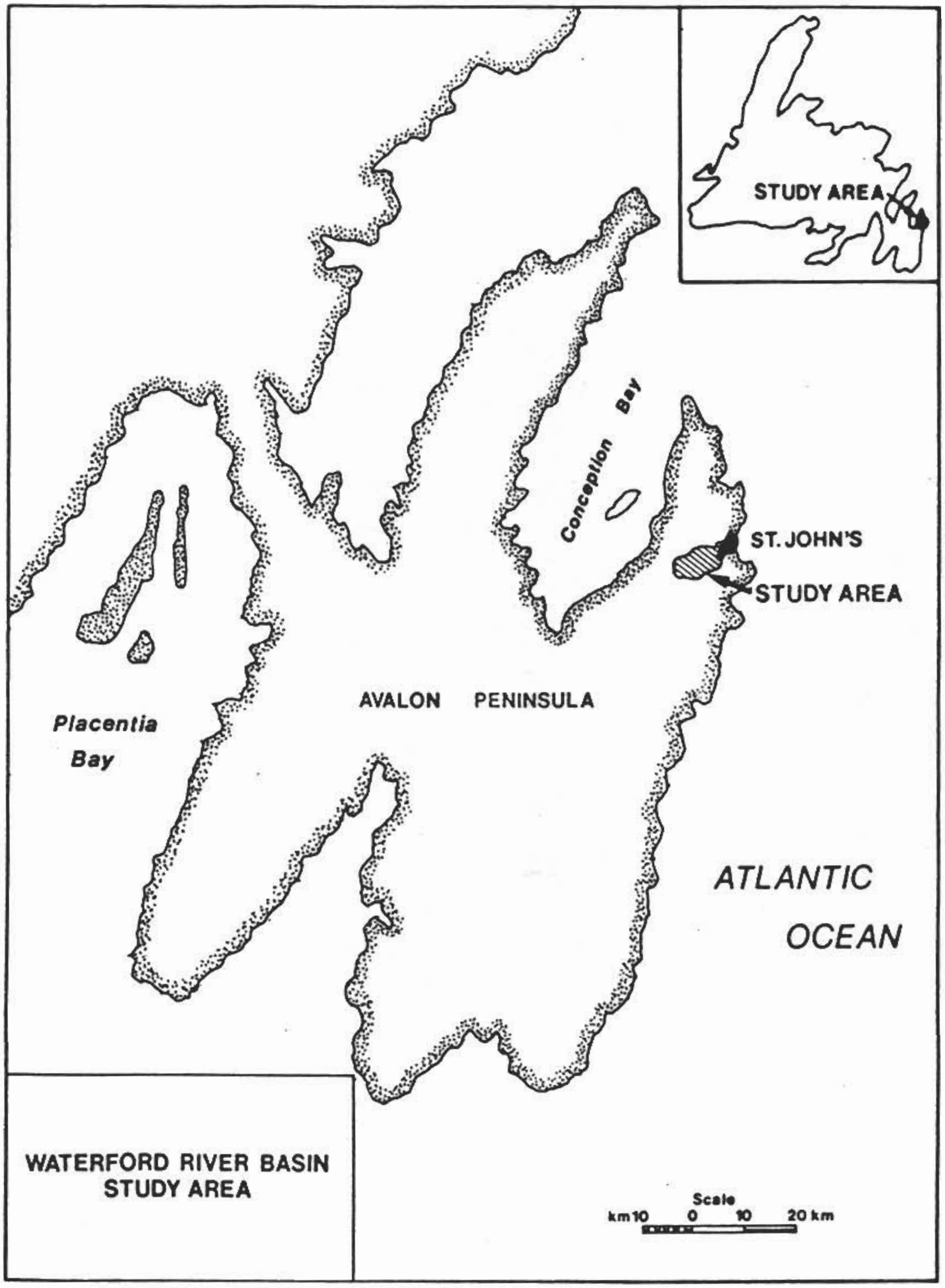
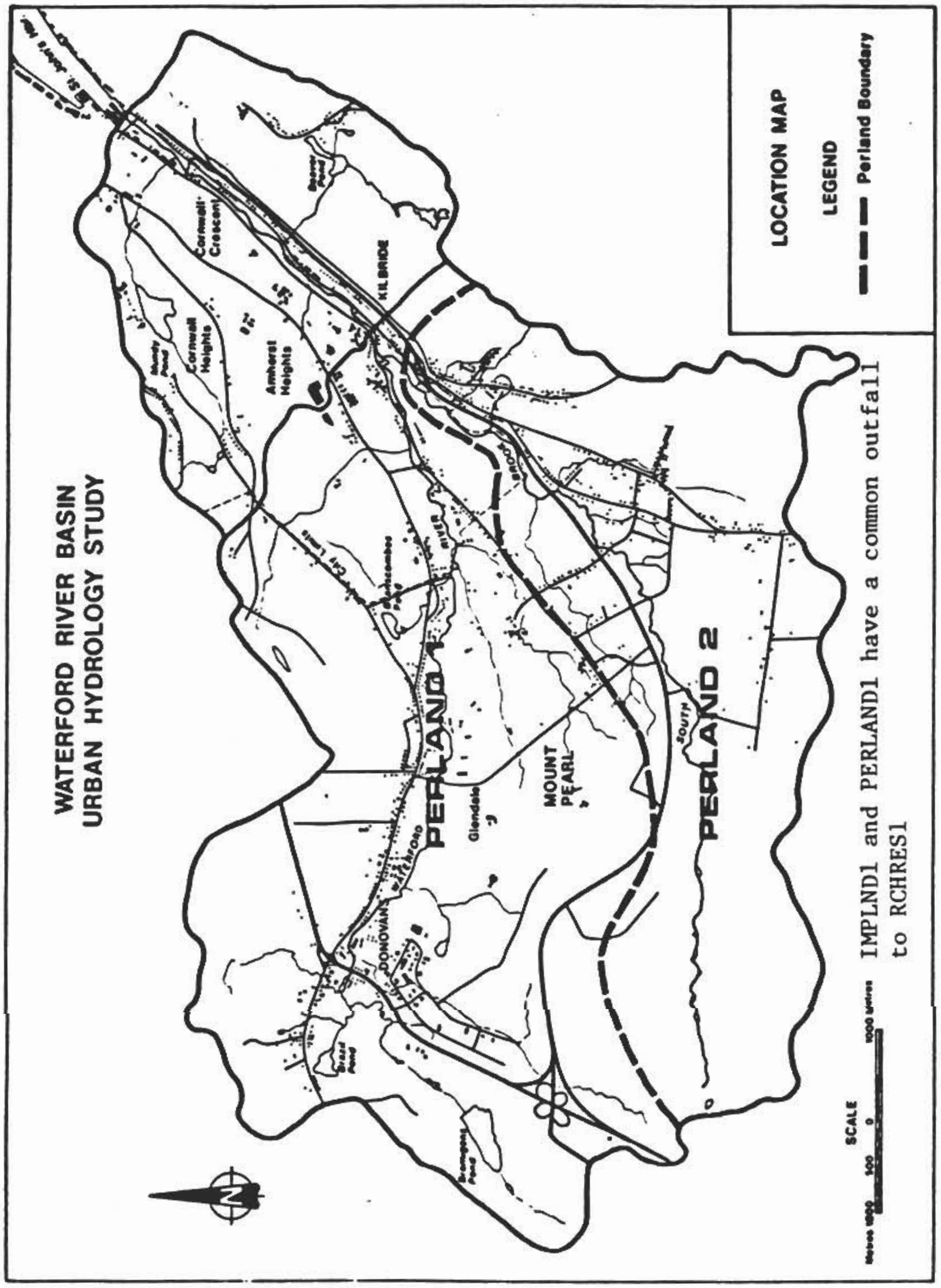


Figure 1. LOCATION MAP



IMPLND1 and PERLAND1 have a common outfall to RCHRES1

Figure 2. Map of the Study Area

As stated earlier, the study area represents a part of the Waterford River Basin upstream of the hydrometric station at Kilbride. The study area measures about 53 km^2 and includes 2.65 km^2 of impervious surfaces. Land uses and features of the study area include forests, agriculture, urban, recreational areas, ponds, bogs, river channels, gravel pits, etc.

2.2 Land Use

More than 50% of the study area is still forested despite the encroachment of the continuing urban development. Because of unfavourable soil conditions, trees are relatively small and only a small portion of land is suitable for agricultural purposes (1). Principal farming activities include dairy and root crops farming.

The urban area includes residential, commercial, institutional, industrial, and recreational park areas, and transportation corridors. A breakdown of the total area according to land use is given later (Table 3).

2.3 Physiographic Features

All rocks in the Waterford River Basin are of the latest Precambrian age (2, 8). Rocks in the basin are overlain by clastic sediments of slate-siltstone, sandstone, conglomerate and granitic rocks. The rock formation has an extensive thickness of about 1000 m to 1500 m (2, 8).

Two bedrock groups control largely the physiography of the basin. The water-resistant beds of arkosic sandstone and conglomerate group form the north-northeasterly trending. The hard silicon beds form prominent hills and rocky ridges in the western and northern parts of the basin. The less resistant tuffaceous siltstones and shales form the low-lying central interior.

About 90% of the field area is covered by veneer of till (8) which together with the orientation of hills and rocky ridges (parallel to the bedrock structures) suggests that precipitation and snowmelt will be largely converted into runoff with little losses by infiltration into the ground.

2.4 Demographic Features

The territory in the study area comes under the jurisdiction of three major municipalities - Mount Pearl, Paradise, and the St. John's Metropolitan municipality. The approximate populations of these municipalities, within the basin boundaries, are 21,500, 3,500, and 3,000, respectively. Note that the population listed for St. John's corresponds only to a small part of the metropolitan area which reaches into the study area. The current trends indicate that future expansions of the urban areas should be primarily in the Mount Pearl area.

2.5 Water Bodies

The major streams in the study area are the Waterford River and its tributary South Brook. There are also three major ponds in the area, with Bremigens Pond, located about 2 km southwest of Donovans Industrial Park, being the largest. The other two major ponds are Deadman Pond and Brazil Pond. Other smaller ponds are located in the north part of the basin.

2.6 Climate

The climate in the study area is moderated by the sea. Consequently, there are limited temperature variations with relatively mild winters and cool summers. High streamflows usually occur in the spring as a result of combined effect of rainfall and snowmelt. Occasionally, high flows have been observed in late fall. In terms of annual extreme discharges at Kilbride, during the 10-year period from 1974 to 1984, the maximum instantaneous discharge of 66.1 m^3/s was observed on November 26, 1981 and the minimum discharge of 0.15 m^3/s was observed on August 13, 1982. Low flows generally occur from June to August and sometimes also during the winter months.

Long-term meteorological statistics measured at the St. John's airport are as follows:

Average daily maximum temperature	8.6°C
Average daily minimum temperature	1.0°C
Yearly precipitation	1513.6 mm
Yearly solar radiation	3179 Langleys
Average yearly wind speed (all directions combined)	24 km/hr.

As obvious from the above data, the temperatures in the basin are moderate and the wind speeds are fairly high. Precipitation occurs, on the average, 207 days a year.

2.7 Soils

The soils in the study area have developed from the underlying slate-siltstone, sandstand stone, conglomerate, and granitic and volcanic rocks. The soils are coarse to moderately-coarse textured, strongly to extremely acidic, and low in natural fertility. They are generally classified as the soils of the humo-ferric and ferro-humic podzol great group (1).

The study basin is characterized by six main soil types - Bauline, Cochrane, Organic, Pouch Core, Red Core and Torbay. Detailed descriptions of these soils are given elsewhere (1, 12). Most of these soils have developed from coarse textured siltstone, slate, sandstone and acid volcanic rocks. Such soils can be characterized by rapid surface drainage, but their internal drainage ranges from poor to very poor with the exception of Cochrane soils which are moderately well to very well internally drained. Rapid surface drainage combined with poor internal drainage lead to fast hydrological response during rainfall or snowmelt.

3.0 MODEL SELECTION AND IMPLEMENTATION

The selection of models for hydrologic modelling requirements in the Waterford River Basin Study has been done by the Modelling Technical Subcommittee using an earlier evaluation of hydrological models (9). Subcommittees deliberations indicated that it was required to model both high and low flows and that such work would be best accomplished by models of various complexity. Flow peaks were of primary interest in the flooding task and delineation of flood plains. On the other hand, for investigations of water quality and the impact of urbanization on the hydrological cycle, low flows were also of interest. It was, therefore, necessary to model both continuous streamflow as well as large storm hydrographs using different types of models.

For determination of high flows, storm hydrographs can be modelled by relatively simple and widely used event models. The earlier mentioned evaluation of available models indicated that this task could be done by means of the HYMO model which is relatively simple and widely used in engineering practice. The modelling work with this model in the Waterford River Basin is described in another technical report in this series (12). For the modelling of streamflow, it was required to use a continuous model which would simulate both high and low flows and would be applicable to future water quality modelling.

Among the available models, the Hydrologic Simulation Program - Fortran (HSPF) model which has been developed under the sponshorship of the U.S. Environmental Protection Agency (10) met such requirements. A brief description of this model and its application to the study area follows.

3.1 HSPF Model Description

The HSPF model is a comprehensive continuous simulation model for predicting watershed hydrological response, water quality, agricultural chemicals migration, and environmental risk assessment. The model employs information on the time history of precipitation, such as rainfall and snowfall, air temperature, such as wet bulb and dry bulb temperatures; wind movement; solar radiation; actual evaporation; land use characteristics, including land use patterns, soil characteristics, and agricultural practices; and, simulates hydrological and chemical processes that occur in the watershed. The result of such simulation is a time history of the quantity and quality of runoff. Furthermore, sediment loads, and nutrient and pesticide concentration can also be predicted.

3.2 Adaptation of the HSPF Model to the Study Area

In the study of the Waterford River Basin, Release 7.0 (10) of the HSPF model has been used. This version had to be adapted to the mainframe computers available to the study team. Such work has been done by the Water Planning and Management Branch (WPMB), IWD, Dartmouth, N.S. In particular, WPMB adapted HSPF for the use on the CDC CYBER 171 computer of the Bedford Institute of Oceanography. Towards this end, the core storage requirement of the HSPF model, 377K, had to be reduced to the 177K of available core storage in the CYBER 171 computer system. In this process, it was necessary to remove model modules simulating water quality. In particular, the following modules were removed:

Land Segment

MSTL - Simulate moisture and solutes transport in soil layers

PEST - Simulates pesticides behaviour

NITR - Simulates nitrogen behaviour

PHOS - Simulates phosphorus behaviour

TRAC - Simulates transport of conservative tracers.

Reach Section

FST - Simulates general quality constituents

OXRX - Simulates primary DO and BOD balances

NUTR - Simulates primary inorganic and phosphorus balances

PLNK - Simulates plankton

PH - Simulates pH and carbon species

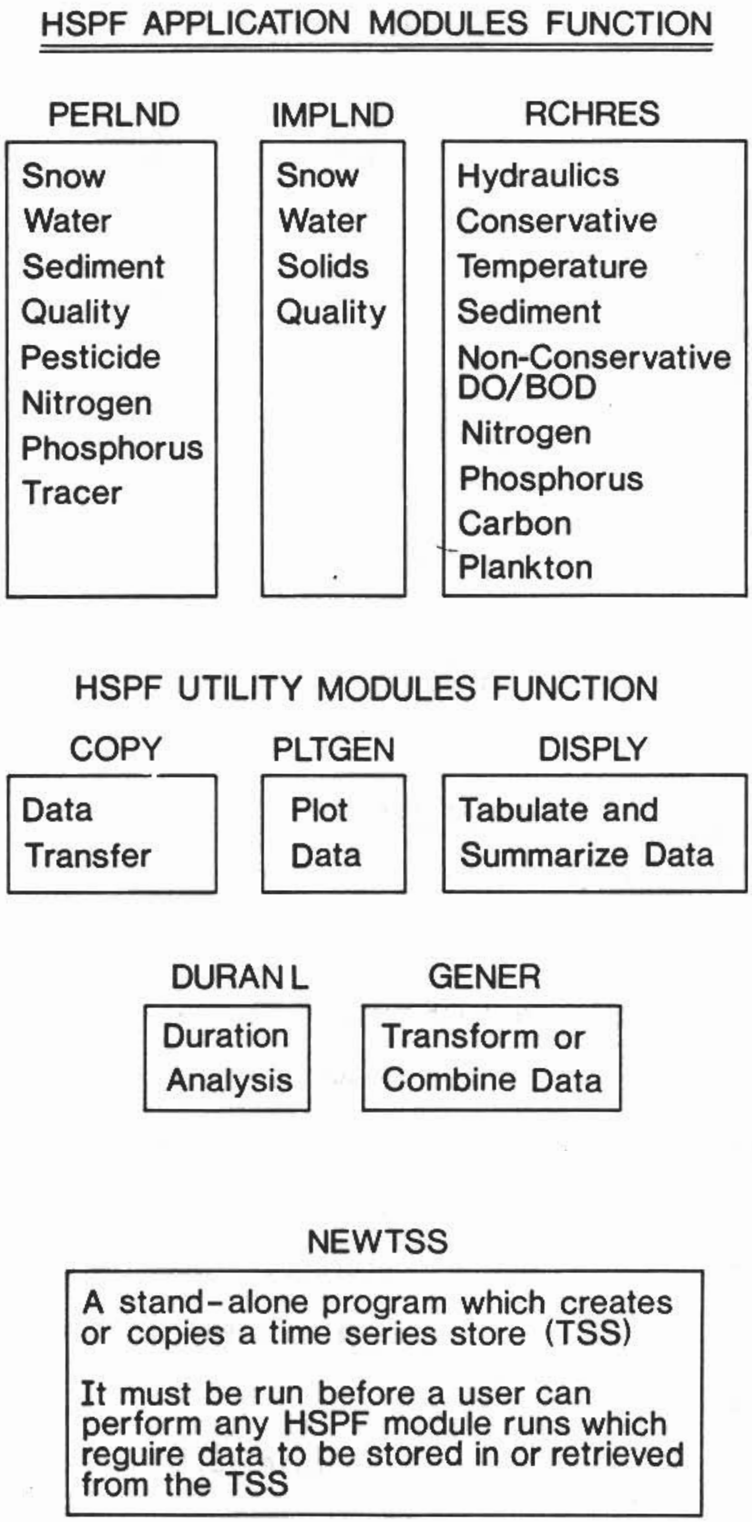
As a result of the above modifications, the modified HSPF model applied to the study area can simulate water quantity processes only.

3.3 HSPF Modules

The HSPF model applied to the study area contains a support program NEWTSS, three application models - PERLND, IMPLND, and RCHRES, and five utility modules - COPY, PLTGEN, DISPLY, DURANL, and GENER. NEWTSS is a stand-alone program which creates, copies and manages the Time Series Store (TSS). This program has to be run before any HSPF modules can be used. General functions of NEWTSS and all the HSPF modules are schematically shown in Fig. 3.

3.4 HSPF Installation on the NWRI CYBER System

The modified version of HSPF prepared by the WPM Branch has been installed on the NWRI CYBER system without major problems. However, core storage limitations adversely affected the operation of the TSS program which must be run interactively with HSPF, so that HSPF modules can access the data base. It was found that the maximum storage available limited the TSS file length to 319 records. Because of this problem, the available Waterford River Basin data base (3) containing 37 months of hourly data could not be fully utilized and only 29 months of data, from January 1, 1981 to May 31, 1983, could be



HSPF APPLICATION MODULES FUNCTION

PERLND	IMPLND	RCHRES
Snow	Snow	Hydraulics
Water	Water	Conservative
Sediment	Solids	Temperature
Quality	Quality	Sediment
Pesticide		Non-Conservative DO/BOD
Nitrogen		Nitrogen
Phosphorus		Phosphorus
Tracer		Carbon
		Plankton

HSPF UTILITY MODULES FUNCTION

COPY	PLTGEN	DISPLY
Data Transfer	Plot Data	Tabulate and Summarize Data

DURANL	GENER
Duration Analysis	Transform or Combine Data

NEWTSS

A stand-alone program which creates or copies a time series store (TSS)

It must be run before a user can perform any HSPF module runs which reguire data to be stored in or retrieved from the TSS

Figure 3. HSPF Model Modules

used. From the 319 records available, the TSS used 315 records for the 29 months of data as follows:

Data Set	**Allocated Space (in records)**
Dry temperature	52
Wet temperature	52
Wind movement	52
Precipitation	52
Solar radiation	52
Streamflow	52
Evaporation	3

Note that the evaporation data set required only 3 records, because it comprised daily values available from June to October. All the other data sets contained hourly values.

3.5 The Waterford HSPF Data Base

3.5.1 Data Series

The Waterford HSPF data base, as compiled by Daurie (3), includes the data on air temperatures (wet and dry bulb), wind speed, precipitation, solar radiation, evaporation (lake and pan), and streamflow. As stated earlier, the preparation of this data base was not included in the terms of reference of the study described in this report and no resources were allocated or time allowed for any modifications of the data base.

The Waterford HSPF data base fully covers a period of three years from May 1, 1980 to May 31, 1983 in the form of hourly data for all phenomena except evaporation. Daily evaporation data, both lake and pan evaporation, were available for the period from June 1 to October 31 for three years from 1980 to 1982. Note that cloud cover data were not included in the data base, because they are required only for water quality simulations. The sources of hydrometeorological data used in the Waterford HSPF data base are listed below.

Type of Data	**Source (Location)**
Dry/wet bulb air temperatures and wind speed	St. John's Airport station
Pan evaporation, lake evaporarion and precipitation	St. John's West station at the Canada Department of Agriculture (CDA) Farm
Streamflow	Kilbride Hydrometric Station

Note that pan evaporation data, available for summer months only, have not been used.

3.5.2 Completeness of the Data Base

The data required for the creation of the Waterford HSPF data base were complete to various extents and the missing data had to be estimated using the procedures described below. For a quick evaluation, the completeness of individual data sets is shown in the table below.

Type of Data	**Percent Complete**
Temperatures (wet and dry)	100%
Wind	100%
Precipitation	86%
Solar radiation	94%
Evaporation (lake)	57%
Streamflow	92%

The table on data record completeness indicates that some data were missing and had to be filled in using various procedures. Such procedures, as excerpted from the Daurie's report (3), are presented below.

Missing solar radiation and streamflow data - substitute data were obtained either by extrapolation or by using daily means. For missing daily pan evaporation data, long-term monthly means were substituted. The missing lake evaporation data were estimated from the following formula:

$$\text{DLE} = \text{DPE} \cdot \frac{\Sigma\text{LE Series}}{\Sigma\text{PE Series}}$$

where DLE = daily lake evaporation, DPE = daily pan evaporation, and LE and PE stand for lake evaporation and pan evaporation, respectively.

Missing precipitation data were estimated using either of the following two methods:

(a) In the case of malfunctioning of the recording equipment, a special correction factor was calculated for each day as:

$$\text{Factor} = \frac{\text{CDA standard gauge catch + snowfall}}{\text{tipping bucket daily catch}}$$

and then applied to the available tiping bucket hourly data.

(b) If the tipping bucket data were completely missing - the hourly data were calculated as the daily standard gauge catch plus snowfall divided by 24 hours.

4.0 PHYSIOGRAPHIC CHARACTERISTICS OF THE STUDY AREA AS USED IN THE HSPF MODEL

The watershed to be modelled by the HSPF needs to be described in terms of the land segments and flow-routing reaches. Although there are no detailed instructions available for such watershed representation, certain general guidelines need to be observed as discussed below.

4.1 Land Segments

The representation of the study area by two pervious and one impervious land segments was established in the early work of the Modelling Working Group (7). Such representation reflected the earlier collected model input data and later changes could not be justified for the available data base. In particular, because there is only one meteorological station in the basin, at the CDA farm, it was not possible to evaluate spatial variations in precipitation and to select the land segments accordingly.

The primary considerations in the division of the study area into land segments included drainage patterns, the spatial distribution of impervious and pervious surfaces, the spatial distribution of overburden, and the distribution of forest canopy and its seasonal variations in the study area. As shown in Fig. 2, the study area was divided into two sub-basins, one for the Waterford River and one for South Brook. The former sub-basin was represented by two land segments, one comprising all pervious surfaces and the other one comprising all impervious surfaces. The South Brook sub-basin was taken as a single pervious land segment. Basic characteristics of all three land segments are summarized in Table 1. The areas shown in Table 1 were adopted from ref. (4). It was noted that slightly different areas were listed independently in ref. (7). No explanation for such minor discrepancies is available. As required for running the HSPF model, the mean lengths and slopes of the overland flow planes in the individual land segments were estimated from the map of the study area. The mean segment elevations, which are required in snowmelt simulations, were also determined from the map.

Table 1. Characteristics of Land Segments Used in HSPF Simulations

	Pervious Land		Impervious Land
Characteristic	Segment 1	Segment 2	Segment 1
Drainage sub-basin	Waterford	South Brook	Waterford
Latitude (degrees)	47.5°N	47.5°N	47.5°N
Area (km^2)	30.25	20.13	2.65
Elevation (m ASL)	150	110	110
Overland flow length (m)	1750	1000	1000
Overland flow slope	0.015	0.015	0.010
Forest cover (%)	34	34	0

4.2 Flow Routing Reaches

In the HSPF model, the stream is divided into a number of reaches which are then used in flow routing. From the theoretical point of view, it is relatively straightforward to identify and characterize drainage channels in the study area and to divide them into a number of reaches of uniform characteristics. Such procedures require, however, detailed data on channel cross-sections and slopes. If such supporting data are not available, any perceived accuracy to be attained by detailed discretization of the channel network is illusory. In view of the fact that no cross-sectional data were available for South Brook, and even for the Waterford River, such data were available only for three very short reaches (about 0.5 km each), it was considered to be realistic to simulate flow routing only in the Waterford River and to divide it into two reaches. The first reach extends from Donovans Industrial Park to Mount Pearl and the second reach extends from Mount Pearl to the hydrometric station at Kilbride.

The basic geometric and hydraulic properties of both flow routing reaches, in the format required by the HSPF model (the so-called FTABLES), are listed in Table 2. Further explanations follow.

In Table 2, for the selected values of the flow depth, the remaining parameters were evaluated using the basic data available in refs. (11) and (12). The surface area was calculated as the width of the water surface times the reach length. The channel volume was calculated for the entire reach. The rating curves at the upstream and downstream ends of both reaches were adopted from ref. (11) and extrapolated to accommodate the simulated flows.

Drainage and land use areas, for both reaches, are listed in Table 3.

The HSPF model uses a storage routing procedure which produces the most accurate results when the time of flow through individual reaches is approximately equal to or slightly shorter than the simulation time step (10). Using such a criterion and estimated travel times (12), it was calculated that, for the simulation time step of one hour, the reach length should be smaller than or equal to 4.7 km. Both reaches employed meet this condition.

Table 2. Geometric and Hydraulic Characteristics of the Waterford River Flow Routing Reaches

Reach	Depth (m)	Surface Area (ha)	Channel Volume (10^6 m^3)	Q_{in} (m^3/s)	Q_{out} (m^3/s)
Reach 1	0.00	0.00	0.0000	0.00	0.00
(L = 3.86 km)	0.10	0.40	0.0002	0.10	0.05
	0.50	1.90	0.0094	1.50	1.30
	0.75	3.90	0.0167	3.60	3.80
	1.00	9.70	0.0337	7.20	7.70
	1.25	15.50	0.0652	12.00	13.00
	1.50	21.60	0.1116	18.00	21.00
	1.75	26.30	0.1715	26.00	30.00
	2.00	33.60	0.2464	36.00	40.00
	2.50	40.90	0.3726	60.00	68.00
	3.00	48.30	0.5956	97.00	106.00
	3.75	61.80	1.0085	170.00	172.00
	4.50	73.40	1.5155	260.00	265.00
Reach 2	0.00	0.00	0.0000	Equal to	0.00
(L = 4.33 km)	0.10	2.10	0.0011	Q_{out} of	0.20
	0.50	4.00	0.0133	Reach 1	3.20
	0.75	5.00	0.0246		7.20
	1.00	7.40	0.0401		13.00
	1.25	10.40	0.0624		19.00
	1.50	13.00	0.0917		27.20
	1.75	16.00	0.1280		37.00
	2.00	19.90	0.1729		47.00
	2.50	31.10	0.3004		70.00
	3.00	34.60	0.4647		98.00
	3.75	46.70	0.7696		147.00
	4.50	69.24	1.2042		205.00

Connectivity of reaches and land segments is also shown in Table 3. In particular, Reach 1 receives flow from pervious segment 1 and impervious segment 1 and drains into Reach 2 which also receives flow from pervious segment 2. Reach 2 has an outlet at the hydrometric station in Kilbride.

Table 3. Waterford River Flow Routing Reaches: Drainage Areas and Their Land Use

Reach No.	Drains: Sub-basin	Drains: Land Segment	Length (km)	Slope	Total Contributing Area (km^2)	Woodland (km^2)	Impervious Area (km^2)	Other Land Area (km^2)
1	Waterford R.	Per.1, Imp.1	3.86	0.008	32.37	15.20	2.12	15.05
2	South Brook	Per.2	4.33	0.016	20.66	7.20	0.53	12.93

5.0 CALIBRATION OF THE HSPF MODEL

Calibration is critical for successful application of the most of the existing hydrological models. The need of calibration seem to increase with the model complexity. In particular, calibration is required to estimate input parameters that cannot be measured directly and it lends confidence to the modelling results. The above statements fully apply to the HSPF model which should be calibrated against a data record about three years long. Ideally, the calibrated model would be then verified against another set of data which has not been used in calibration. Such an approach could not be taken in the Waterford River Basin study, because the entire data base covered only three years and computer limitations prevented the use of the whole data record. Consequently, the HSPF model was calibrated against the 29 months of data that could be fitted into the available core storage and any verifications were postponed until more data from the study area would become available in future studies.

5.1 Scope of Calibration

Calibration is a major task in the application of the HSPF model which may require 30 to 50% of the total study resources (6). Such requirements follows from the fact that the model has numerous parameters and the ultimate goal of calibration is a close agreement between extensive records of observed and simulated data. Since calibration is an iterative process of parameter evaluation and refinement, the user needs to know when an adequate degree of model calibration has been achieved and further calibration would be unproductive. Towards this end, it is recommended to establish the desired goodness of fit criteria before the calibration process starts. For the Waterford River Basin study, such criteria were adopted from ref. (6) and presented in Table 4. It should be further explained that the criteria in Table 4 largely apply to annual and monthly values. Individual events may show much larger deviations with little impact on the overall calibration.

Table 4. *Evaluation of Percentage Differences Between Simulated and* Observed Values (6)

Phenomena	Calibration Results		
	Very Good	Good	Fair
Hydrology/hydraulics	<10	10 - 15	15 - 25
Sediment	<15	15 - 25	25 - 35
Water Quality	<20	20 - 30	30 - 40

The criteria shown in Table 4 were adopted in the Waterford River Basin study and for all hydrologic parameters, it was strived to keep the mean differences between the simulated and observed values below 10% (rated as very good in Table 4).

The criteria in Table 4 may seem to be somewhat lax, particularly when referring to annual or monthly values. They are, however, realistic in view of the fact that the available calibration data and their accuracy impose severe limitations on calibration. It should be recognized that the most accurate measurements under field or natural conditions contain at least a 5 to 10% variation from the actual or true values. Such limitations certainly apply to the Waterford River Basin data, particularly to the precipitation and flow measurements. The assumption of uniform areal precipitation, described by the precipitation record from the CDA station, is a major source of error with direct effects on the simulation results, because precipitation is the driving force of HSPF simulations. Uncertainties in streamflow measurements in the Waterford River may be as high as ±30% for high flows in the extrapolated or poorly defined parts of the rating curves for the flow control sections.

5.2 Calibration Procedures and Results

Calibration has to be done systematically to avoid unnecessary simulation runs. In hydrologic calibration, it is recommended (6) to start with the annual balance, followed by the seasonal or monthly adjustments, and adjustments of event hydrographs. Such a procedure was more or less followed with minor deviations necessitated by the characteristics of the study area. The calibration process involved the following steps:

1. Estimate the initial (reference) values of all HSPF model parameters.
2. Calibrate annual and seasonal/monthly flows.
3. Calibrate snowmelt parameters.
4. Calibrate hydrographs for selected storms.

Individual steps are further described below.

5.2.1 Estimates of Initial Parameter Values

A complete set of HSPF parameters contains more than 100 entries, if monthly parameter values are used. The discussion of such a large data set is beyond the scope of this report. Consequently, only the most important parameters which strongly affect simulation results are discussed in this section. Such parameters are listed in Table 5 and their values have been adjusted in the calibration process. For other parameters, the default values listed in the HSPF manual were used (10). A complete listing of the input data file is given in the Appendix.

Table 5. Important HSPF Hydrologic Calibration Parameters

Parameter	Definition
General Hydrologic Parameters	
LZSN	The lower zone nominal storage
INFILT	The infiltration capacity of the soil
AGWRC	The gtroundwater recession rate
UZSN	The upper zone nominal storage
IRC	The interflow recession parameter (today's outflow rate/yesterday's outflow rate)
INTFW	The interflow inflow parameter
LZETP	The lower zone evapotranspiration parameter
FOREST	The fraction of the pervious land area covered by forest (may be kept constant throughout the year, if there is no difference between the summer and winter forest cover)
DEEPFR	The fraction of groundwater inflow entering deep (inactive) groundwater storage which cannot be recovered. In the Waterford River Basin, the majority of geological structures are bedrocks and this parameter was set equal to zero.
Snowmelt Parameters	
TSNOW	The air temperature below which precipitation occurs in the form of snow, under saturated conditions
CCFACT	A parameter used to correct the condensation/convection melt equation for field conditions
MWATER	The maximum water content of the snowpack
MGMELT	The maximum snowmelt rate due to ground heat
Initial Water Storages	
UZS	The upper zone storage
LZS	The lower zone storage
CEPS	The interception storage
SURS	The surface storage (on the overland flow plane)
IFWS	The interflow storage
AGWS	The active groundwater storage
GWVS	An index relating the antecedent active groundwater inflow to the groundwater table slope

5.2.2 Calibration of Annual, Seasonal and Monthly Flows

The first task of HSPF calibration is to establish annual balance which is defined by the following equation:

$$\text{Precipitation} - \text{Actual Evapotranspiration} - \text{Deep Percolation} - \delta\,\text{Soil Moisture Storage} = \text{Runoff}$$

For the study area, the above relationship can be somewhat simplified by assuming no percolation and changes in soil moisture storage. Thus, the annual balance can be obtained by adjusting evapotranspiration in the watershed. Before making such an adjustment, it was of interest to compare the precipitation and streamflow, measured in the study area, as shown in Table 6.

Table 6. Precipitation and Streamflow Observed in the Study Area

Period	Precipitation (mm)	Streamflow (mm)	Streamflow / Precipitation
June 1981 - May 1982	1953	1563	0.80
June 1982 - May 1983	1612	1317	0.82
Jan. 1981 - May 1983	4163	3515	0.84

The streamflow/precipitation ratio for the entire period of 29 months is slightly overestimated, because streamflow observed from January to May 1981 partly resulted from precipitation deposited and stored on the watershed during an earlier period. When calculating the annual balance for the period from June to May, which may be taken as the water year in the study area, the average streamflow/precipitation ratio was detemrined as 0.81.

The data in Table 6 show very large ratios of streamflow/precipitation which indicate low evapotranspiration. On the annual basis, such evapotranspiration would range from 250 to 350 mm. It should also be recognized that such low evapotranspiration could be calculated for erroneous data, if the precipitation data are underestimated and the streamflow data overestimated. It was, therefore, desirable to check the data from the study area against those from similar watersheds in Newfoundland. Such checking was done by the Water Resources Branch, Environment Newfoundland and confirmed that the relatively low evapotranspiration values are possible for the climate and physiography of the study area. After this verification, calibration of evapotranspiration proceeded.

In HSPF simulations, annual evapotranspiration is controlled by the input meteorologic data series, and paramters LZSN, INFILT and LZETP explained in Table 5. In particular, the model assumes that the major portion of evapotranspiration occurs from the lower soil moisture zone and increasing LZSN should increase actual evapotranspiration. Actual evapotranspiration is also very sensitive to the parameter LZETP which indicates the fraction of watershed with deep rooted vegetation. Thus increasing LZETP will increase evapotranspiration and vice versa. Finally, the INFILT parameter may increase transfer of water to the lower zone and thereby increase evapotranspiration.

Table 7. 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	0.25 - 250	30
INFILT	0.0025 - 120	0.5
AGWRC	0.001 - 1.0	0.98
UZSN	0.250 - 40	10.0
IRC	0.01 - 0.5	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

To obtain the annual evapotranspiration in the range from 250 to 350 mm, all the three above discussed parameters were varied within fairly wide ranges shown in Table 7. Although the adjustments of these parameters helped to adjust evapotranspiration towards the desired value, the full adjustment was obtained only by simultaneously adjusting the MFACT correction factor in the meteorologic input series to the value of 0.70. Such adjustments brought the total simulated streamflow over the calibration period of 29 months to within 1% of the observed value and surpassed the calibration criteria listed in Table 4.

Besides adjusting the above parameters, it was also required to define the initial water storages in the watershed. Properly adjusted initial values improve the agreement between the observed and simulated streamflow, particularly during the initial months of the simulation period. Without adjustments of the initial values, the model would consider all water storages empty at the start of simulation and this would lead to some underestimation of the streamflow. The initial water storages were selected from the simulation runs using the values simulated for the first and second anniversary of the starting date of simulations. The listing of initial storage values employed is shown in Table 8.

After obtaining the annual water balance, the seasonal or monthly flow distribution had to be adjusted to fit the observed data. In particular, it is required to match the seasonal flows, both low and high. Such adjustments are accomplished by dividing the

Table 8. **Initial Water Storages Used in HSPF Simulations**

Initial Water Storage (mm)	Land Segment			Remark
	PERLND1	PERLND2	IMPLND1	
UZS	35	35	-	
LZS	62	62	-	
CEPS	2	2	-	
SURS	15	15	-	
IFWS	0.0	0.0	-	Default
AGWS	0.09	0.09	-	
GWVS	0.025	0.025	-	
RETS	-	-	0.025	
SURS	-	-	0.025	Default

incoming moisture among surface runoff, interflow, upper zone soil moisture storage, percolation to lower zone soil moisture and groundwater storage.

The seasonal or monthly adjustments start with the consideration of groundwater. For this purpose, the DEEPFR parameter is used to direct the groundwater contributions to deep inactive groundwater storage. As mentioned earlier, such contributions were considered negligible in the study area and DEEPFR was taken as zero.

The remaining flow distribution adjustments were achieved by varying the parameters INFILT, LZSN and AGWRC (See Table 7). Increasing the infiltration parameter INFILT reduces immediate surface runoff, including interflow, and increases the groundwater component. In such a way, runoff is delayed and takes place later in the season in the form of an increased groundwater or base flow. Decreasing INFILT produces the opposite results (6). Besides INFILT, LZSN also controls the volume of runoff from groundwater, but the rate of outflow from the groundwater storage is controlled by the parameter AGWRC.

Some difficulties were encountered during the calibration process. Firstly, it was noted that in the first year of observations (1981), a higher percentage of precipitation was converted into streamflow than in the second year (1982). Although such differences may be real, they may also be caused by uncertainties in the observed data. On the other hand, the HSPF model worked very consistently and the aforementioned differences in streamflow generation could not be reflected in the simulated results based on the available data base. Consequently, it was necessary to calibrate the HSPF in such a way that the water balance for the whole simulation period is preserved and the differences between the two years, 1981 and 1982, are averaged out. This was achieved by making the simulations to slightly underestimate the 1981 observed streamflow and to slightly overestimate the 1982 streamflow. Such adjustments led to somewhat worsened fit of monthly flows.

The second source of problems was simulation of snowmelt. When using the generally recommended parameter values (6, 10), good results were obtained for 1981, but in 1982, snowmelt was significantly delayed and then occurred quickly in late April and early May with excessive monthly streamflows. It was, therefore, necessary to calibrate the snowmelt submodel to reduce such discrepancies. Again, some of such problems may be caused by the input data and, in

Table 9. **Observed Precipitation and Streamflow and Simulated Streamflow**

		Mean Hourly Streamflow (mm/hr)											
Year	Quantity	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	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	Preciitation	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							

particular, inability to describe accurately the basin-wide conditions by the data from a single meteorological station.

Snowmelt has a substantial impact on winter and spring streamflow in the study area. This is largely caused by the temperate climate with common mild spells occurring through the winter. The monthly streamflow values (see Table 9) indicate that snowmelt volumes are particularly important from February to April. During the calibration process, it was necessary not only to match the monthly values, but the hourly values had to be also maintained within some realistic range of values to avoid problems in the next stage of calibration - the matching of event hydrographs.

Snowmelt calibration involves the following eight parameters: SNOWCF, MFACT, TSNOW, SNOEVP, CCFACT, MWATER, MGMELT and COVIND. Four of these, TSNOW, CCFACT, MWATER and MGMELT have been described earlier (Table 5) and the remaining four are explained below.

SNOWCF	The precipitation correction factor accounting for poor catch efficiency.
MFACT	The precipitation correction factor used in the NETWORK Block to adjust areal precipitation.
SNOEVP	The parameter adjusting the snow evaporation equation to field conditions.
COVIND	The maximum snowpack depth for which the entire watershed is covered with snow.

In general, snowmelt simulations by the HSPF model are sensitive to the air temperature and solar radiation time series, which represent the major driving forces for the energy balance melt calculations. Both types of input data can be adjusted, by means of the MFACT factors, to better reflect the field conditions. These factors have not been used in snowmelt calibrations and calibration has been achieved by adjusting the process parameters. The final calibrated parameter values are shown in Table 7. The observed and simulated monthly-mean hourly streamflows are shown in Fig. 4.

In the overall evaluation, the monthly streamflow was reproduced, on the average, within ±15% of the observed values. Such results would be evaluated as "good" using the criteria given earlier in Table 4. It was noted that the goodness of fit was adversely affected by poor results in several months with relatively low streamflow. The last step in the calibration process was the calibration of streamflow hydrographs described in the next section.

5.2.3 Calibration of Storm Hydrographs

The final step of hydrologic calibration is the adjustment of simulated storm hydrographs, particularly their peaks, to match the observed ones. Such adjustment is achieved by means of hydrologic parameters discussed first and also by means of hydraulic parameters discussed later.

Shapes of simulated hydrographs are effectively altered by the interflow parameter, INTFW. Increasing INTFW reduces peak flows and, at the same time, runoff volumes remain practically unchanged.

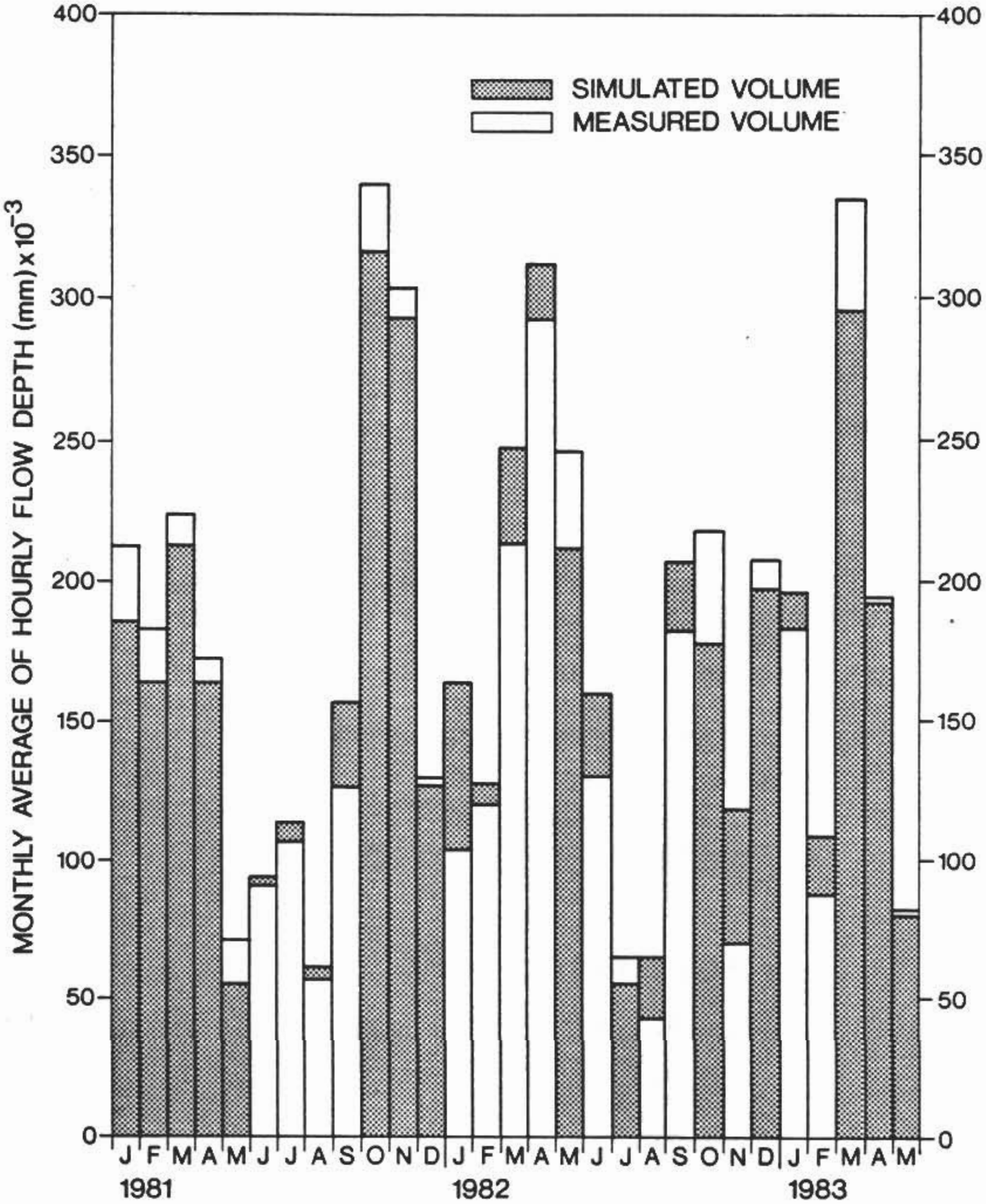


Figure 4. Simulated and Observed Monthly Streamflow Volumes in the Waterford River Basin at Kilbride, Newfoundland

On large watersheds, the IRC parameter (the interflow recession parameter) can be used to adjust the recession of the interflow portion of the hydrograph. For the study area, the major adjustments of hydrographs have been achieved by the INTFW parameter.

Minor adjustments of the hydrographs can be also achieved by the UZSN and INFILT parameters, but their adjustments affect the overall water balance and may require several iterations involving all three levels (annual, seasonal/monthly, and event) of calibration.

Hydrograph peaks are also affected by flow routing performed by the RCHRES module. In particular, the FTABLE (Table 2) is important in this regard. The FTABLES for the Waterford River were prepared from the limited available data (11 and 12) and in the absence of additional supporting data, calibration of hydrographs by means of the RCHRES module was avoided.

The results of comparison of simulated and observed peak flows, greater than 10 m^3/s, are shown in Table 10. For the 29 events listed in Table 10, a very good match of observed and simulated peaks was achieved for the parameter values listed in Table 7. This is reflected by a good agreement between the mean simulated and observed values (within several percents). For the individual events, the differences between the observed and simulated values are about ±20%. The agreement between the simulated and observed hourly streamflows can be observed in Fig. 5 which shows the full 29 months records of simulated and observed streamflow.

Table 10. Comparison of Observed and Simulated Hydrograph Peak Flows

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	9/07/81	13.5	14.4	6.7
4	25/09/81	12.4	12.4	0.0
5	5/10/81	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	8/11/81	27.6	28.3	2.5
10	26/11/81	62.1	62.5	0.6
11	8/03/82	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	1/07/82	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	3/10/82	22.9	29.4	28.4
21	4/10/82	53.2	29.5	-45.0
22	30/11/82	10.7	11.6	8.4
23	7/01/82	15.8	16.0	1.3
24	15/01/83	12.9	8.9	-31.0
25	3/03/83	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

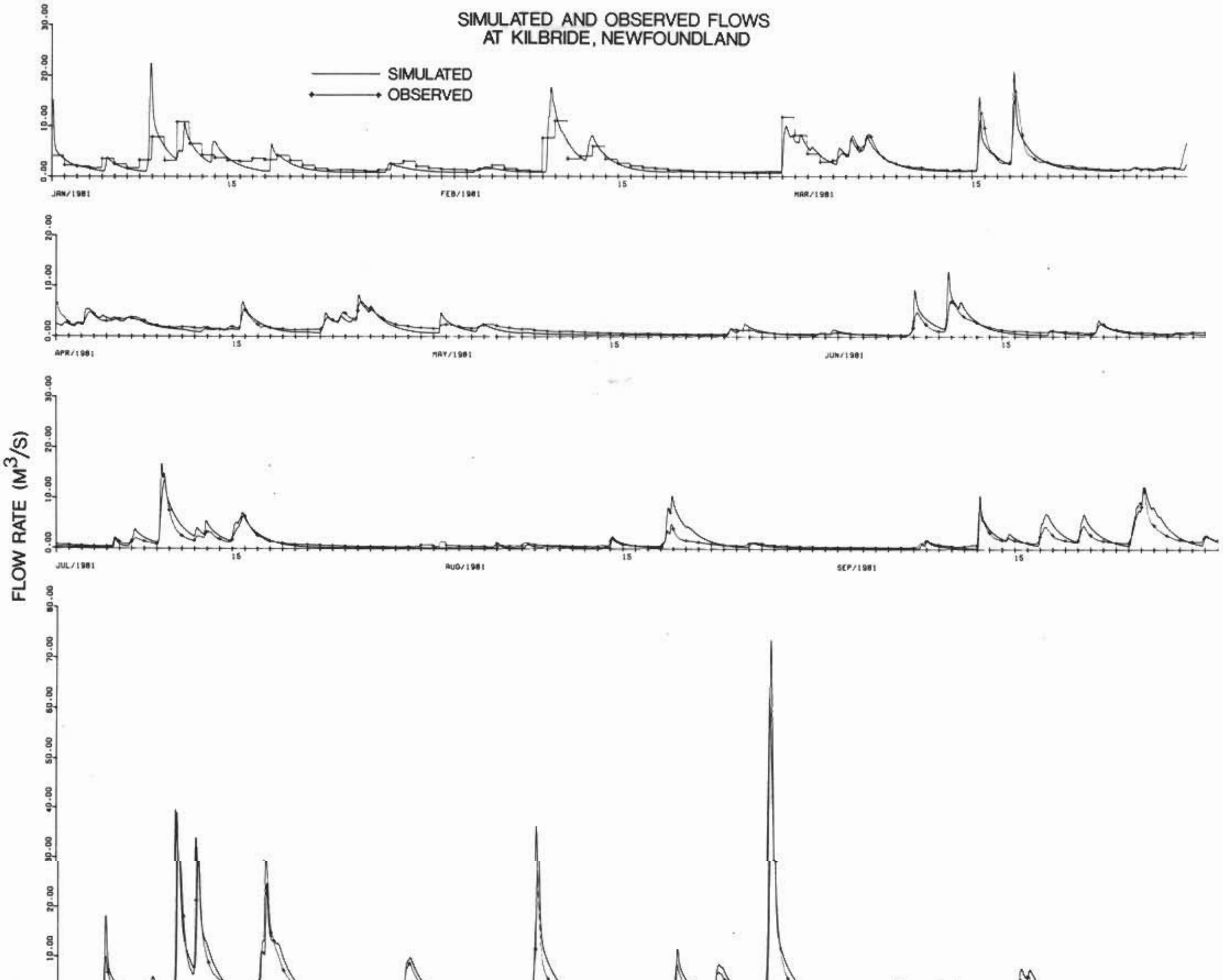


Figure 5. Simulated and Observed Flow Records at Kilbride, Newfoundland

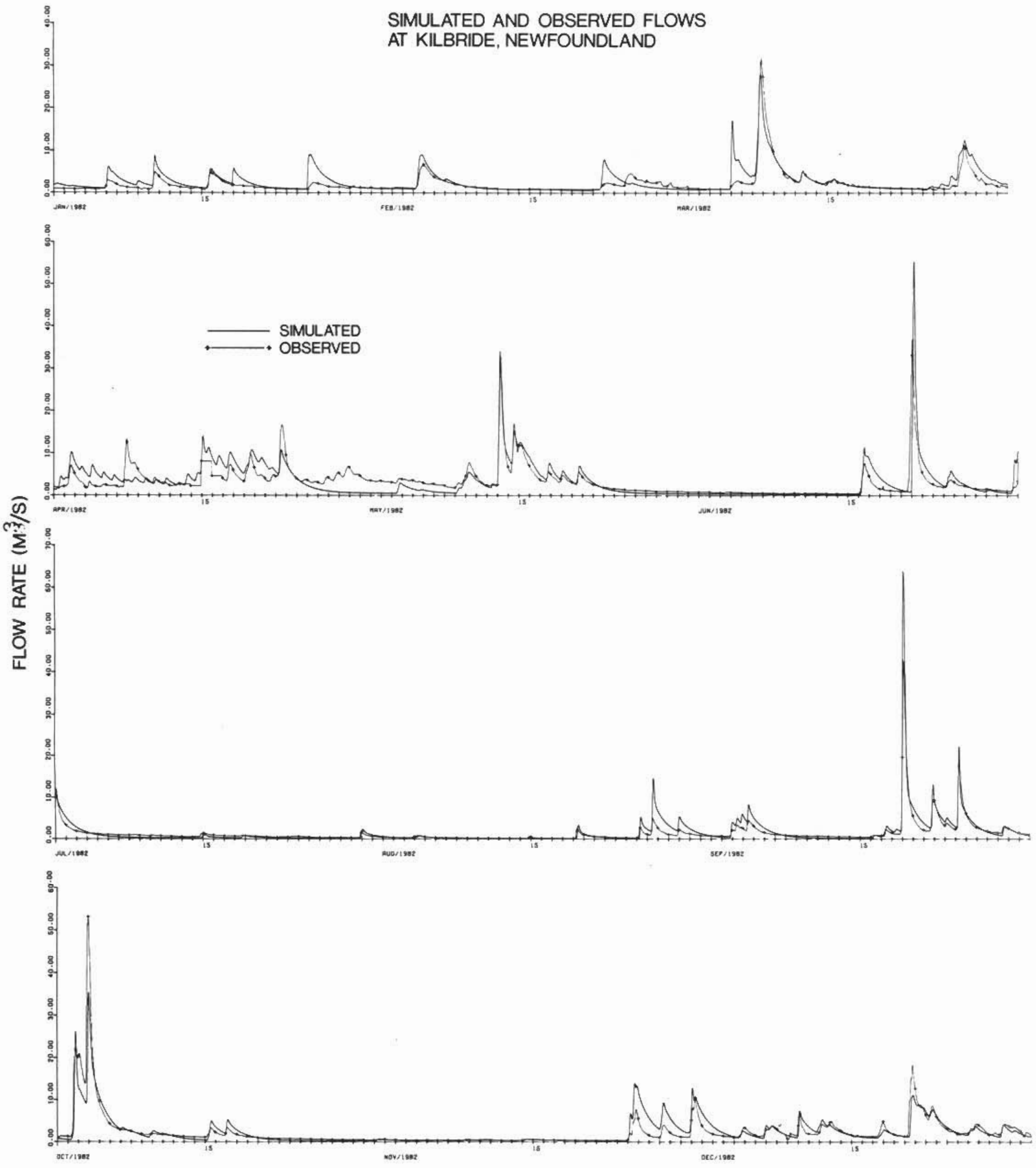


Figure 5. Continuation (a)

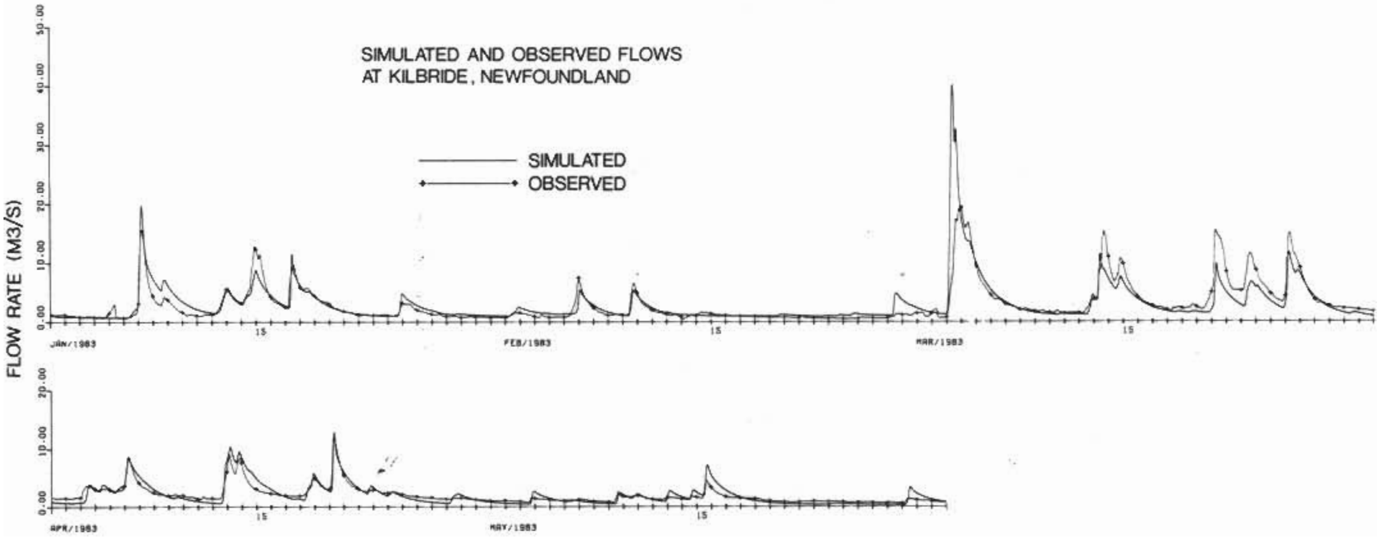


Figure 5. Continuation (b)

Following hydrograph calibration, the HSPF model was considered to be well-calibrated, for the available data base, and suited for simulations for future land use scenarios.

6.0 STREAMFLOW SIMULATION FOR FUTURE LAND USE SCENARIOS

6.1 Land Use Dynamics

Land use patterns in the Waterford River Basin have been studied by the Land-Use Sub-Committee and reported elsewhere (13). This Sub-Committee examined the land use changes in the basin during the period from 1973 to 1984 and noted some significant changes. The expanding land uses included residential (+2.3 km^2), commercial/industrial/institutional (+1.5 km^2), unproductive (+2.0 km^2), and other (+0.6 km^2) land. Declines occurred in the agricultural (-1.6 km^2) and forest (-4.7 km^2) lands (13).

Besides the survey of past changes, there were no other data which could be used to predict the future land use. It was therefore decided to approximate the future developments in the study area in three stages obtained by increasing the existing impervious area by 50%, 100% and 200%. Such a range of values would be more than adequate to investigate the changes in the basin hydrologic response resulting from any future developments in the basin. It was furthermore assumed that new developments would take place in the vicinity of Mount Pearl. Basic characteristics of the current and hypothetical future land use scenarios are shown in Table 11.

Table 11. The Existing and Future Land Use Scenarios

Land Use Scenario	Areas (km^2) Total Basin	Pervious Segments PERLND1	Pervious Segments PERLND2	Impervious Segment-IMPLND1
The existing (1984)	53.03	30.25	20.13	2.65
Future #1	53.03	28.90	20.13	4.00
Future #2	53.03	27.60	20.13	5.30
Future #3	53.03	24.95	20.13	7.95

6.2 HSPF Simulations for Future Land Use Scenarios

The HSPF model calibrated against the Waterford River Basin data base was applied to the three future land use scenarios. In such simulations, all the model parameters were selected as shown in Table 7 and only the areas of land segments were varied as shown in Table 11. The simulation runs for future scenarios were evaluated in terms of annual, monthly and hydrograph peak flows. Such data are presented in Tables 12 and 13.

It can be inferred from Table 12 that any future development in the study area will not affect significantly the 1984 annual or monthly streamflows. By tripling the current (1984) impervious area, the annual streamflow volume increases by only 1%. This follows from the fact that under the existing conditions about 84% 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.

Table 12. Streamflow Simulated for Various Land Use Scenarios

		Mean Hourly Streamflow (mm/hr)												Streamflow (mm)
Year	Land Use Scenario	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	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								632
	F1	0.196	0.109	0.295	0.192	0.079								631
	F2	0.196	0.109	0.295	0.192	0.079								631
	F3	0.196	0.109	0.295	0.192	0.079								631

Table 13. 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*

The simulation results for peak flows, given in Table 13, show more sensitivity to progressing development of the basin than streamflow volumes. It would appear that if the impervious area is doubled the peak flows will increase, on the average, by about 10%.

The increases for the largest peaks seem to be relatively larger, in the range from 15 to 25%. Such increases would be significant in terms of increased incidence of flooding.

7.0 DISCUSSION OF SIMULATION RESULTS

The HSPF model has been used to reproduce the hydrologic response of the study area with very good or good match between the observed and simulated results. In this process, there were some limitations encountered and such limitations need to be fully understood when interpreting the results in this report or when planning future work. Such limitations are discussed below in a fairly arbitrary order.

Problems with study organization - the separation of the data preparation task from the actual modelling task, which was necessitated by the limited resources of co-operating agencies, proved to be unfavourable for study conduct. In particular, the input data base was planned and prepared without the actual experience in running the HSPF model. A number of errors were noted in the data base and had to be corrected during the modelling work. More extensive reviews or modifications of the input data base during the modelling phase were prevented by limited resources.

In retrospect, it is believed that better modelling results could be obtained for 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 high simulated discharges, it is necessary to know the channel geometry and the 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.

The modelling task was made tedious by the limitations of the available computer. In the beginning, much effort was devoted to just finding out the maximum simulation period and devising program overlays necessary for running the model. At best, only 29 months could be simulated in a single run and, consequently, the available 36 months data base could not be fully utilized. Individual runs required fairly long processing times (about 20 minutes) on the CYBER system and this limited the frequency of runs to about one per day. Such a low frequency then slowed down the study progress.

Considering the above limitations, the simulation results obtained are fairly good. The simulated streamflow matches the observed one for annual and monthly volumes, as well as for peak and low flows. Very high percentage of precipitation is converted into streamflow because of relatively low basin evapotranspiration. Consequently, any future development does not seem to affect much the volume of streamflow, but only its distribution resulting in increased peak flows. 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 would require detailed characterization of the future development in terms of imperviousness, drainage density, and roughness and connectivity of drainage elements. Such information was not available at this time. It is conceivable that future runoff peak flow increases resulting from both increased volume and speed of runoff would exceed changes in the watershed imperviousness. It appears that the HYMO modelling procedurs (12) focussed mostly on runoff volume changes and, consequently, did not indicate any increases in runoff peaks. In this regard, the HSPF results are more realistic.

Any future extensions of the study described here should concentrate on extending the data base, so that it could be divided into independent segments for model calibration and verification, further improvements in the input data in terms of estimates of watershed precipitation and better descriptions of the flow routing channels (it may be desirable to route flows through South Brook as well); extension of the simulation period beyond 29 months; and, simulations of water quality.

8.0 CONCLUSIONS

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. To obtain such an agreement, it was necessary to calibrate the HSPF model in a series of runs progressively adjusting the annual and seasonal water balance and finally the event flows. Besides the general hydrologic parameters, it was also necessary to calibrate the snowmelt subroutine in order to obtain a good match for monthly streamflows and, even more importantly, for event peak flows. The limited supporting data for flow routing sub-routine did not justify any calibration of flow routing calculations.

The calibrated HSPF model was applied to three hypothetical future land use scenarios representing increases in the basin impervious 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. The doubling of the impervious area would result in increases of the largest peak flows by up to 25%.

9.0 RECOMMENDATIONS

It is recommended to adopt the basic set up of the HSPF model described in this study for future investigations of water resource problems in the Waterford River Basin. The water quantity part of the model is fully operational and reasonably well calibrated. It can serve for future studies of both high and low flows. Further improvements in the input data series and model calibration are possible, but not essential for practical work. It is, however, required to set up the water quality part of the HSPF model and to calibrate it. Such work can utilize the existing streamflow simulation experience and the water quality data collected under the Waterford River Basin Urban Hydrology Study.

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