THE HYDROCLIMATOLOGICAL CHARACTERISTICS OF A PEATLAND-DOMINATED CATCHMENT IN SOUTHEASTERN NEWFOUNDLAND

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THE HYDROCLIMATOLOGICAL CHARACTERISTICS OF A PEATLAND-DOMINATED CATCHMENT IN SOUTHEASTERN NEWFOUNDLAND

BY

© Jeffrey Leslie Barnes, B.A. (Hons.)

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ABSTRACT

Little is known about the hydrology of peatland in Newfoundland despite the extensive tracts of peatland found there. This thesis attemtps to characterize the hydroclimatology of the Old Sams River (2.55 km^2), a small peatland-dominated catchment on the southern Avalon Peninsula.

Detailed hydrometeorological investigations were carried out throught a 76-day study period to monitor the transition from wet to dry hydrometeorological conditions typically experienced in spring and summer. The study undertakes a comparative analysis of these data with those of two gauged catchments also located on the Avalon Peninsula, Northwest Brook (53.3 km^2) and Northeast Pond River (3.63 km^2), both of which have much less peatland.

Evaluation of the seasonal hydroclimatological representativeness of the study period demonstrates that all three catchments experienced a range of hydrometeorological conditions, undergoing a transition from warmer and wetter than normal conditions to much drier than normal conditions.

The analyses demonstrate that in comparison with that experienced at the other two catchments, under the drier than normal conditions in the latter part of the study period, the Old Sams River gradually released moisture which was stored in its peatlands. However, the hydroclimatology of the Old Sams River catchment is such that its peatlands seldom become sufficiently dry to enable them to act as a regulator of streamflow in this way. Under normal conditions, high water table persists year-round, causing the hydrologically-active layer to encourage rapid, spate-like streamflow response to precipitation. The hydroclimatological conditions at Old Sams River differ from those observed for other peatlands reported in the literature, where runoff can often cease for long periods under dry summer conditions.

The importance of the hydrologically-active layer in the generation of runoff was demonstrated by the frequent occurrence of depressions in the recession phase of the hydrograph at Old Sams River. These appear to be directly related to the diurnal pattern in the meteorological parameters responsible for evapotranspiration. These evapotranspiration-induced depressions in the hydrograph resulted in a rapid decrease in discharge to a mid-day value between 60.5% and 91.7% of the previous overnight discharge, and was 55.1% to 96.7% of the overnight recovery discharge.

(KEY WORDS: peatland, blanket bog, hydrology, hydroclimatology, hydrometeorology, evapotranspiration, Newfoundland).

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My wife Kathleen and my children Nicholas, Sarah, and Julia were subjected to a considerable amount of neglect over the past years as a result of the many nights and weekends I've spent writing this thesis. In appreciation of their patience and love, I dedicate this thesis to them.

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INTRODUCTION

1.1 PEATLAND RESEARCH AND DEVELOPMENT IN NEWFOUNDLAND

Peatlands are an important component of the hydrologic cycle. Because of their sponge-like properties, it is commonly held that they act as regulators of streamflow, gradually releasing their moisture over prolonged dry periods. Although the above notion is not well substantiated by the literature, peatlands do store large volumes of water. The hydrology of peatland is thus an important aspect of water resources in Canada, where the estimated surface area of peatland is 1.1 million km^2, 12% of the total land area (Radforth, 1968). Despite this, research in this field has been limited in Canada.

The hydrology of peatland is of even greater importance on the Island of Newfoundland where 20,000 km^2, 17% of the total land area, is peatland (Healey, 1963). Rayment and Chancey (1966), Rayment and Cooper (1968), and Rayment (1970) investigated the problem of peatland drainage for agriculture. More recently, Paivanen and Wells (1978) provided guidelines for the development of peatland drainage sytems for forestry. Only Rayment and Cooper (1968) considered the water balance and water table conditions on both virgin and drained peatland.

On the Island of Newfoundland, Federal and Provincial government research has concentrated on various aspects of peatland development. Serious interest in its peatland as a resource extends back 30 years, when the Newfoundland and Labrador Department of Mines began publication of a series of preliminary reports and investigations including Gillespie (1954), Løddesøl (1955), Lear (1960), McKillop (1963), and McKillop and Day (1963). Healey (1961; 1963) reported on some aspects of organic terrain in Technical Memoranda to the National Research Council's Associate Committee on Soil and Snow Mechanics. Later, Heikurainen (1968), Pollett (1969), Dickson (1971), Richardson and Chaffey (1973; 1977), Richardson, et al. (1976), Richardson (1979), and Squires (1979) investigated the development of peatland for forestry. Rayment (1965), Rayment and Heringa (1972), Rayment and Winter (1975), Mathur and Rayment (1977), Jasmin and Hamilton (1979), and Rayment and Penney (1979) investigated various aspects of the development of peatland for agriculture. Their research was undertaken at the Argiculture Canada Peat Sub-station at Colinet. Peatland classification, nutrient status, and phytosociology were investigated by Pollett (1972a; b; and c), Pollett and Bridgewater (1973), Robertson, et al. (1973), Wells (1976; 1981), Pollett and Wells (1979), and Robertson (1979).

Pollett (1968) provided the first comprehensive assessment of the peatland resources of Newfoundland. Later, Pollett and Rayment (1973) reviewed peatlands and their development. The most recent overview of its peatlands was provided by Pollett and Wells (1979).

A major impetus in recent research and development of peatland was the formation, in 1977, of the Newfoundland and Labrador Peat Association. Their inaugural meeting in 1977 generated the first comprehensive publication on all aspects of peatland development in the Province (Pollett, et al., 1979). Although this was primarily a review of peatland research and development, i.e., Pollett and Wells (1979), Richardson (1979), Squires (1979), Jasmin and Hamilton (1979), and Rayment and Penney (1979), it also considered new uses of Newfoundland peat for fuel (Gosine, 1979; and Mercer, 1979) and horticulture (Traverse, 1979).

The development of peatland in Newfoundland has not yet advanced beyond government research and government-subsidized demonstration projects. Assisted financially by the Provincial and Federal Governments, Abitibi-Price Ltd. began a fuel peat operation at its Bishop's Falls pulp and paper mill in 1979. A similarly-funded demonstration project using peat as a domestic fuel began in 1981 at St. Shotts under the direction of the local development association. Also in 1981, again with the support of the Provincial and Federal Governments, the Terra Nova Power and Development Corporation developed and commenced production of an oil-absorbent peat product for use in the clean-up of oil spills. Whether or not the development of peatland in Newfoundland will evolve into a diverse and commercially viable industry remains to be seen.

The hydrology of peatland on the Island of Newfoundland remains for the most part unstudied. The impact of existing and future development on the water resources of Newfoundland's peatland is unknown and to this date has not been considered.

1.2 THE HYDROLOGY OF PEATLAND

The distinct lack of knowledge of the hydrology of peatland in Newfoundland and in Canada as a whole is in stark contrast to the extent of literature devoted to this subject in other countries. Most research in the hydrology of peatland has been in the Soviet European countries, and to a lesser extent in Great Britain, Ireland, and the United States.

It is generally thought that peatlands act as regulators of streamflow by storing enormous quantities of water and gradually releasing them through prolonged dry periods. However, the work of several researchers has indicated that to some extent this is a mistaken notion; it is an oversimplification of the hydrologic characteristics of peatland. The ensuing discussion reviews the literature and investigates these conflicting views.

1.2.1 Water Retention Properties of Peat

In his review of the literature concerning the physical and chemical properties of peat, Walmsley (1977) noted that the void ratio, the ratio of the volume of spaces to the volume of solids, ranges from as low as 2 for amorphous peat, to as high as 25 for fibrous peats. The reported range of porosity, the total volume of water continued at saturation, was from 80.7% to 95.2%, with an average of 92.0%. He observed that there is a difference in the nature of porostiy in different peat types. In undecomposed moss peats, large easily drained pores release between 50% and 80% of their water to normal drainage at low levels of water suction. In contrast, well-decomposed peats are characterized by many very small pores, yielding only 10% to 15% of their water to normal drainage at low water suctions.

Boelter (1966) concluded that as a general rule all peat types, regardless of plant source or degree of decomposition, contain more than 80% water by volume at saturation. Walmsley (1977) noted that the gravimetric moisture content for a variety of peat types ranges from 100% to over 3,000%.

The hydraulic conductivity of peat was investigated extensively by a number of authors including Hanrahan (1954), Phalen (1961), Baden and Eggelsmann (1963), Boelter (1965), Irwin (1966), Boelter (1972), Korpijaako and Radforth (1972), Ingram, et al. (1974) and Rycroft, et al. (1975a; and b). Research in the hydraulic conductivity of peat was reviewed by Walmsley (1977). Saturated hydraulic conductivity reported by various authors ranges from as low as 1.0 x 10^{-7} *cm sec*$^{-1}$ (Phalen, 1961) to as high as 1.6 x 10^{-1} *cm sec*$^{-1}$ (Boelter, 1972). Rycroft, et al. (1975a) reported the results of laboratory and field studies of saturated hydraulic conductivity of peat which reveal a variation of 10 orders of magnitude between 1.0 x 10^{2} and 1.0 x 10^{-8} *cm sec*$^{-1}$.

Hanrahan (1954), Boelter (1965), Rycroft, et al. (1975a) and Walmsley (1977), have noted that hydraulic conductivity within peat decreases with increasing degree of decomposition. Boelter (1965) attributed this difference to differences in pore size distribution. Elzen (1961) concluded that while there is only a small decrease in porosity with increasing degree of decomposition, there is a considerable decrease in the effective diameter of pores. Walmsley (1977) suggested that the size and continuity of pores are affected by the arrangement of particles, resulting in the wide range of hydraulic conductivities in peat. Rycroft, et al. (1975a) demonstrated that variation in hydraulic conductivity of peat is related to a number of physical and chemical characteristics, as well as their botanical composition. They reported that hydraulic conductivity decreases regularly with increases in overburden pressure, bulk density, substance volume, and degree of humification.

Dai and Sparling (1973), Ingram et al. (1974), and Rycroft, et al. (1975b) found that at any one peatland site, the hydraulic conductivity does not always vary linearly with increasing head. This deviates from Darcy's Law, which is normally used to describe flow through porous media. In Darcy's Law, the flux density and the hydraulic gradient are related linearly to the hydraulic conductivity by the relationship

$$q = K \frac{\Delta H}{L},$$

where q is the flux density (volume of water flowing through a cross-sectional area in a unit of time), K is the hydraulic conductivity, ΔH is the difference between the two heads, and L the length of column containing material ($\Delta H/L$ is the hydraulic gradient). Ingram, et al. (1974), and Rycroft, et al. (1975b) found that while this deviation occurs with well-humified peat, Darcy's Law appears to be obeyed in peat of a lesser degree of decomposition. It is important to note that to date, the literature does not report on the hydraulic conductivity of unsaturated peat.

1.2.2 The Hydrologically-Active Layer[1]

Ivanov (1953) and Romanov (1953; 1961) originally proposed the concept of a hydrologically-active layer in peatland, a surface layer in which most moisture exchange takes place. According to Goode, et al. (1977), this hydrologically-active layer includes living vegetation, provided it is sufficiently dense to form pores for capillary water, and the uppermost layers of peat, those which characteristically demonstrate a rapid decline in degree of decomposition and hydraulic conductivity with depth. The lower boundary of the hydrologically-active layer is not well defined; above it, considerable changes in hydrophysical properties occur, while below it, these changes appear to be negligible.

Depth-related decreases in hydraulic conductivity and related hydrophysical changes in this hydrologically-active layer are widely reported in the literature, for example, Ivanov (1953), Romanov (1961), Vorobiev (1963), Boelter (1965), and Korpijaako and Radforth (1972). Goode, et al. (1977) observed that hydraulic conductivity close to the surface of the hydrologically-active layer is often several orders of magnitude greater than at its base. As a consequence, lateral subsurface flow decreases as the water table falls towards the base of the hydrologically-active layer. Ivanov (1953) suggested that lateral flow below the hydrologically-active layer accounts for only about one percent of the total runoff from the raised bog which he investigated.

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[1] This is not to be confused with the active layer in permafrost.

The physical structure of the hydrologically-active layer and its effect on moisture characteristics are discussed in Romanov (1961), Dooge (1972), and Novikov (1972). Goode, et al. (1977) noted that investigations into the concept of a hydrologically-active layer had taken place primarily in areas of domed ombrogenous bogs. They suggested that similar conditions could conceivably prevail in the ridges of minerotrophic peatlands, or in the surface layer of blanket or slope bogs, all of which typically demonstrate similar hydrophysical characteristics. However, it is not known if a comparable hydrologically-active layer exists in topogenous fens. Further work in this area is required to characterize the hydrologically-active layer in various peatland types.

1.2.3 Water Table and Runoff in the Hydrologically-Active Layer

The importance to runoff of the hydrologically-active layer is demonstrated by a number of authors, including Ivanov (1953), Romanov (1953; 1961), Chapman (1965), Robertson, et al. (1968), Bay (1968; 1969), Dooge (1972), Novikov (1972), Goode, et al. (1977), and Tomlinson (1979). Typically, runoff from peatland decreases with increasing water table depth. Romanov (1961) found that in raised bogs near Leningrad, runoff ceased when the water table depth dropped below 25 *cm* from the upper surface of the bog. Similarly, Robertson et al. (1968) reported the same critical value of 25 *cm* for a raised bog in Scotland. Chapman (1965) showed that a major reduction in runoff occured at water table depths of 8 *cm* in a blanket bog in northern England. Here runoff ceased when the water table depth dropped below 20 *cm*. Bay (1968) reported a logarithmic relationship between runoff and water table depth in forested bogs in Minnesota.

1.2.4 Water Balance Considerations

Few studies have investigated the water balance in peatland catchments. Robertson, et al. (1968) investigated the water balance of a raised bog in Scotland. They reported that runoff occurs through most of the year, but runoff does cease when the water table is below 25 *cm*, which typically occurs during periods of low precipitation and/or high potential evapotranspiration.

Burke (1972) investigated rainfall/runoff relationships on two 0.35 *ha* plots of blanket peat in Ireland. The undrained plot demonstrated rapid runoff response to precipitation events, with runoff ceasing frequently between these events. In the drained plot, runoff response was much less dramatic, and runoff persisted throughout the 11 month period of observation. The artifical lowering of the water table resulted in an increased ability to absorb precipitation. Thus, the drainage of these peatlands could potentially result in the beneficial regulation of streamflow, reducing flood peaks and sustaining runoff through dry periods.

From these, and the investigations of others, Goode, et al. (1977) argued that in areas of oceanic climate where precipitation is substantial year-round, runoff from bogs will occur rapidly and produce frequent spates. However, at other times, particularly in summer, there may be periods in which runoff may be virtually non-existent. Robertson, et al. (1968) demonstrated that water table levels can drop dramatically in short periods of particularly high evapotranspiration, or by virtue of extended periods of low precipitation. Baden and

Eggelsmann (1968), in their study of a sub-oceanic raised bog in Germany, demonstrated that for much of the summer, runoff is negligible, but that only one day of heavy rain is required to restore the water table to a height at which runoff occurs. Here, the summer is characterized by long periods during whcih little or no runoff occurs, interspersed with brief periods of intense runoff.

It is apparent that the hydroclimatological conditions which prevail over a peatland catchment are critical factors in determining its hydrologic characteristics. During prolonged dry periods, runoff may be greatly regulated by peatland. However, under the normally wet conditions experienced in peatlands, they do not appear to act as regulators of streamflow.

1.2.5 Discussion

Peatlands do store large quantities of water. Hydro-physical properties vary dramatically with depth near the surface, resulting in the existence of a hydrologically-active layer. The water balance of peatlands appears to be determined largely by interactions within this layer.

Runoff from natural peatlands is typified by rapid runoff response to precipitation. However, during periods of high evapotranspiration and/or extended periods of low precipitation, runoff may decrease dramatically or cease altogether. The commonly held notion that natural peatlands act as regulators of streamflow, gradually releasing water over prolonged periods, may well be a gross misconception of their hydrological characteristics. In fact, such characteristics are demonstrated only during summer periods of low precipitation and/or high rates of evapotranspiration. In peatlands which have been drained for development purposes, there is a moderation of the spate-like runoff response to precipitation. It is under these conditions that peatlands absorb precipitation and gradually release it over prolonged dry periods.

CHAPTER 2

RESEARCH DESIGN AND METHODOLOGY

2.1 THE NEED FOR RESEARCH ON THE ISLAND OF NEWFOUNDLAND

The importance of peatland as a water resource and the role it plays in the water balance is well documented in the literature. However, despite considerable research in other aspects of peatland on the Island of Newfoundland, the hydrology of its peatland remains largely unknown. With increased interest in the development of peatland in recent years, there is a pressing need for research in this field. Without this, it will be impossible to adequately assess the impact of future developments on not only the hydrology of peatlands themselves, but perhaps more importantly, on the water balance and water resources of any catchment which has peatland within its drainage area.

2.2 STUDY OBJECTIVES

The objective of this study is to characterize the hydro-climatology of a small peatland-dominated catchment in southeastern Newfoundland. The catchment studied is the uppermost tributary of the Old Sams River which is located on the coastal uplands of the southern Avalon Peninsula (Figure 2.1). A total of 53.3% of its 2.55 km^2 area is blanket bog (see Section 3.3.4.1). Chosen both for its pristine state and the areal extent of blanket bog within its confines, the study catchment offers an excellent opportunity for the evaluation of the role played by peatland in the hydrology of the Avalon Peninsula region.

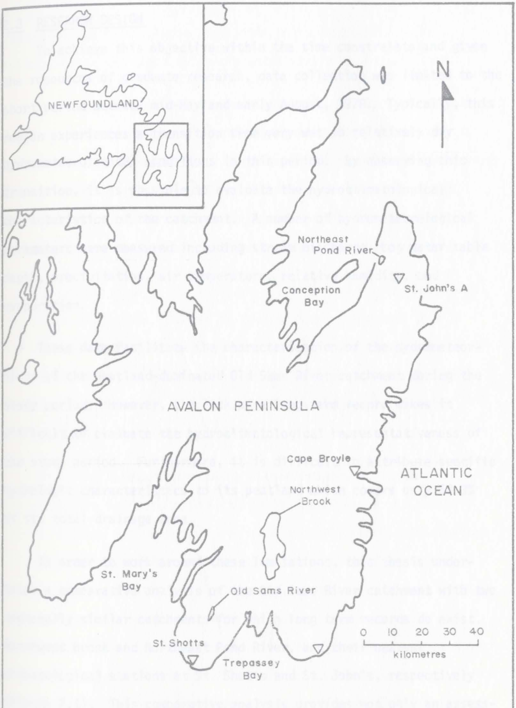

FIGURE 2.1 LOCATION OF STUDY CATCHMENTS AND CLIMATOLOGICAL STATIONS

2.3 RESEARCH DESIGN

To achieve this objective within the time constraints and given the resources of graduate research, data collection was limited to the short period between mid-May and early August, 1978. Typically, this region experiences a transition from very wet to relatively dry hydrometeorological conditions in this period. By observing this transition, it is possible to evaluate the hydroclimatological characteristics of the catchment. A number of hydrometeorological parameters were measured including stream discharge, bog water table depth, precipitation, air temperature, relative humidity, and evaporation.

These data facilitate the characterization of the hydrometeorology of the peatland-dominated Old Sams River catchment during the study period. However, the lack of a long term record makes it difficult to evaluate the hydroclimatological representativeness of the study period. Furthermore, it is difficult to attribute specific hydrologic characteristics to its peatland which covers only 53.3% of its total drainage area.

In order to work around these limitations, this thesis undertakes a comparative analysis of the Old Sams River catchment with two regionally similar catchments for which long term records do exist, Northwest Brook and Northeast Pond River, and their nearest climatological stations at St. Shotts and St. John's, respectively (Figure 2.1). This comparative analysis provides not only an assessment of the hydroclimatological representativeness of the study period, but also owing to their relatively lesser amounts of peatland, a means of evaluating those hydrologic characteristics of the Old Sams River catchment which are attributable to its peatland.

The much larger Northwest Brook catchment, 53.2 km^2 in drainage area, is the Water Survey of Canada hydrometric station nearest to the Olds Sams River catchment. The St. Shotts Atmoshperic Environment Service climatological station is the closest to both catchments. Although not as extensively covered by peatland, 7.86% of the Northwest Brook catchment is covered by slope bog (see Section 3.3.4.2).

Of similar size to the Old Sams River catchment, the Northeast Pond River catchment, 3.63 km^2 in drainage area, has much less peatland with only 2.5% of its area covered by domed bog (see Section 3.3.4.3). Meteorologic data for this comparative analysis were obtained from the nearby Atmospheric Environment Service climatological station at St. John's.

While this comparative analysis does provide a means of evaluating the hydroclimatological representatives of the study period, it does not necessarily provide a straightforward evaluation of the hydrologic characteristics which are attributable to the peatland of the Olds Sams River catchment. However, Chapter 3 describes in considerable detail the location and land use, physiography, geology, vegetation, and hydroclimatology of the three catchments. By comparison of these parameters between basins, it is possible to better ascertain the hydrologic characteristics which are attributable to the presence of extensive peatland areas in the Old Sams River catchment.

Chapter 4 summarizes the hydrometeorologic data for each catchment during the study period.

Chapter 5 provides the comparative analysis of these data. The seasonal hydroclimatological representatives of the study period is assessed. The hydrometeorology of the Old Sams River catchment is characterized, and is compared and contrasted with that observed for the Northwest Brook and Northeast Pond River catchments. Where possible, the characteristics attributable to peatland are discussed.

Chapter 6 summarizes the analysis and makes relevant conclusions. The significance of these is discussed in view of the literature and the water resources of the region. The direction for future research is suggested.

2.4 DATA COLLECTION FOR THE OLD SAMS RIVER CATCHMENT

In order to achieve the study objective outlined in Section 2.2 it was necessary to obtain hydrometeorological data for the Old Sams River catchment during the study period. The following parameters were measured:

(1) stream stage;
(2) precipitation;
(3) air temperature and relative humidity;
(4) evaporation; and
(5) bog water table depth.

Stream stage and discharge monitoring stations were established near the mouth of the study catchment (Figure 2.2). Precipitation, air temperature, relative humidity, and evaporation were monitored at a centrally located meteorologic station 1.5 *km* north of the catchment mouth (Figure 2.2). A total of 19 wells used to measure bog water table depth were located throughout the catchment (Figure 2.2).

2.4.1 Stream Stage and Discharge

Stream stage was measured with a continuous recording, float-actuated stage recorder. In order to estimate a continuous record of stream discharge, a stage-discharge rating curve was established. Individual point-in-time stream discharge measurements were made through a range of stream stage conditions using the current meter velocity-area method (Church and Kellerhals, 1970).

The continuous recording, float-actuated stage recorder provided up to 10 days of data on an ink traced chart. The instrument was sensitive to fluctuations in stage of one *mm*. The stage recorder was housed and supported in a wooden frame which extended from the peat bank (Figure 2.3). The float was suspended in a galvanized steel stilling well beneath the recorder housing. The stilling well was located in the stream near the bank. The base of the stilling well extended to the bottom of a deep pool. The pool was part of a bedrock-controlled pool and riffle sequence, with well-defined peat banks about two *m* in height. This site was less than ideal, primarily because of the proximity of streaming turbulent flow. However, for the duration of the study, there was no recorded oscillation due to this turbulence.

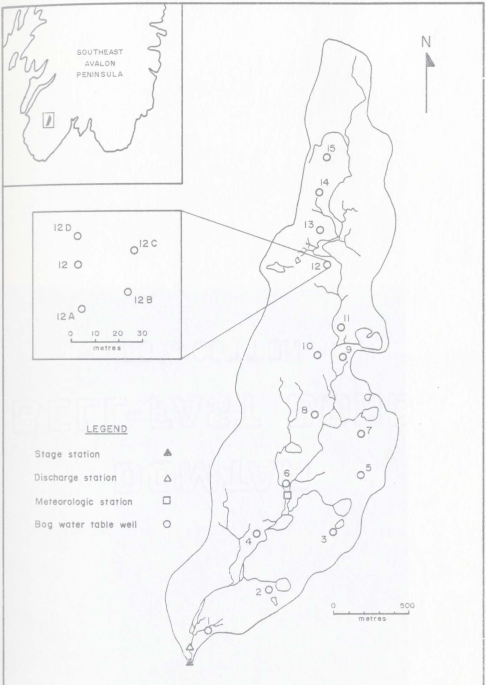

FIGURE 2.2 OLD SAMS RIVER HYDROMETEOROLOGIC NETWORK

Figure 2.3 Stage Recorder and Stilling Well, Old Sams River

For the purpose of establishing the stage-discharge rating curve, stream discharge was determined through a range of stage conditions. The location of the stage recorder was not a suitable site for the determination of discharge because of turbulent flow and the irregular bedrock-controlled bed. Approximately 100 *m* upstream of the stage recorder a straight section was selected for stream discharge determination (Figure 2.2). This section experienced relatively less turbulence. The lack of suitable confining banks precluded the use of this site as the stage recorder site.

A total of ten discharge measurements were made under various stage conditions. A Price standard current meter was used for the first determination of discharge. This instrument was found to be too large and impractical for continued use in this small stream. The second discharge measurement was made using numerous measurements of velocity with a cork float. Mean velocity was related to surface float velocity by a factor of 0.66. The remaining eight measurements were made with a Price 625 pygmy current meter on loan from the National Calibration Service, Inland Waters Directorate, Environment Canada. This instrument proved to be the most suitable for discharge measurement in this small stream.

Discharge was determined in the method described for small streams by Church and Kellerhals (1970). The current meter was used to determine velocity at 0.6 of the depth over a period of approximately 60 seconds. Measurements were made at 10 *cm* intervals (the width of the meter) across the stream. Although the stream was only slightly more than 2 *m* in width at this site, this procedure enabled the determination of discharge at a minimum of 20 locations across the section. An example of these data is shown in Table 2.1.

The resultant rating curve is shown in Figure 2.4. The correlation coefficient of 0.984 is significant at the 0.1% level of confidence. Actual stage and discharge observations are summarized in Table 2.2.

2.4.2 Meteorologic Observations

A meteorologic station was established 1.5 *km* upstream of the mouth of the Old Sams River catchment, lying approximately 153 *m* asl (Figure 2.2). The site was on the flood plain of the main channel. Its valley bottom location offered some shelter from wind. For the purposes of the present study, it is assumed that precipitation, air temperature, relative humidity, and evaporation do not vary significantly over the Old Sams River catchment. This assumption is made with reservations that even for such a small catchment, this may not always be the case. Figure 2.5 shows the station location.

2.4.2.1 Precipitation

Precipitation was measured using a continuous recording Sangamo Type B-2 tipping bucket rain gauge. This instrument is known as the Atmospheric Environment Service (AES) tipping bucket rain gauge (Marsalek, 1981) and is manufactured to Environment Canada specifications. It is 62.2 *cm* in height and has a 25.4 *cm* inside diameter, knife-edged receptacle for the interception of rainfall. The

TABLE 2.1 DETERMINATION OF STREAM DISCHARGE FOR THE OLD SAMS RIVER, JUNE 28, 1978

Section No.	Width (*cm*)	Depth (*cm*)	Area (cm^2)	Velocity ($cm\ sec^{-1}$)	Discharge ($\ell\ sec^{-1}$)
1	10	18.9	189	14.2	2.68
2	10	14.5	145	14.5	2.10
3	10	20.2	202	19.9	4.02
4	10	20.3	203	15.3	3.11
5	10	17.9	179	16.3	2.92
6	10	15.4	154	15.3	2.36
7	10	19.3	193	11.9	2.30
8	10	22.8	228	7.8	1.78
9	10	23.2	232	7.8	1.74
10	10	18.3	183	11.9	2.18
11	10	21.7	217	13.8	2.99
12	10	20.0	200	12.4	2.48
13	10	20.4	204	9.3	1.90
14	10	21.5	215	13.5	2.90
15	10	18.1	181	12.0	2.17
16	10	19.9	199	12.7	2.53
17	10	20.0	200	10.1	2.02
18	10	17.0	170	7.9	1.34
19	10	13.0	130	6.8	0.88
20	15	12.1	182	5.3	0.96
Total					45.36

Observation complete at 13:40 *hrs* NST

Stage = 25.1 *cm*

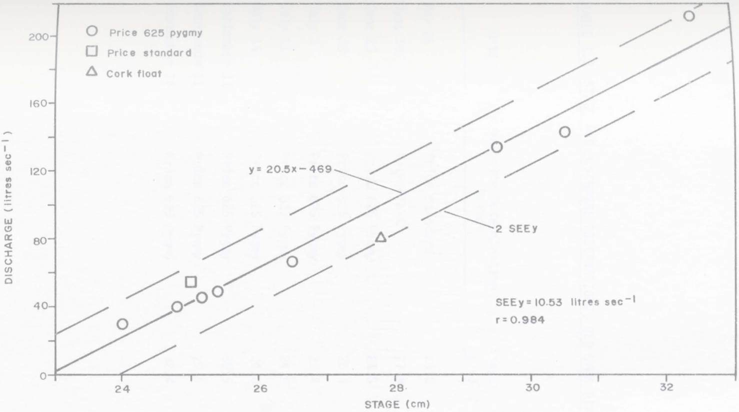

FIGURE 2.4 STAGE-DISCHARGE RATING CURVE

TABLE 2.2 STAGE AND DISCHARGE OBSERVATIONS, OLD SAMS RIVER, 1978

Date	Velocity Determination Method	Stage (*cm*)	Discharge ($\ell\ sec^{-1}$)
May 26	Price standard	25.0	54.3
June 18	Cork Float	27.8	80.7
June 23	Price 625 Pygmy	26.5	66.1
June 28	Price 625 Pygmy	25.1	45.3
July 3	Price 625 Pygmy	25.4	49.0
July 11	Price 625 Pygmy	24.8	39.6
July 16	Price 625 Pygmy	24.0	29.5
September 11	Price 625 Pygmy	30.5	143
September 11	Price 625 Pygmy	29.5	134
September 14	Price 625 Pygmy	32.4	213

Figure 2.5 Meteorologic Station Showing Location of Stephenson Screen, Precipitation Gauge, and Evaporation Pan. Old Sams River is in the Foreground.

receptacle funnels rain water into one of a pair of balanced tipping buckets. When 0.2 *mm* of rain collects in one bucket, the balance tips, empties the full bucket, and positions the other bucket under the funnel spout. Each tip of a bucket activatives a mercury switch which causes the recorder to register one step on the drum chart. The collecting area of the instrument is 506 cm^2. It is sensitive to 0.2 *mm* of rainfall. It is accurate to within ± 2% at a rainfall rate of 50.8 $mm\ hr^{-1}$ (manufacturer's specifications). Seven day charts were used in this study.

Marsalek (1981) investigated the calibration of the AES tipping bucket rain gauge and found that at low intensities of less than 25 $mm\ hr^{-1}$, the recorded intensity may exceed the actual intensity. However, it is reported that these underestimations are negligible given that the largest difference between low recorded and actual intensities is less than 0.14 $mm\ hr^{-1}$. For intensities greater than 25 $mm\ hr^{-1}$, the recorded intensity is always smaller than the actual intensity. The difference between the two intensities can exceed 10% for intensities of greater than 200 $mm\ hr^{-1}$. During the study period, rainfall intensities did not approach the 25 $mm\ hr^{-1}$ rate. Based on these observations, it is concluded that due to these errors in calibration, the instrument may have underestimated the actual precipitation during the study period by a negligible amount only.

The gauge location was consistent with that recommended by Bruce and Clark (1966). It was located in a relatively sheltered area where winds tended to be relatively light. There was no rain shadow effects caused by nearby objects such as buildings or trees. The gauge was not shielded. It is recognized that under strong wind conditions, the gauge could have registered an undercatch of as much as 15% (Bruce and Clark, 1966). However, any discussion of gauge undercatch due to the effects of wind at this site would be difficult without wind velocity data and further study.

2.4.2.2 Air Temperature and Relative Humidity

Air temperature and relative humidity were measured with a Casella London continuous recording thermohygrograph at the meteorologic station (Figure 2.2). The instrument was housed in a Stephenson screen at a height of approximately 1.5 *m* above the ground surface. The louvered structure was installed so that its door opened on the north side, preventing direct sunlight from falling on the instrument during inspection.

The instrument measured relative humidity between 0% and 100%, and air temperature between -10°C and 40°C. The instrument recorded both parameters with ink tracer pens on a seven-day chart. The measurement of temperature was sensitive to ± 0.1°C. The measurement of relative humidity was sensitive to ± 0.1%. For both parameters, the instrument response time could be up to 15 minutes.

2.4.2.3 Evaporation

For a part of the study period pan evaporation was measured at the meteorologic station (Figure 2.2). A makeshift evaporation pan was constructed from the bottom of a 205 ℓ oil drum, 60 *cm* in diameter by 20 *cm* in height. This is smaller than the "Class A" pan which measures 122 *cm* in diameter by 25 *cm* in height (Bruce and Clark, 1966).

The evaporation pan was painted white for maximum reflectivity. As with the "Class A" pan, it was installed on a 10 *cm* wooden frame for ventilation. This enabled the water to better assume the ambient air temperature. Water level fluctuations in the evaporation pan were measured with a hook gauge and stilling well. The hook gauge was sensitive to 0.01 *mm*. On days with measureable precipitation, the precipitation was subtracted from the evaporation amount. It was not possible to determine the pan coefficient for conversion of pan evaporation to lake evaporation.

2.4.3 Bog Water Table

A total of 19 bog water table wells were installed to determine the range of water table level in the peatland of the Old Sams River catchment. The location of these is shown in Figure 2.2. Well numbers 1-15 were broadly dispersed throughout the peatland of the catchment, and in total, were intended to be representative of the entire catchment. The remaining four sites (12A-12D) were located in the immediate vicinity of well number 12. These were intended to provide data on the variation of water table conditions over a smaller area.

A monitoring system to record water table depth continuously was considered. Unfortunately, the necessary instrumentation was not available. In its place, the manual system was chosen to at least enable determination of the range of variability of water table depths from one observation period to another, and to allow for the estimation of missing daily water table data by correlation with stream discharge.

The water table wells were constructed from 1.83 *m* lengths of rigid PVC pipe, with an insider diameter of 50.8 *mm*. Numerous 12.7 *mm* holes were drilled in the bottom 1.5 *m* of each pipe. These allowed equalization of the well with the water table in the surrounding peat. A cork was inserted into the bottom of the pipe to prevent the instrusion of peat during installation. Each pipe was easily installed by one person pushing it into the peat. At some sites, it was necessary to lightly hammer the pipe the last few *cm*. Once installed, the cork was driven out of the well bottom with a steel rod. The top of the well was sealed with a rubber bung. Water table depth was easily measured with a metre stick. This measuring technique was sensitive to ± 1 *mm*. Well number 3 is shown in Figure 2.6.

2.5 DATA COLLECTION FOR THE NORTHWEST BROOK CATCHMENT AND ST. SHOTTS

Hydrometeorologic data for Northwest Brook and St. Shotts were not collected as a part of the field investigations of this study. These data were obtained from the Water Survey of Canada and the Atmospheric Environment Service, Environment Canada, respectively.

Northwest Brook at Northwest Pond is the Water Survey of Canada hydrometric station number 02ZN001 (Environment Canada, 1980). It is located on the southern Avalon Peninsula, latitude 46° 51' 08" N, longtitude 53° 18' 11" W (Figure 2.1). The station began operation in July, 1966. The continuous stream discharge record is computed from continuous stage records and the established stage-discharge rating curve.

Figure 2.6 Bog Water Table Well Number 3

The St. Shotts AES climatological station (Environment Canada, 1982) is located in the community of St. Shotts on the tip of the southern Avalon Peninsula, latitude 46° 38' N, longtitude 53° 35' W (Figure 2.1). Its elevation is 46 *m* asl. Air temperature measurements are made from self-registering maximum and minimum thermometers. Housed in a Stephenson screen, the thermometers are approximately 1.5 *m* above the ground surface. Maximum and minimum temperature and precipitation are measured twice daily at 08:00 *hrs* and 17:00 *hrs* NST. The official Canadian rain gauge is used for rainfall measurement to the nearest 0.2 *mm*. The rim of the gauge is 40 *cm* above the ground surface. Its circular orifice is 11.3 *cm* in diameter. Snowfall is measured with a standard snow ruler by measuring the depths of freshly fallen snow at a number of representative points. The average is recorded to the nearest 0.2 *cm*. The water equivalent is obtained by dividing snowfall by 10.

2.6 DATA COLLECTION FOR THE NORTHEAST POND RIVER CATCHMENT AND ST. JOHN'S

Hydrometeorologic data for Northeast Pond River and St. John's A were not collected as a part of the field investigations of this study. These data were obtained from the Water Survey of Canada and Atmospheric Environment Service, Environment Canada, respectively.

Northeast Pond River is the Water Survey of Canada hydrometric station number 02ZM006 (Environment Canada, 1980). It is located on the northeastern Avalon Peninsula, latitude 47° 38' 06" N. longtitude 52° 50' 14" W (Figure 2.1). The station began operation in April, 1953. It is an International Hydrologic Decade bench mark station.

The continuous stream discharge record is computed from continuous stage records and the established stage-discharge rating curve.

The St. John's A AES climatological station (Environment Canada, 1982) is located at St. John's International Airport on the north-eastern Avalon Peninsula, latitude 47° 37' N, longtitude 52° 45' W (Figure 2.1). Its elevation is 140 *m* asl. St. John's A is both an ordinary and principal climatological station. Temperature and precipitation is observed in the same manner as noted for St. Shotts. In addition to this, a continuous record of a number of meteorological factors is maintained. Of relevance to the present study, continuous precipitation records are measured with an AES tipping bucket rain gauge, similar to that used for the Old Sams River.

CHAPTER 3

STUDY AREA

This chapter describes in detail the location and land use, physiography, geology, vegetation, and hydroclimatology of the three catchments studied. The Old Sams River catchment, which was the focus of the field work carried out for this thesis, is given particular emphasis.

3.1 LOCATION AND LAND USE

The three catchments studied are all upland basins on the Avalon Peninsula of Newfoundland. The Old Sams River catchment is located 13 *km* north of St. Shotts (Figure 2.1). It is 9 *km* inland from both St. Mary's Bay and Trepassey Bay. On the southeast tip of Newfoundland, it is almost completely surrounded by the open Atlantic Ocean.

The centre of the Northwest Brook catchment is 25 *km* northeast of the Old Sams River catchment and approximately 25 *km* inland from the open Atlantic Ocean to the east (Figure 2.1). The hydrometric station is located 12 *km* northeast of Trepassey Bay.

Northeast Pond River is approximately 113 *km* and 86 *km* north-northeast of the Old Sams River and Northwest Brook catchments, respectively. It is located 1-2 *km* east of Conception Bay, and lies 10 *km* west of the open Atlantic Ocean (Figure 2.1).

The Old Sams River catchment was entirely in a natural wilderness condition at the time of the study. Northwest Brook was also relatively untouched by man, although its upper reaches were diverted northwest in 1952 as part of Newfoundland Light & Power Co. Limited's small scale development of the Horse Chops River at Cape Broyle (Figure 2.1). It is presumed that this small diversion had little effect on the river apart from a reduction in flow proportionate to the lost drainage area. Constructed in association with this hydroelectric development, there is a small access road in the uppermost region of the remaining gauged portion of the Northwest Brook catchment. Both the Old Sams River and Northwest Brook catchments experience moderate to heavy recreational use by hunters, berry-pickers, and snowmobiles. The hydrological effects of these are probably insignificant.

The Northeast Pond River catchment is subjected to more extensive use by man. According to the Newfoundland and Labrador Forest Inventory (Anonymous, 1971), forest stands have experienced light to severe cutting. Approximately 1 *km* of paved road lies within the catchment area. Local residents make heavy use of the area for hunting, berry-picking, and recreational use of all-terrain vehicles. There is an extensive network of trails and pathways.

3.2 PHYSIOGRAPHY

3.2.1 Relief

The Old Sams River catchment was mapped by crude means with a surveyor's level, the interpretation of 1:15,840 scale aerial photographs, and the field reconnaissance of physical features, especially the location of small tributary streams (Figure 3.1). Northwest Brook was mapped using the 1:50,000 scale National Topographic System (NTS)

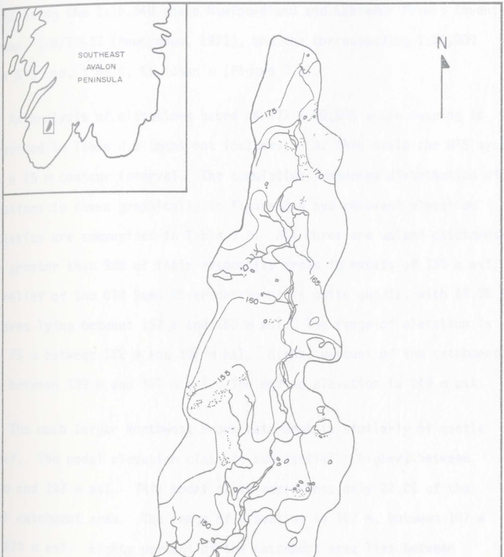

FIGURE 3.1 OLD SAMS RIVER, PHYSIOGRAPHY AND DRAINAGE

map, 1 K/14, Biscay Bay River (Figure 3.2). Northeast Pond River was mapped using the 1:15,840 scale Newfoundland and Labrador Forest Inventory map, 1 N/10-32 (Anonymous, 1971), and the corresponding 1:50,000 scale NTS map, 1 N/10, St. John's (Figure 3.3).

An analysis of elevations based on NTS 1:50,000 scale mapping is summarized in Table 3.1 (maps not included). At this scale the NTS system uses a 15 *m* contour interval. The cumulative frequency distribution of elevations is shown graphically in Figure 3.4 and relevant elevation statistics are summarized in Table 3.2. All three are upland catchments with greater than 90% of their respective areas in excess of 130 *m* asl. The relief of the Old Sams River catchment is quite gentle, with 65.3% of its area lying between 152 *m* and 168 *m* asl. The range of elevation is only 75 *m* between 122 *m* and 197 *m* asl. Eighty percent of the catchment lies between 139 *m* and 161 *m* asl. The median elevation is 149 *m* asl.

The much larger Northwest Brook catchment is similarly of gentle relief. The modal elevation class is substantially higher, between 183 *m* and 197 *m* asl. This modal class represents only 22.2% of the total catchment area. The range of elevation is 167 *m*, between 107 *m* and 274 *m* asl. Eighty percent of the catchment area lies between 137 *m* asl and 213 *m* asl. The median elevation is 165 *m* asl.

By contrast, the Northeast Pond River catchment displays a greater range of relief than the smaller Old Sams River catchment and almost as great as the much larger (15 times) Northwest Brook catchment. The modal elevation class is 152 *m* to 168 *m* asl. The range of elevation is 137 *m*, between 122 *m* and 259 *m* asl. Eighty percent of the catchment area lies between 131 *m* and 197 *m* asl. The median

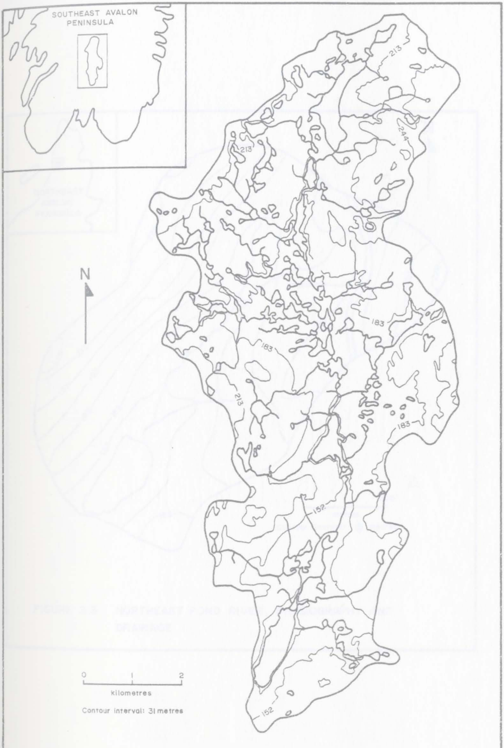

FIGURE 3.2 NORTHWEST BROOK, PHYSIOGRAPHY AND DRAINAGE

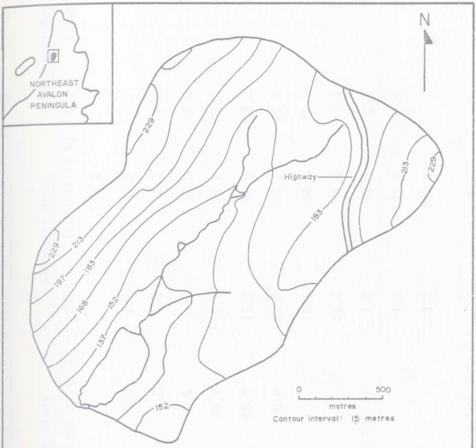

FIGURE 3.3 NORTHEAST POND RIVER, PHYSIOGRAPHY AND DRAINAGE

TABLE 3.1 ELEVATION DISTRIBUTION BY ELEVATION CLASS AND CUMULATIVE PERCENTAGES*

Elevation	Old Sams River		Northwest Brook		Northeast Pond River	
(m)	(%)	(cumulative %)	(%)	(cumulative %)	(%)	(cumulative %)
95-107				0.0		
107-122		0.0	1.7	1.7		0.0
122-137	1.0	1.0	5.5	7.2	8.0	8.0
137-152	24.5	25.5	5.0	12.2	17.0	25.0
152-168	65.3	90.8	12.0	24.2	22.0	47.0
168-183	8.2	99.0	19.8	44.0	17.0	64.0
183-197	1.0	100.0	22.2	66.2	20.0	84.0
197-213			18.6	84.8	10.0	94.0
213-229			10.6	95.4	3.0	97.0
229-244			2.9	98.3	2.0	99.0
244-259			1.5	99.8	1.0	100.0
259-274			0.2	100.0		

* Based on 1:50,000 scale NTS mapping, elevations above sea level

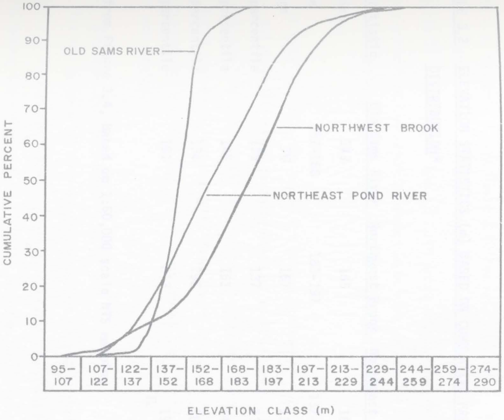

FIGURE 3.4 CUMULATIVE FREQUENCY DISTRIBUTION OF CATCHMENT ELEVATIONS BASED ON 1:50,000 SCALE NTS MAPPING

TABLE 3.2 ELEVATION STATISTICS (*m*) BASED ON CUMULATIVE FREQUENCY DISTRIBUTION*

Statistic	Old Sams River	Northwest Brook	Northeast Pond River
Median	149	165	180
Mode	152-168	183-197	152-168
Range	75	167	137
10 percentile	139	137	131
25 percentile	145	161	145
75 percentile	154	196	183
90 percentile	161	213	197

* From Figure 3.4, based on 1:50,000 scale NTS mapping

elevation is 180 *m* asl, much higher than those of the other two catchments.

Elevation statistics for the Old Sams River catchment derived from the more detailed mapping in Figure 3.1 are summarized in Table 3.3, Figure 3.5, and Table 3.4. The modal elevation class is 155 *m* to 160 *m* asl. The range in elevation is 50 *m*, considerably less than the 75 *m* observed on the 1:50,000 scale NTS mapping (Table 3.2). Eighty percent of the total catchment area lies between 143 *m* and 167 *m* asl, emphasizing the gentle relief. The median elevation is 154 *m* asl.

In summary, all three areas are upland catchments. The Old Sams River and Northwest Brook catchments are of similar gentle relief. Although the range of elevation is similar to the much larger Northwest Brook catchment, the Northeast Pond River catchment, by virtue of its much smaller size, has a much more dramatic relief than the other two catchments.

3.2.2 Drainage Characteristics

For the purpose of inter-basin comparison, a simple Hortonian analysis of stream and drainage basin characteristics has been carried out following the methodology originally outlined by Horton (1932, 1945). Gardiner and Park (1978) noted that there are limitations inherent in Hortonian analysis. These pertain to data sources, data measurement, techniques of analysis, and interpretation of the relationships involved. For the purposes of the present study, inter-basin comparisons provide a simple but effective means of quantifying

TABLE 3.3 ELEVATION DISTRIBUTION FOR THE OLD SAMS RIVER CATCHMENT BY ELEVATION CLASS AND CUMULATIVE PERCENTAGES*

Elevation (m)	Area (%)	Cumulative Area (%)
130-135	0.3	0.3
135-140	2.1	2.4
140-145	6.3	8.7
145-150	10.5	19.2
150-155	21.9	41.1
155-160	28.3	69.4
160-165	10.9	80.3
165-170	10.9	91.2
170-175	5.4	96.6
175-180	3.4	100.0

* Derived from Figure 3.1

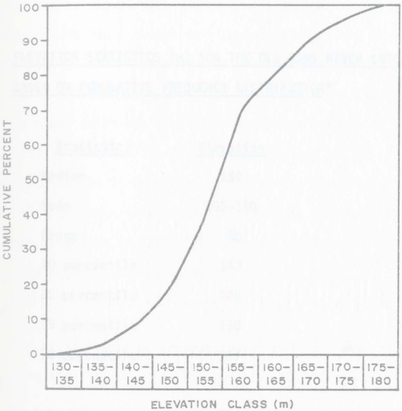

FIGURE 3.5 CUMULATIVE FREQUENCY DISTRIBUTION OF ELEVATIONS BASED ON DETAILED MAPPING IN FIGURE 3.1, OLD SAMS RIVER CATCHMENT

TABLE 3.4 ELEVATION STATISTICS (*m*) FOR THE OLD SAMS RIVER CATCHMENT BASED ON CUMULATIVE FREQUENCY DISTRIBUTION*

Statistic	Elevation
Median	154
Mode	155-160
Range	50
10 percentile	143
25 percentile	149
75 percentile	160
90 percentile	167

* From Figure 3.5, based on mapping in Figure 3.1

differences in drainage basin morphometry.

Newfoundland and Labrador Forest Inventory maps at the 1:15,840 scale (Anonymous, 1971) are used for the present analysis. These provide the largest scale mapping available for all three basins. Figure 3.3 which shows the Northeast Pond River catchment, was drawn from this mapping. To avoid unnecessary duplication, Forest Inventory mapping of the Old Sams River catchment is not included in this text. However, the detailed, ground-truthed 1:15,840 scale map (Figure 3.1) of the Old Sams River catchment does show the stream network in considerably greater detail. The Forest Inventory map of the Northwest Brook catchment is too large to include in this text. However, the relevant morphometric statistics of the analysis are summarized for each catchment in Table 3.5. These include:

(1) N_u, the number of streams, N, in any given order, u;

(2) L_u, the total length of streams, L, in any given order, u, in *km*;

(3) L, the total length of streams in all orders, in *km*;

(4) $\overline{L}_u$, the mean length of streams, $\overline{L}$, in any given order, u, in *km*;

(5) A, the total drainage basin area, in km^2;

(6) D, is the drainage density, the ratio of the total length of streams in all orders, L, to the total drainage area, A, in $km\ km^{-2}$; and,

(7) S, the basin shape factor, the ratio of the basin length to the basin width.

Horton (1932, 1945) considered the length of a higher order stream to extend from the head in a fingertip tributary to its mouth. Morisawa

TABLE 3.5 HORTONIAN BASIN AND STREAM CHARACTERISTICS*

Statistic**	Old Sams River	Northwest Brook	Northeast Pond River
N_1	5	69	2
N_2	3	20	1
N_3	1	6	0
N_4	0	1	0
L_1 (km)	1.20	30.52	0.62
L_2 (km)	0.97	30.92	2.38
L_3 (km)	4.21	17.34	0.00
L_4 (km)	0.00	15.40	0.00
$\bar{L}_1$ (km)	0.24	0.44	0.31
$\bar{L}_2$ (km)	0.32	1.55	2.38
$\bar{L}_3$ (km)	4.21	2.89	0.00
$\bar{L}_4$ (km)	0.00	15.40	0.00
L (km)	6.38	94.18	3.00
A (km^2)	2.55	53.3	3.63
D ($km\ km^{-2}$)	2.50	1.77	0.83
S	3.63	2.38	1.48

* Based on 1:15,840 scale Newfoundland and Labrador Forestry Inventory Maps (Anonymous, 1971)

** See text for definition of statistics

(1968) argued that this method ensures conformity with the "laws" of drainage composition. Other modified Hortonian methodologies tend to underestimate the length of higher order streams becuase they do not allow for headward extension of the higher order segments to their source.

Although the drainage area is considerably smaller than that of Northeast Pond River, the total stream length, L, is over twice as great in the Old Sams River catchment. Drainage density is greater in the Old Sams River catchment than in the other two catchments, particularly that of Northeast Pond River. This difference is emphasized by the presence of three stream orders in the Old Sams River catchment, as compared with only two in the Northeast Pond River catchment. The shape factor, S, for the Old Sams River catchment is substantially greater than that found for the Northwest Brook catchment, a reflection of its more elongated shape. However, the Northwest Brook catchment is itself much more elongated than the relatively more rotund Northeast Pond River. The mean length, L_u, recorded for first and second order streams in the Old Sams River catchment is quite small. This is a result of its dense network of lower order streams which all contribute directly to the axial third order trunk stream. Northwest Brook conforms well to Horton's "law" of stream orders (Horton, 1945), whereby a semi-logarithmetic plot of the number of streams, N_u, against stream order, u, yields a relatively straight line (Figure 3.6). Such a relationship is not noted for the two smaller catchments (Figure 3.6).

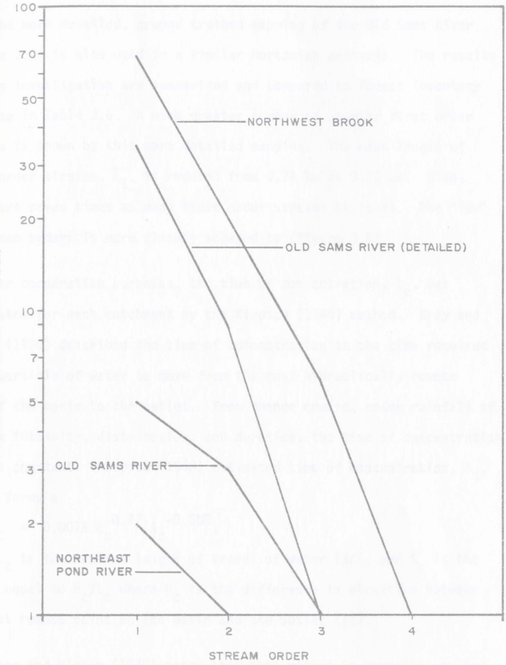

FIGURE 3.6 RELATIONSHIP BETWEEN NUMBER OF STREAMS AND STREAM ORDER, 1:15,840 SCALE MAPPING

The more detailed, ground truthed mapping of the Old Sams River (Figure 3.1) is also used in a similar Hortonian analysis. The results of this investigation are summarized and compared to Forest Inventory map data in Table 3.6. A much greater number of shorter first order streams is shown by this more detailed mapping. The mean length of first order streams, $\overline{L}_1$, is reduced from 0.24 *km* to 0.13 *km*. Also, there are seven times as many first order streams in total. The "law" of stream orders is more closely adhered to (Figure 3.6).

For comparative purposes, the time of concentration, t_c, was calculated for each catchment by the Kirpich (1940) method. Gray and Wigham (1970) described the time of concentration as the time required for a particle of water to move from the most hydraulically remote part of the basin to the outlet. From thence onward, under rainfall of uniform intensity, distribution, and duration, the time of concentration remains constant. Kirpich (1940) estimated time of concentration, t_c, by the formula

$$t_c = 0.0078 \, L_c^{0.77} \, S_c^{-0.385},$$

where L_c is the maximum length of travel of water (*ft*), and S_c is the slope, equal to H_c/L_c where H_c is the difference in elevation between the most remote point on the basin and the outlet (*ft*).

Gray and Wigham (1970) noted that this method is normally applied to small catchments of less than 13 km^2. Thus the method is inappropriately applied to Northwest Brook. However, the intention here is, in the absence of detailed hydrograph analyses, to compare the theoretical basin response times to uniform rainfall. This is done with cautious qualification.

TABLE 3.6 COMPARISON OF HORTONIAN BASIN AND STREAM CHARACTERISTICS FOR THE OLD SAMS RIVER CATCHMENT BASED ON 1:15,840 SCALE FOREST INVENTORY MAPPING AND GROUND TRUTHED MAPPING* PREPARED FOR THIS STUDY

Statistic**	Forest Inventory	Ground Truthed
N_1	5	35
N_2	3	9
N_3	1	1
L_1 (km)	1.20	4.51
L_2 (km)	0.97	1.71
L_3 (km)	4.21	5.23
$\overline{L}_1$ (km)	0.24	0.13
$\overline{L}_2$ (km)	0.32	0.19
$\overline{L}_3$ (km)	4.21	5.23
L (km)	6.38	11.45
A (km^2)	2.55	2.55
D ($km\ km^{-2}$)	2.50	4.49
S	3.63	3.75

* Figure 3.1

** See text for definition of statistics

The Northeast Pond River catchment has a time of concentration substantially less than that of the smaller Old Sams River catchment (Table 3.7). The much larger Northwest Brook has a substantially greater time of concentration.

Several of the drainage characteristics of the Old Sams River catchment, particularly drainage density, stream length, and basin area, indicate that streamflow response to rainfall could be expected to be more rapid than for the other two catchments. However, basin shape and time of concentration of the Old Sams River catchment indicate that streamflow response to rainfall there should be substantially slower than for the slightly larger Northeast Pond River catchment.

Using the mapping in Figure 3.1 and the delineation of peatland noted in Section 3.3.4 below, it has been possible to investigate stream length in various orders as related to the presence of peatland on their banks. On 1:15,840 scale Newfoundland and Labrador Forest Inventory mapping (Anonymous, 1971), both Northwest Brook and Northeast Pond River catchments have no streams which drain peatland directly. By marked contrast, in the Old Sams River catchment, virtually all streams drain peatland directly (Table 3.8). The concentration of the drainage network in the peatland of the Old Sams River emphasizes the hydrologic importance of peatland in the catchment. The greater drainage density and shorter first and second order stream lengths indicate the requirement for a more efficient drainage network. It is postulated that this dense drainage network configuration may be a reflection of the spate-like behaviour of runoff characteristic of peatland areas. With rapid runoff typically gener-

TABLE 3.7 DERIVATION OF THE TIME OF CONCENTRATION

	Basin Length of Travel, L_c		Elevation Difference, H_c		Slope, S_c	Time of Concentration, t_c
	(m)	*(ft)*	*(m)*	*(ft)*		*(min)*
Old Sams River	4,360	14,300	50	164	0.1115	69
Northwest Brook	13,800	45,100	107	350	0.00776	194
Northeast Pond River	2,610	8,560	107	350	0.0409	29

TABLE 3.8 STREAM LENGTH, L_u, RELATED TO PRESENCE OF PEAT ON STREAM BANK, OLD SAMS RIVER CATCHMENT*

Stream Order	Total Stream Length of a Particular Order, L_u (%)		
	Not Draining Peat	Peat Both Banks	Peat One Bank
1	9.6	75.6	14.8
2	5.5	94.5	0.0
3	0.0	100.0	0.0

* Derived from Figure 3.1 and Figure 3.9

ated from the hydrologically-active layer, a greater number of short streams are required for channel maintenance than in non-peatland areas.

3.3 GEOLOGY

3.3.1 Bedrock Geology

3.3.1.1 Regional Setting

According to Williams (1978), and Williams, et al. (1972, 1974), the Avalon Peninsula is part of the Avalon Zone of the Appalachian Orogen which also appears in Cape Breton and Massachusetts, with correlatives in Virginia and the Carolinas. Bedrock is primarily late Precambrian (Hadrynian) volcanic and sedimentary rocks, locally overlain by Cambrian, Ordovician, and younger Palaeozoic strata.

The Trepassey Peninsula, studied by Williams and King (1979), is composed mainly of Hadrynian volcanic and clastic sedimentary rocks, intruded by gabbro and granite, and folded into broad upright, gently-plunging anticlinoria and synclinoria. The oldest rocks belong to the Harbour Main Group, an assemblage indicating an environment of mainly terrestrial silicic volcanism. This was either locally accompanied or followed by marine deposition of the Conception Group, which is characterized by green siliceous volcaniclastic sedimentary rocks. A proximal volcanic terrain during the lower Conception Group is suggested by the presence of agglomerate and tuff. However, the occurence of local tuff beds diminishes upward into the younger St. John's and Signal Hill Groups, and represents a waning of volcanic activity with the encroachment of earlier volcanic centres by increasingly thick Precambrian sedimentary deposits. Anderson (1972) and Williams and King (1979) reported that the oldest rocks of the Harbour Main Group date back 800 million years, with subsequent deposition spanning some 230 million years. While the age of deformation is unknown, it does postdate the youngest Precambrian rocks. Williams, et al. (1972), described the fold style as typical of that of the Acadian Devonian deformation.

3.3.1.2 Old Sams River Catchment

Williams and King (1979) mapped the Old Sams River catchment as a part of the regionally extensive Drook Formation of the Conception Group. It is characterized by parallel-bedded olive green to grey and buff argillaceous chert, siliceous siltstone and sandstone, and silicified tuff, and locally includes thick sandstone beds alternating with shale, siltstone, and minor purple argillite.

An extensive veneer of Pleistocene and Holocene sediments has severely limited the occurence of bedrock outcrop in the Old Sams River catchment. Bedrock-controlled ridges are subdued but noticeable features along the western margin of the basin. An outcrop at the mouth of the catchment reveals greenish, mesocrystalline to macrocrystalline silicified tuffs in beds 15 cm to 60 cm wide, striking 15° E of N, and dipping 44° W. Along the western ridge of the catchment, two further outcrops occur. One, a greenish shale, strikes 4° E of N, and dips 85° W, and shows evidence of severe contemporary weathering. The other, which strikes 15° W of N, and dips

78° W, consists of greenish, mesocrystalline silicified tuffs. It contains cleavage noncoplanar to the axis of folding, which strikes 99° E of N, and dips 80° N. Williams and King (1979) noted that such cleavage in the Drook Formation, which results from pressure noncoplanar to the axis of folding, is probably more common than was previously recognized. Precise measurement is difficult due to the limited occurrence of bedrock outcrop and extensive contemporary weathering where it does occur.

Both the western and eastern ridges of the basin appear to be bedrock controlled, although no outcrops were found to confirm this on the eastern ridge. Major drainage in the catchment (see Section 3.2.2), primarily second order streams and the mainstem third order stream, is oriented slightly east of north, and appears to reflect the structural orientation of the basin. However, the orientation of many first order streams may well be a manifestation of cleavage noncoplanar to the axis of major folding.

3.3.1.3 Northwest Brook Catchment

Williams and King (1979) mapped the Northwest Brook catchment as part of the Drook Formation of the Conception Group. Like the Old Sams River catchment, it is characterized by parallel-bedded olive green to grey and buff argillaceous chert, siliceous siltstone and sandstone, and silicified tuffs. Williams and King (1979) noted that whereas in the region of the Old Sams River catchment local inclusions of sandstone beds are thicker and sandier, in the Northwest Brook catchment, equivalent facies of thinner cherty beds are reported.

Bedrock controlled ridges strike east-northeast through most of the catchment. Relief and drainage appear to reflect this structural control. Williams and King (1979) did not report direct observation of bedrock outcrops within the catchment.

3.3.1.4 Northeast Pond River Catchment

The Northeast Pond River catchment has been more extensively mapped than the other two catchments. Figure 3.7 shows the bedrock geology of the catchment. Rose (1952) and Hsu (1975) assumed the existence of a fault striking north-northeast, dividing the rocks of the older Harbour Main Group from those of the Conception Group. Rose (1952) suggested that the Harbour Main Group is overlain unconformably by the Conception Group. However, he observed that interbedded sedimentary rocks in the Harbour Main Group are similar to the sedimentary units of the Conception Group which are interbedded with volcaniclastic rocks. From this, Rose (1952) postulated that the unconformity represents a relatively short intervening period.

Hsu (1975) mapped the area west of the assumed fault as part of the lower Harbour Main Group. It is composed of basaltic pillow lava, minor red and green sandstone, siltstone, argillite, and chert (Figure 3.7).

East of the assumed fault, Hsu (1975) noted the conformable association of three Conception Group formations. The oldest, underlain unconformably by the Harbour Main Group, is composed of green to grey laminated to massive arkosic sandstone with intercalated green argillite, and rare pillowed basalt. This is overlain by a thin

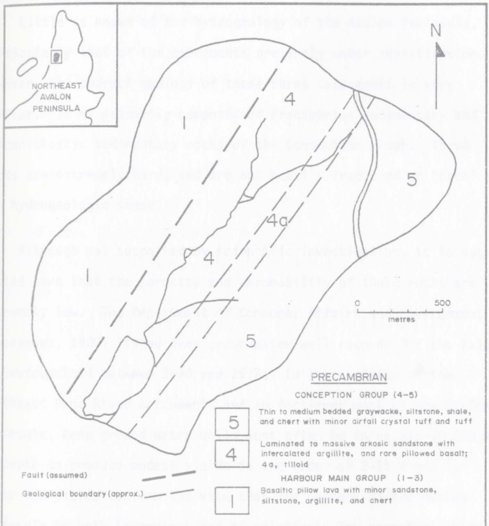

FIGURE 3.7 NORTHEAST POND RIVER, BEDROCK GEOLOGY, AFTER HSU(1975)

tilloid, which is itself overlain by the youngest rocks in the catchment, green to grey and red, thin to medium-bedded greywacke, siltstone, shale, and chert, with minor airfall crystalline tuff and tuff.

3.3.1.5 Hydrogeology

Little is known of the hydrogeology of the Avalon Peninsula, particularly that of the catchments presently under investigation. However, the bedrock geology of these three catchments is very similar. It is primarily composed of Precambrian sedimentary and volcaniclastic sedimentary rocks of the Conception Group. These rocks are extremely hard, and are not heavily fractured or "open" in the hydrogeologic sense.

Although not supported by scientific investigation, it is suggested here that the porosity and permeability of these rocks are extremely low. The Department of Consumer Affairs and Environment (Anonymous, 1980) listed deep groundwater well records for the Island of Newfoundland between 1950 and 1977. In the vicinity of the Northeast Pond River catchment, and in fact over most of the Avalon Peninsula, deep ground water wells must often be in excess of 100 *m* in depth to produce modest yields in the order of 2-15 $\ell \ min^{-1}$. These low yields confirm the view that the bedrock of the Avalon Peninsula is both impervious and of relatively low porosity. Hydrogeologically, these rocks could be classed as aquicludes.

The hydrogeology of the three catchments studied is thought to be of little significance to the present study. It is suggested that the contribution to base flow by groundwater is relatively small. Assumming this, streams on the Avalon Peninsula could be expected to demonstrate rapid baseflow recession. Under this hydrogeologic regime, the hydrologic significance of peatland is amplified.

3.3.2 Post-Orogeny Erosion and Peneplanation

After the Acadian Orogeny in Devonian times, the geologic history of the Avalon Peninsula has been one of erosion and peneplanation. Henderson (1972) suggested that the present complex surface is a response to many changes in the intensity of erosion as affected by variations in elevation. It is suggested that the conditions which prevailed prior to Late Cenozoic glaciation were those of an increase in erosion as elevation increased during Mesozoic rifting and the opening of the Atlantic (Rogerson, 1983). Subsequent downwarping has erased much of the effect of the uplift, but has greatly enhanced the effects of present coastal erosion by submerging the shoreplain deposits which normally protect the coast from marine erosion (Henderson, 1972).

In their treatise on the surface of Newfoundland, Twenhofel and MacClintock (1940) identified the existence of three upland erosion surfaces, the remnants of older, dissected peneplains. On the Avalon Peninsula, only one of these is noted, the Lawrence Peneplain. The Lawrence Peneplain is manifested by extensive upland surfaces of gently rolling topography between 100 *m* and 150 *m* asl (Henderson, 1972). Rogerson (1983) postulated that these erosion surfaces are Mesozoic and early Cenozoic in age, the Lawrence Peneplain being the lowest in elevation and the youngest in age.

The Old Sams River catchment is a part of the Lawrence Peneplain. It is characterized by the gentle relief distinctive of a mature erosion surface (Figure 3.8). Elevations range from 130 *m* to 180 *m* asl (Figure 3.5 and Table 3.4), extending slightly higher than reported for the Lawrence Peneplain by Henderson (1972).

The gentle relief of the Lawrence Peneplain also dominates the landscape of the Northwest Brook catchment. While elevations are higher, ranging from 107 *m* to 274 *m* asl, relief is characteristic of a mature erosion surface. In contrast, the relief of the Northeast Pond River catchment is much less characteristic of the Lawrence Peneplain. This is especially true along the western ridge. It is underlain by rocks of the Harbour Main Group, which are slightly more resistant to erosion.

3.3.3 Late Cenozoic Glaciation and Surficial Geology

The early work of Murray (1883) and Howley (1918) suggested that in Late Cenozoic times, the whole Island of Newfoundland was overrun by continental glacier that had moved from the west down the gulf of St. Lawrence. Later, MacClintock and Twenhofel (1940) hypothesized that Labradorean ice had moved across Newfoundland to a maximum on the Grand Banks. Their view was based on the extent of glacial features on the Island. More recently, however, Rogerson (1981; 1982; and 1983) suggested that while prevalent, the gross effects of glaciation noted by these early authors are not the dominant landscape element of Newfoundland. Rather, they have served to highlight the structural trend of the Island's Precambrian Geology. The surface of

Figure 3.8 North-northeast View of the Old Sams River Catchment From a Point Approximately 200 m West of its Mouth, Showing the General Relief Distinctive of a Mature Erosion Surface. Light-coloured Areas are Blanket Bogs and Dark-coloured Areas are Heathland.

Newfoundland is dominated by the remnants of Mesozoic and early Cenozoic peneplanation as noted by Twenhofel and MacClintock (1940), Henderson (1972), and Rogerson (1981; 1982; and 1983).

While the extent of Late Cenozoic glaciation remains in question, evidence substantiating the existence of successive Wisconsin glaciations on the Island of Newfoundland has been reported by Brookes (1970; 1974; 1977a; and 1977b), Brookes, et al. (1982), Grant (1976; 1977a; and 1977b), and Tucker and McCann (1980). They have substantiated the existence of a complex of local ice caps which had spread out radially to the coast. These were independent of continental ice, except on the Great Northern Peninsula where it had invaded across the Straits of Belle Isle.

Henderson (1972) recognized that the orientation of striations and the provenance of erratics and other directional indicators show that during the last Late Wisconsin glaciation, a separate and distinct ice cap existed over the Avalon Peninsula. This had previously been hypothesized by MacClintock and Twenhofel (1940). Grant (1976) suggested that the Avalon ice cap was thin and digitate, extending down bays to lower sea levels, and skirting the termini of some peninsulas. His tentative mapping of the Late Wisconsin ice limits suggest that both the Old Sams River and Northeast Pond River catchments were ice free at this time, and proximal to a rather digitate ice mass. This would suggest that glacial features in and around these areas are pre-Late Wisconsin in age. According to Grant (1976), the Northwest Brook catchment was under ice during the Late Wisconsin.

Henderson (1972) noted that the physiographic effects of late Cenozoic glaciation are limited on the Avalon Peninsula. With the exception of restricted areas of linearly concentrated ice flow and consequent deep local excavation, remnants of preglacial peneplanation are relatively unaffected by glaciation, and larger landforms reflect the preglacial landscape. These ideas were also pursued for all of Newfoundland by Rogerson (1981; 1982; and 1983).

Henderson's (1972) mapping of the surficial geology of the Avalon Peninsula showed that all three drainage areas are overlain by thin stoney glacial till, 1.5 *m* to 6 *m* thick, and/or a discontinuous thin veneer of till, with some ledges and knobs of rock outcrop. The extensive tracts of peatland in the Old Sams River catchment were also noted as obscuring glacial or other unconsolidated materials.

3.3.4 Peatland

Wells (1976; 1981) classified the peatlands of eastern Newfoundland into six morphological types. These are domed bog, blanket bog, slope bog, basin bog, ribbed fen, and slope fen. In their inventory of peatland in eastern Newfoundland, Northland (1980) mapped unique morphological types in each of the three catchments which are presently under consideration. Peatland in the Old Sams River catchment is exclusively blanket bog. In the Northwest Brook catchment, only slope bog is present. In the Northeast Pond River catchment, only dome bog was identified.

3.3.4.1 Old Sams River

The total area of blanket bog in the Old Sams River catchment is 136 *ha*, 53.3% of its drainage area (Figure 3.9). The blanket bog in the Old Sams River catchment is part of one extensive peatland tract which continues over topographic boundaries, extending into adjacent catchment areas. Northland (1980) noted that the total area of this single bog is 440.5 *ha*.

Wells (1976; 1981) described blanket bogs as treeless, one to two *m* in depth, rarely exceeding a depth of two *m*, and having small pools scattered with no obvious pattern over their surface. Characteristically, they cover both hills and valleys, interrupted only by small streams. Blanket bogs have not been documented elsewhere in eastern North America. However, correlatives of the eastern Newfoundland blanket bog occur in north Atlantic maritime climates. They have been noted in Ireland (Barry, 1954), England (Osvald, 1949), Scotland (Fraser, 1954; Boatman, 1972), Wales (Moore, 1972), and Norway (Hafsten and Solem, 1976).

Tansley (1949), Sjors (1950), and Wells (1981) have all attributed blanket bog development mainly to climatic conditions. The distribution of blanket bog is restricted to areas which have cool summers, high precipitation, and high atmospheric humidity. Their development is independent of ground water influxes, since they grow up above the local pre-development water table.

Stratigraphic analyses by Wells (1976; 1981) have suggested that blanket bogs probably originated as small marshes and fens in shallow

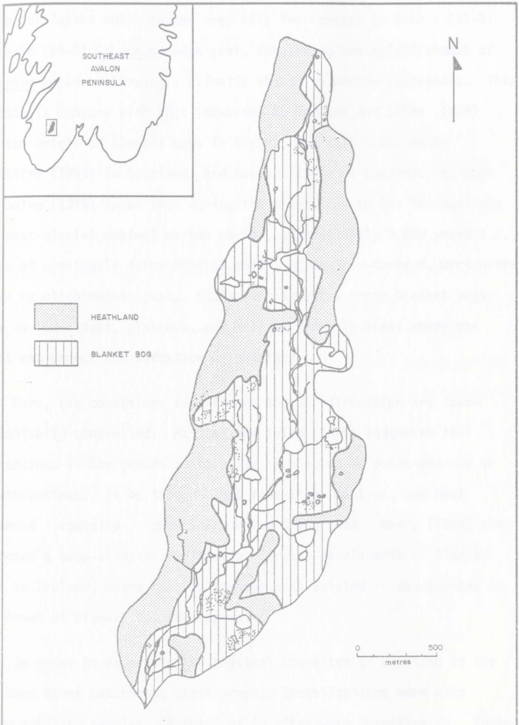

FIGURE 3.9 OLD SAMS RIVER, VEGETATION

basins. The basins were eventually filled by a sedge peat (H6-8). The upper layers which formed over this fen consist of fibric (H1-3) to mesic (H4-5) Sphagnum-sedge peat, suggesting the establishment of Sphagnum mosses following a climatic change to wetter conditions. This hypothesis concurs with that forwarded by Hafsten and Solem (1976) for the origin of blanket bogs in Norway, and that observed by Ratcliffe (1964) in Scotland, and Conway (1947) in England. Hafsten and Solem (1976) found that during the transition to the increasingly wet post-glacial optimal warmth period, approximately 8,000 years B.P., areas of previously drier mineral soils, often tree-covered, were overgrown by oligotrophic peat. Characteristically, these blanket bogs grow on low ridges, plateaux, and hill saddles, in areas where one might not expect the formation of peatland.

Here, the conditions for blanket bog paludification are topo-climatically controlled. Hafsten and Solem (1976) suggested that depressions in the ground surface may have acted as point sources or growth-centres. It is thought that from these centres, the peat extended radially over surrounding dry ground. Barry (1954) also proposed a topo-climatic explanation for the development of blanket bogs in Ireland, where topo-soligenous peat existed in depressions at the onset of blanket bog development.

In order to ascertain the physical character of peatland in the Old Sams River catchment, stratigraphic investigations were made using a Hiller sampler. A total of 19 sites were investigated. These sites were immediately adjacent to the 19 water table observation wells (see Section 2.1.5 and Figure 2.2). Randomly distributed throughout the bog, fifteen of these sites (1-15) were selected to be representative of the major bog units. The sampling density was approximately 0.11 sites per *ha*, i.e., 15 sites in 136 *ha*. The remaining four sites (12A-12D) were intended to relate depth of water table with peat stratigraphy and vegetation over a much smaller area in the vicinity of well number 12. In this case, there were five sites in an area of approximately 0.006 *ha*, or 83 sites per *ha*.

The stratigraphy and depth of peat at each site is shown in Figure 3.10. The depth of peat at these sites ranges from 55 *cm* to 183 *cm*, with a mean depth of 131 *cm*. With few exceptions, the stratigraphy is increasingly humified with depth, and reflects a gradual transition from a fibric (H1-3) to a meso-fibric (H3-4) Sphagnum-sedge peat. As noted by Wells (1976; 1981), this stratigraphic relationship is typical of the eastern Newfoundland blanket bog type. Many sites show an increase in the degree of humification with depth, and an increasing occurrence of sedge, roots, and twigs, with depth. In some instances, this trend is accompanied by decomposition ranging from H5-10. At each site, the profile shows an abrupt boundary with the mineral soil or bedrock. The only exception is at site 1, where a 15 *cm* organic to mineral transition layer occurs between a depth of 117 *cm* and 132 *cm*. This layer is underlain by a coarse-textured mineral soil.

Sites 4-15 and 12A-12D are in flat to gently sloping togographic lows. Their respective bog units are bordered by either mineral ridges

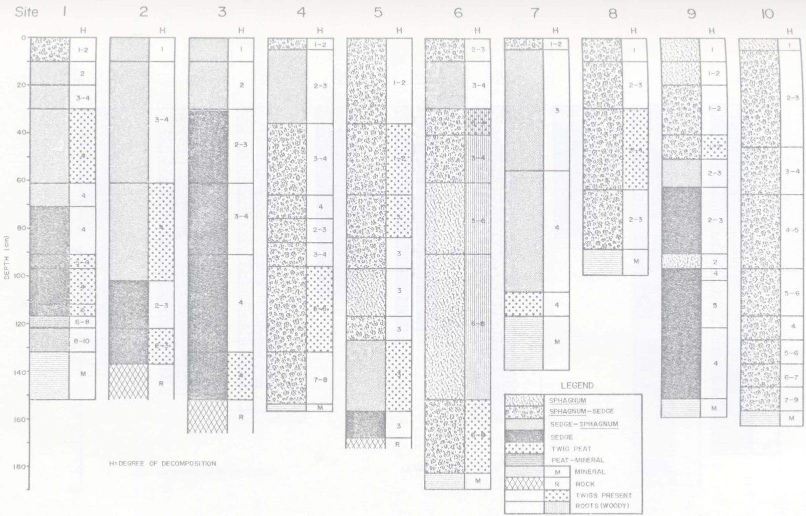

FIGURE 3.10 PEAT STRATIGRAPHY IN THE VICINITY OF WATER TABLE OBSERVATION WELLS (CONT'D)

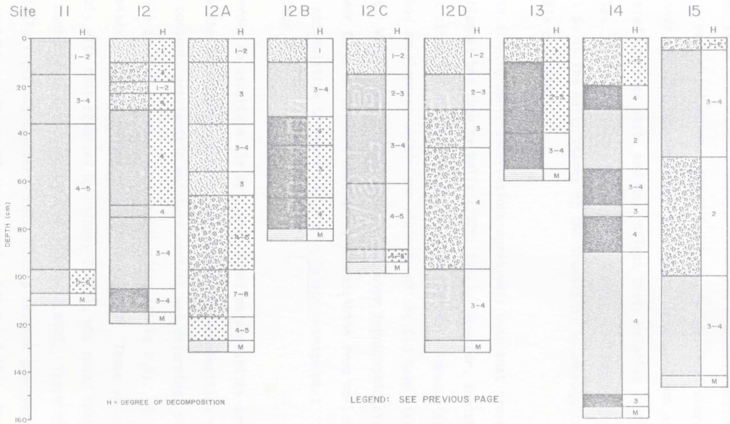

FIGURE 3.10 (CONT'D) PEAT STRATIGRAPHY IN THE VICINITY OF WATER TABLE OBSERVATION WELLS

and/or the main third order stream. Profiles show increasing decomposition and sedge content with depth, reflecting a gradual transition to ombrogenic peat development. Sites 1-3 occur in bog areas where the peat extends over the catchment divide. These three sections are predominated by sedge peat, and may reflect their relative developmental immaturity. It is possible that in these areas, peatland development may still be in the early stages of the transition to ombrogenic water table conditions.

These stratigraphic observations agree well with that presented for the blanket bog type by Wells (1976; 1981). However, the stratigraphy at sites 1-3 may be indicative of the relative immaturity of blanket bog development within the vicinity of the Old Sams River catchment. Where these blanket bogs extend over topographic divides, they appear to be at present undergoing a transition from well humified fen peat accumulation to mesic and fibric Sphagnum-sedge peat accumulation.

In order to ascertain the moisture retention properties and to determine the relationship between the degree of decomposition and moisture content, gravimetric moisture content was determined through the profile at five of the stratigraphic sites (Table 3.9). Gravimetric moisture content ranges from 157% to 1,863%. These values fit comfortably with that reported by Walmsey (1977), who found that peat moisture contents in Canada range from 100% to 2,640%. There is a statistically significant inverse relationship between gravimetric moisture content and degree of decomposition (Figure 3.11). The

TABLE 3.9 GRAVIMETRIC MOISTURE CONTENT OF PEAT AT FIVE STRATIGRAPHIC SITES

Site Number	Sample Depth (cm)	Degree of Decomposition (H)	Moisture Content (%)
12	5	1	753
12	10-15	3	756
12	18-23	1-2	889
12	23-30	4	737
12	50	4	991
12	70-75	4	789
12	100	3-4	880
12	110	3-4	942
12B	5	1	1863
12B	20	3-4	593
12B	30-33	3-4	375
12B	40	4	293
12B	50	3	157
12B	75	4	208
13	5	1	1430
13	30	2-3	605
13	50	3-4	1100
14	0-10	1-2	1027
14	10-20	1-2	1091
14	20-30	4	983
14	50	2	1246
14	65	3-4	1208
14	70-75	3	1375
14	85-95	4	952
14	100	4	1559
14	150	3	878
15	5	1-2	1093
15	50	3-4	944
15	100	2	1010
15	150	3-4	763
Standard Deviation*			380

* Best estimate of the standard deviation

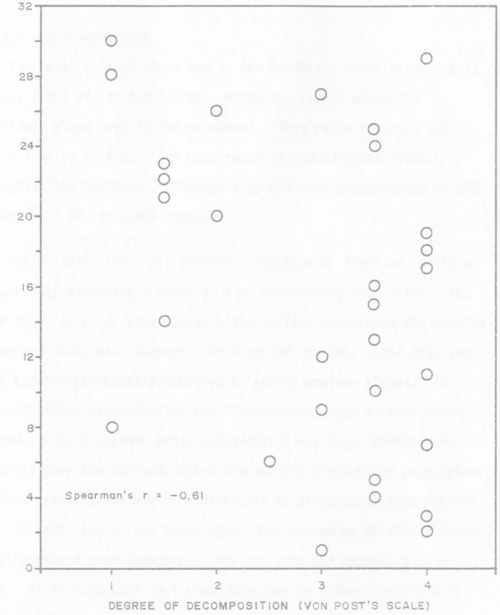

FIGURE 3.11 RELATIONSHIP BETWEEN GRAVIMETRIC MOISTURE CONTENT AND DEGREE OF DECOMPOSITION

Spearman's rank correlation coefficient of -0.61 is significant at the 0.1% level of confidence.

3.3.4.2 Northwest Brook

The total area of slope bog in the Northwest Brook catchment is 419 *ha*, 7.86% of its total area. Northland (1980) mapped 67 individual slope bogs in the catchment. They range in areal extent from 0.4 *ha* to 34.4 *ha*. The occurrence of slope bog was noted throughout the catchment, although they are more concentrated in the western half of its upper reaches.

Wells (1976; 1981) has defined slope bogs as treeless, shallow bogs, rarely exceeding a depth of 2 *m*, and sloping from 5-15%. The water table is at or very close to the surface throughout the growing season and pools are uncommon. In forested regions, slope bogs are small and topographically confined to poorly drained slopes. In areas of higher precipitation and frequent fog, such as that experienced in the Northwest Brook catchment, slope bogs develop more uniformly over the surface, often approaching blanket bog proportions. In these areas, slope bogs are difficult to distinguish from blanket bog. In fact, two of the large slope bogs mapped by Northland (1980) actually extend over topographic divides into the adjoining catchments. It is suggested that slope bogs may be either transitional to blanket bog or, from a classificatory perspective, marginal blanket bogs. Slope bogs have not been documented elsewhere in eastern North America (Wells, 1981).

Stratigraphic analyses of slope bogs by Wells (1981) suggested that they have undergone a fen-to-bog succession similar to that noted for blanket bog. The humic bottom layers (H8-9) consist of a sedge-woody peat typical of fens. The middle and upper layers are composed more of Sphagnum mosses with sedges (e.g., sedge-Sphagnum-woody, H6-7; Sphagnum-sedge, H6-7; and Sphagnum-sedge, H1-3 (top 50 *cm*)). The surface layer is composed primarily of undecomposed Sphagnum mosses.

Despite its proximity, and similar physiography and geology, it is apparent that the Northwest Brook catchment has in relative terms, substantially less peatland than the Old Sams River catchment. It is presumed that slope bogs are the prevalent peatland type here rather than blanket bogs because the topo-climatic regime is marginal to that required for their extension over topographic divides.

3.3.4.3 Northeast Pond River

Although Wells (1981) included the Northeast Pond River catchment in his slope bog region, there are no slope bogs found here. Peatland is not a major component of the surface of the area, with only one bog in the entire catchment. This is a domed bog, 8.9 *ha* in extent, comprising only 2.5% of the total catchment area (Northland, 1980).

Domed bogs occur in the coniferous forest region of the Avalon Peninsula (Wells, 1981). They are treeless, deep (4-5 *m*), and characterized by a convex surface. Domed bogs occur throughout most of North America (Damman, 1977; Heinselman, 1963; Rigg, 1937; Zoltai, et al., 1975), Britain, Northern Europe, and Scandinavia (Bellamy, 1972), and Russia (Bradis and Andrienko, 1972; Katz 1926).

Wells (1981) reported that the stratigraphy of domed bogs is analagous to the blanket and slope bog types, following a fen-to-bog successional pattern. The bottom 30-40 *cm* consists of a highly decomposed (H-9) humic, sedge-woody peat, overlain by a 200 *cm* fibric layer (H4-7) of Sphagnum-sedge peat. The top 150 *cm* is composed mainly of Sphagnum-sedge peat (H1-3).

3.4 VEGETATION

The vegetation of the Avalon Peninsula is composed of three main groups: boreal forest, heathland, and peatland. The boreal forest is dominated by balsam fir (Abies balsamea) and black spruce (Picea mariana). Heathland vegetation has been classified by Meades (1983) into four major types: Alpine, Empetrum, Moss, and Kalmia Heath. Peatland vegetation has been classified by Wells (1981) into three communities: dry bog, wet bog, and fen.

3.4.1 Heathland

In Newfoundland, heathland has been traditionally referred to as "barrens" (Meades, 1983). Their dominant ericaceous shrubs are known as "goowiddy", and associated coniferous krummholtz as "tuck" or "tuckamore" (Meades, 1983). Nonetheless, heathlands in Newfoundland demonstrate all the common traits evaluated for world heathlands (Meades, 1983):

(1) the presence, but not necessarily the dominance, of the heath families -- Diapensiaceae, Empetraceae, Epacridaceae, Ericaceae, Grubbiaceae, Prionotaceae, Vacciniaceae; and

(2) their ecological restriction to soils very low in plant nutrients.

The four major heath types classified by Meades (1983) are discussed below.

The Alpine Heath type (Meades, 1983) is composed of bare soil which alternates with cushions dominated by Empetrum eamesii. It is characterized by the occurrence of several arctic-alpine species, i.e., Diapensia lapponica, Arctostaphylos alpina, Loiseleuria procumbens, Juncus trifidus. These heathlands are usually restricted to high mountain ridges but they are also found on the exposed headlands of the south coast.

The Empetrum Heath type is dominated by vegetation carpets of Empetrum nigrum and/or Empetrum eamesii (Meades, 1983). All woody plants are compressed into vegetation cushions and only perennial grasses and herbs project 10-20 *cm* above the ground level. The vegetation carpet is continuous, with wind/erosion scars forming less than 10% of its total area. These heathlands occur on coastal headlands and inland ridges.

Meades (1983) distinguished the Moss Heath type from the Empetrum Heath type by the dominance of Racomitrium lanuginosum in the vegetation carpet. This is a successionally stable heath type which occurs in the coastal regions of the southern Avalon Peninsula. It is an extreme maritime type and its location is restricted to this area, where climatic conditions preclude the development of forest.

The Kalmia Heath type is an ericaceous dwarf shrub vegetation dominated by Kalmia angustifolia (Meades, 1983). Dwarf shrubs form a dense closed thicket vegetation, 30-50 *cm* in height, with mosses and lichens in the ground stratum. This heath type occurs on sheltered sites and it represents a chronosequence of the boreal forest.

3.4.2 Peatland

Wells (1981) has classified peatland vegetation of the Avalon Peninsula into three communities: dry bog, wet bog, and fen. These have been synthesized from eight plant associations. Four of these, all fen associations, are not discussed because their presence is not noted in the three catchments under consideration.

According to Wells (1981), the KALMIO-SPHAGNETUM FUSCI dry bog association comprises the largest vegetation unit of peatland in the region. It represents the nutrient-poor dry flats and hummocks of domed, blanket, slope, and basin bogs. Sphagnum fuscum comprises most of the vegetation mat. Dwarf shrubs (less than 50 *cm* high) such as Ledum groenlandicum and Kalmia angustifolia are common. Empetrum nigrum and tussocks of Scirpus cespitosus are also common. Wet, weakly minerotrophic areas of slope and blanket bogs are characterized by species such as Pyrus floribunda, Calamagrostis inexpansa, Myrica gale, Solidago uliganosa, Sphagnum flavicomans, and Smilaina trifolia. Lichens such as Cladonia rangiferina, C. arbusula, C. alpestris, and C. mitis are abundant on drier hummocks; often, they overgrow the Sphagnum fuscum hummocks to form the VACCINIO-CLADONIETUM BORYI association. Common on exposed coastal bogs, the VACCINIO-CLADONIETUM BORYI association is differentiated from the KALMIO-SPHAGNETUM FUSCI by the presence of such exposure indicators as Vaccimium vitis-idaea, Cladonia boryi, Cornicularia aculeata, and Hypogymnia physodes.

Wet bog communities classified by Wells (1981) are restricted to the wet hollows of domed, blanket, basin, and slope bogs. He noted that the SCIRPO-SPHAGNETUM TENELLI association exceeds 4 m^2 in areal extent, occuring along the border of pools or as shallow depressions in the bog surface. It is distinguished from other wet bog vegetation by the following species: Rhynchospora alba, Odontoschisma sphagni, Sphagnum tenellum, S. pulchrum, S. cuspidatum, Vaccinium macrocarpon, Cladopodiella fluitans, and Utricularia cornuta. A constant species throughout other peatland communities, Ledum groenlandicum occurs infrequently, restricted by the existence of the water table at the surface.

Wells (1981) noted that on slightly drier sites, Kalmia angustifolia, Cladonia arbuscula, C. mitis, C. alpestris, and C. rangiferina, are present. The differential species Sphagnum pulchrum, Vaccinium macrocarpon, and Utricularia cornuta are rare or absent on these sites. Calamagrostis inexpansa, Myrica gale, and Aster nemoralis are indicators of weakly minerotrophic sites on slope bogs.

The SCIRPO-SPHAGNETUM MAGELLANICI association classified by Wells (1981) represents the wet Sphagnum "lawns" of slope bogs, and to a lesser extent, domed, blanket, and basin bogs. Sphagnum magellanicum, S. rubellum, S. papillosum, and S. flavicomans, form a carpet as large as 200-300 m^2. Microlepidozia steacea, Polytrichum strictum, and Empetrum nigrum are common. Larix laricina, less than 1 m in height, occur sporadically. Carex exilis, C. oligosperma, and C. cespitosus are often abundant, especially where influenced by seepage. Here, Myrica gale, Solidago uliginosa, Aster nemoralis, Calamagrostis inexpansa, and Carex rostrata are also present. Drier sites are characterized by Kalmia angustifolia, Dicranum scoparium, Cladonia arbuscula, C. mitis, C. alpestris, and C. rangiferina.

3.4.3 Old Sams River

The vegetation of the Old Sams River catchment can be divided into two broad categories, heathland and peatland. Their distribution within the catchment is shown in Figure 3.9. Peatland vegetation is found on 53.3% of the catchment area, with 43.2% and 3.5% being represented by heathland and surface water, respectively. There is no occurrence of boreal forest.

All four heathland types are noted within the catchment area. Heathland is restricted to the higher elevations of the eastern and western ridges of the catchment. The Alpine Heath type is found in isolated locations at the top of wind-swept ridges. It is extremely limited in its areal extent. The Empetrum Heath and Moss Heath types are more common, but are also limited to the wind-swept ridges. The Moss Heath type is unique to this southern coastal region, and is distinguished by the presence of Racomitrium lanuginosum. The Kalmia Heath type is most prevalent, dominating the more protected slopes of the catchment.

All four bog associations are noted within the Old Sams catchment. The KALMIO-SPHAGNETUM FUSCI dry bog association is common, although owing to its maritime location, the VACCINIO-CLADONIETUM BORYI association is dominant. It is postulated that minerotrophic indicator species are present not because of ground water influences as suggested by Wells (1981), but rather, the effect of salt-enriched oceanic precipitation as noted in England by Gorham (1953).

Wet bog communities are also present, but are more limited in areal extent than the dry bog communities. Both the SCIRPO-SPHAGNETUM TENELLI and SCIRPO-SPHAGNETUM MAGELLANICI associations occur less frequently than the dry bog communities. As with the dry bog communities, the common occurrence of Myrica gale and other minerotrophic indicators appears to be a result of oceanic precipitation rather than groundwater seepage. The occurrence of groundwater seepage does not appear to be common in the blanket bogs of this catchment.

3.4.4 Northwest Brook

The vegetation of the Northwest Brook catchment is more diverse than that of the Old Sams River catchment, and is divided into three categories: boreal forest, heathland, and peatland. Mapping of their distribution is not included because of the size of the area involved. However, the total area attributed to each category, based on Anonymous (1971) and Northland (1980), is summarized in Table 3.10. Unlike the Old Sams River catchment, the dominant vegetation category is heathland, approximately 10 times greater in area than peatland. In lower protected areas, there is some boreal forest.

In the Newfoundland and Labrador Forest Inventory (Anonymous, 1971) only two stands of productive forest land, 6.0 *ha* and 12.4 *ha* respectively, were identified. These are located in sheltered areas at low elevations near the mouth of the catchment. They are 75-100% softwood, with a top height of nine *m*, and a crown cover between 41%

TABLE 3.10 TOTAL AREA ATTRIBUTED TO VEGETATION CATEGORIES IN THE NORTHWEST BROOK CATCHMENT*

Vegetation Category	Area (km^2)	Area (% of total)
Heathland	41.6	78.0
Peatland	4.19	7.9
Boreal Forest	2.52	4.7
Surface Water	9.38	9.4
Total	53.3	100.0

* Derived from mapping by Anonymous (1971) and Northland (1980)

and 70%. The remaining boreal forest is classified as non-productive forest, and is identified as softwood scrub. Similarly, this softwood scrub is restricted to areas of lower elevation and greater shelter.

According to Meades (1983), heathlands in this area are predominantly the Kalmia Heath and Empetrum Heath. The Kalmia Heath is dominant in the upper reaches of the catchment. Empetrum Heath is dominant in the southern half of the catchment. No field investigations were carried out. However, it is postulated that in areas of higher elevation, the Alpine Heath may be represented in wind-swept locations. This was found to be the situation in the nearby Old Sams River catchment, despite the relatively lower elevations of its ridges. It is unlikely that the Moss Heath type would be found in this catchment.

As noted in Section 3.3.4.2, the peatland of the Northwest Brook catchment is of the slope bog morphological type. Although no field investigations were undertaken, it is likely that the KALMIO-SPHAGNETUM FUSCI dry bog association comprises the largest vegetation unit in the peatlands of the catchment. However, the morphological character of slope bogs is such that there are likely to be weakly minerotrophic areas dominated by the VACCINIO-CLADONIETUM BORYI association. Wet bog areas probably would have representatives of both the SCIRPO-SPHAGNETUM TENELLI and especially the SCIRPO-SPHAGENTUM MAGELLANICI associations.

3.4.5 Northeast Pond River

The vegetation of the Northeast Pond River catchment is substantially different than that of both the Northwest Brook and the

Old Sams River catchments. The distribution of the main vegetation categories is shown in Figure 3.12, and is based on Anonymous (1971) and Northland (1980). The total area attributed to these various categories is summarized in Table 3.11. Boreal forest is the dominant vegetation category, covering 86.1% of the total catchment area. Both heathland and peatland play a lesser role than they do in the other two catchments.

Productive boreal forest covers 51.7% of the total catchment area. According to the Newfoundland and Labrador Forest Inventory (Anonymous, 1971), this productive forest is made up of trees six to nine *m* in height. Although some small stands have undergone severe cutting near the mouth of the basin, crown cover in the remaining productive forest is between 75% and 100%. There appears to be a distinct altitudinal trend in the distribution of vegetation from productive forest, to non-productive forest, to heathland.

Although no field investigations were carried out in the present study, the distribution of heathland in this area (Meades, 1983) suggests that the Kalmia Heath probably dominates sheltered locations, with Empetrum Heath restricted to the wind-swept areas along the tops of ridges.

Although no field investigations were carried out to verify this, the single domed bog (Section 3.4.3) is probably predominated by the KALMIO-SPHAGNETUM FUSCI dry bog association. The wetter hollows are probably characterized by both the SCIRPO-SPHAGNETUM TENELLI and SCIRPO-SPHAGNETUM MAGELLANICI associations.

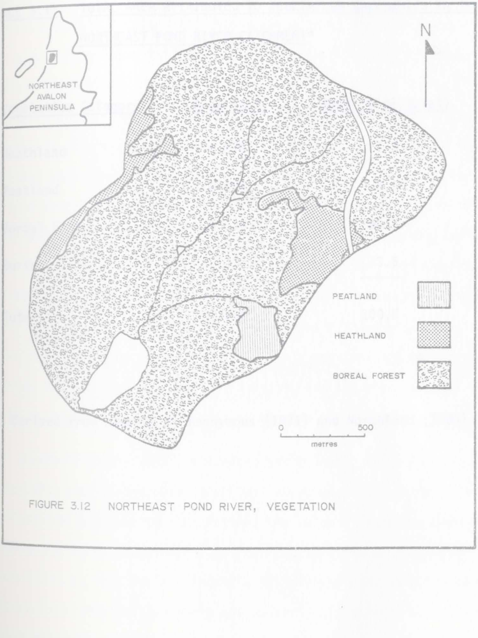

FIGURE 3.12 NORTHEAST POND RIVER, VEGETATION

TABLE 3.11 TOTAL AREA ATTRIBUTED TO VEGETATION CATEGORIES IN THE NORTHEAST POND RIVER CATCHMENT*

Vegetation Category	Area (km^2)	Area (% of total)
Heathland	0.279	7.7
Peatland	0.094	2.6
Boreal Forest	3.126	86.1
Surface Water	0.131	3.6
Total	3.630	100.0

* Derived from mapping by Anonymous (1971) and Northland (1980)

3.5 HYDROCLIMATOLOGY

3.5.1 Climate

Banfield (1981) divided the Province of Newfoundland and Labrador into ten climatic zones. The Avalon Peninsula is in the south and southeast coasts and immediate hinterlands zone, that which experiences the greatest maritime influences. Annual precipitation is between 1500 *mm* and 2000 *mm*. The heaviest precipitation occurs during southerly air-streams, especially over inland hills. Winters are relatively mild with less than half of the total precipitation falling as snow; snow cover is intermittent. Freezing rain occurs frequently in late winter. Summers are cool with frequent sea fog. The Old Sams River and Northwest Brook catchments lie within the southern Avalon Peninsula sub-zone, which has even milder winters and very cool summers. The Northeast Pond River catchment lies in the northern Avalon Peninsula sub-zone, which has less mild winters with more frequent snowfalls, especially during northeasterly flow. This sub-zone has warmer and sunnier summers than the southern sub-zone and the main zone on the south coast of Newfoundland, west of the Avalon Peninsula.

Banfield (1981; 1983) attributed the climate of the Island of Newfoundland to the inter-related influences of the northern hemisphere mid-latitude atmospheric circulation, the Island's location with reference to the Canadian mainland, and the proximity of an extensive cold ocean surface. The Avalon Peninsula is influenced by both the cold Labrador current, and southerly and easterly air-streams which may arrive following an oceanic fetch of 1,000 *km* or more. As a consequence, Banfield (1981) suggested that the climate of the Island of Newfoundland would best be described as "modified continental". Based on his classification, the climate of the Avalon Peninsula, especially in the southern sub-zone, experiences the greatest maritime-oceanic modification.

The ensuing dicussion focuses on the major climatic factors, air temperature, precipitation, relative humidity and fog, and evaporation, recorded at the St. Shotts and St. John's A climatic stations. St. Shotts is the climatic station nearest to the two southern catchments in this study, located approximately 12 *km* and 36 *km* south-southwest of the centre of the Old Sams River and Northwest Brook catchments, respectively (Figure 2.1). St. John's A is the climatic station nearest to the Northeast Pond River catchment, and is located only six *km* east of its centre (Figure 2.1).

3.5.1.1 Temperature

Mean daily temperature for St. Shotts and St. John's is summarized in Table 3.12. Although the mean daily temperature for the year is the same at both stations, 4.8 °C, the climatic differences identified by Banfield (1981) for the northern and southern climatic sub-zones of his south and southeast coasts and immediate hinterlands zone are clearly demonstrated. St. Shotts experiences cooler summers and warmer winters than St. John's. In July, mean daily temperatures differ by 3.3 C° between stations. In February, mean daily temperatures differ by 2.0 C° between stations. The range of daily mean maximum and minimum temperature is 7.6 C° at St. John's, and only 5.8 C° at

TABLE 3.12 MEAN DAILY TEMPERATURE (°C)* AT ST. SHOTTS AND ST. JOHN'S A

	St. Shotts (46 *m* asl) †				St. John's A (140 *m* asl) ††			
	Max	Min	Mean	$\hat{\sigma}$**	Max	Min	Mean	$\hat{\sigma}$**
January	1.0	-4.8	-2.1	1.8	-0.5	-7.2	-3.9	2.0
February	0.6	-5.2	-2.5	2.1	-1.0	-7.9	-4.5	2.5
March	1.2	-3.9	-1.6	1.0	0.9	-5.5	-2.3	1.6
April	4.0	-1.2	1.4	0.7	4.5	-2.2	1.2	1.4
May	7.4	1.4	4.7	1.1	9.7	1.1	5.4	1.4
June	11.1	4.8	7.8	1.2	15.8	5.9	10.9	1.6
July	15.2	9.4	12.3	0.8	20.2	10.7	15.5	1.5
August	16.9	11.4	14.1	0.7	19.4	11.1	15.3	1.5
September	14.8	8.7	11.7	1.0	15.6	7.5	11.6	1.0
October	11.0	4.8	7.7	0.8	10.4	3.4	6.9	0.8
November	7.3	1.5	4.3	0.9	6.5	0.2	3.4	1.5
December	2.6	-3.1	-0.3	1.8	1.6	-4.6	-1.5	1.0
Year	7.8	2.0	4.8	0.5	8.6	1.0	4.8	0.7

* From Environment Canada (1982)

** Best estimate of the standard deviation of mean daily temperature

† Normals, 1951-1980, based on 5 to 19 years data, adjusted by the difference method (Environment Canada, 1982)

†† 1951-1980

St. Shotts. In May through August, St. John's experiences much warmer temperatures than St. Shotts. For the remainder of the year, St. John's is substantially cooler than St. Shotts.

3.5.1.2 Precipitation

Mean monthly precipitation for St. Shotts and St. John's A is summarized in Table 3.13. Precipitation at St. Shotts is slightly less than that described by Banfield (1981) for the southern Avalon Peninsula climatic sub-zone. However, Den Hartog and Ferguson (1975) concluded that on the basis of observed runoff data, calculation of evapotranspiration, and the assumption of no net change in soil moisture storage, actual mean annual total precipitation is between 1600 *mm* and 1700 *mm* at both St. Shotts and St. John's. Banfield (1981; 1983) attributed this discrepancy to a considerable undercatch by precipitation gauges over the year as a whole, especially at coastal stations where precipiation is often accompanied by high winds. Banfield (1981) arrived at his classification of climatic zones on the basis of the estimation by Den Hartog and Ferguson (1975).

Snowfall contributes a much greater amount to total precipitation at St. John's (Table 3.13). This was observed by Banfield (1981). At St. Shotts, only 25.1 *mm*, 24.3% of the total precipitation in February, falls as snow, whereas at St. John's, 74.6 *mm*, 53.3% of the total precipitation in February, falls as snow. Banfield (1983) attributed these higher values at St. John's to the influences of altitude, proximity of open sea, aspect, and the synoptic weather pattern.

He suggested that the St. John's area experiences orographically

TABLE 3.13 MEAN MONTHLY TOTAL PRECIPITATION, RAINFALL, AND SNOWFALL (*mm*)* AT ST. SHOTTS AND ST. JOHN'S A

	St. Shotts††				St. John's A†††			
	Rainfall	Snowfall†	Total Precipitation	$\hat{\sigma}$**	Rainfall	Snowfall†	Total Precipitation	$\hat{\sigma}$**
January	109.9	21.9	139.5	53.6	77.9	81.4	155.8	54.2
February	91.7	25.1	103.1	50.3	69.7	74.6	140.1	48.2
March	114.0	23.8	131.3	30.2	67.0	65.0	131.9	39.8
April	114.7	4.8	122.9	61.0	78.1	34.6	115.6	38.5
May	106.0	0.4	110.2	56.1	38.5	11.1	101.8	38.5
June	109.3	0.0	106.3	38.8	36.5	2.0	85.6	36.5
July	104.2	0.0	104.2	42.6	35.9	0.0	75.3	35.9
August	112.1	0.0	112.1	52.9	64.0	0.0	121.6	64.0
September	132.5	0.0	132.5	41.7	45.7	T***	116.7	45.7
October	129.8	0.0	129.6	59.5	47.9	4.4	145.5	47.9
November	138.9	2.3	136.8	31.4	62.4	21.2	162.5	62.4
December	110.3	13.3	124.7	47.5	62.7	65.1	161.2	62.7
Year	1373.4	91.6	1453.2	186.5	1157.3	359.4	1513.6	215.5

* From Environment Canada (1982)
** $\hat{\sigma}$ is the estimate of the standard deviation of total precipitation
*** T is trace
† Water equivalent
†† Normals, 1951-1980, based on 5 to 19 years data, adjusted by ratio method
††† 1951-1980

increased quantities whenever snow is accompanied by winds from northerly and easterly points. On average, snow falls at St. John's in all months but July and August, while St. Shotts on average, is snow-free June through October.

On average, from December through July, and in September, St. Shotts receives greater rainfall than St. John's (Table 3.13). In August, October, and November, St. John's receives slightly greater rainfall. The annual range of mean monthly rainfall is 47.2 *mm* at St. Shotts, much less than the 73.9 *mm* recorded for St. John's.

The range of mean monthly total precipitation is also less at St. Shotts, 36.4 *mm*, than at St. John's, 87.2 *mm* (Table 3.13). At St. Shotts, total mean monthly precipitation exceeds 100 *mm* in every month.

The number of days with measureable rainfall, snowfall, and precipitation at St. Shotts and St. John's A is summarized in Table 3.14. St. John's receives measureable rainfall on 32 days more than St. Shotts annually. In winter months, St. John's receives measureable snowfall on substantially more days than St. Shotts. On average, there are 79 more days with measureable precipitation at St. John's annually. Banfield (1983) suggested that snowfall is less frequent and also less substantial over the south coast of the Avalon Peninsula because transient winter low pressure systems follow tracks further to the north. St. Shotts receives either rain or no precipitation at these times.

TABLE 3.14 DAYS WITH MEASUREABLE RAINFALL, SNOWFALL, AND PRECIPITATION* AT ST. SHOTTS AND ST. JOHN'S A

	St. Shotts			St. John's A		
	Rain	Snow	Precipitation	Rain	Snow	Precipitation
January	10	4	13	10	18	23
February	6	4	10	8	16	20
March	8	4	12	10	15	21
April	9	1	10	12	10	19
May	11	0	11	15	3	17
June	11	0	11	13	T**	13
July	12	0	12	13	0	13
August	10	0	10	15	0	15
September	10	0	10	15	T	15
October	14	0	14	18	2	19
November	13	1	13	16	7	19
December	10	2	12	11	17	23
Total	124	16	138	156	88	217

* From Environment Canada (1982), normals, 1951-1980

** T represents Trace

3.5.1.3 Relative Humidity and Fog

Table 3.15 summarizes the long-term mean relative humidity for standard daily observation hours in January, April, July, and October at Cape Race (Figure 2.1) and St. John's A. Relative humidity is not measured at St. Shotts. However, Cape Race provides a representative surrogate station for St. Shotts. It is located 30 *km* southeast of the centre of the Northwest Brook catchment, and 33 *km* east-southeast of the centre of the Old Sams River catchment. Cape Race experiences a summer maximum in relative humidity. Banfield (1981; 1983) attributed this to frequent onshore flow of humid air that has been strongly cooled, often to the dew point, after passage over the cold ocean surface. St. John's shows a more pronounced annual cycle with a summer minimum and winter maximum. At St. John's, in summer, the oceanic influence on temperature is much less than that experienced at St. Shotts (Table 3.11). Banfield (1983) suggested that this condition allows relative humidity to respond more directly to the seasonal temperature cycle at St. John's.

At both stations, on average, relative humidity is lowest during the early afternoon and highest overnight. Banfield (1983), however, noted that at many locations on the southern coasts, in summer, there is an additional humidity peak in the late morning or afternoon, whenever daytime sea breezes transport damp air onshore.

The mean number of days per month and year with fog (visibility less than 1 *km*) reported at some time during the day is summarized in

TABLE 3.15 MEAN RELATIVE HUMIDITY (%)* FOR SELECTED MONTHS AND TIMES OF DAY AT CAPE RACE AND ST. JOHN'S

Month	Time (*hr*)	Cape Race	St. John's
January	02	87	89
	08	90	87
	14	86	77
	20	87	85
April	02	92	89
	08	90	85
	14	85	74
	20	91	87
July	02	97	89
	08	93	81
	14	89	66
	20	94	82
October	02	90	89
	08	88	84
	14	81	73
	20	91	87

* From Banfield (1983), normals, 1941-1970

Table 3.16 for Cape Race and St. John's A. The coastal areas of Newfoundland experience high fog frequencies, especially in spring and summer when warmer air masses are strongly chilled from below by the Cold Labrador Current (Banfield, 1981; 1983). These advection sea fogs are often carried over southern coastal districts. Banfield (1983) noted that Cape Race, at the southeast tip of the Avalon Peninsula, experiences the greatest number of days with fog for all stations in Newfoundland. In the northern Avalon Peninsula, as at St. John's, there is less summer fog due to a general excess of offshore over onshore winds (Banfield, 1981; 1983). Banfield (1981; 1983) observed that on most cloud-free days, advective sea fogs evaporate a few kilometres inland from the coastlines; however, with stronger winds under cloudy skies, fog can extend further inland, often producing mist, low cloud, and even drizzle over high ground.

Banfield (1981; 1983) reported the occurrence of fog due to low cloud cover in high terrain. This occurs in association with warm sectors of low pressure systems (particularly in fall and winter), or in spring when moist air is advected over a cold land surface. This phenomenon probably occurs in all three catchments, whereby higher ground experiences a thick fog, while adjacent lower elevations experience only a low cloud base.

3.5.1.4 Evaporation, Evapotranspiration, and Water Deficit

The lack of evaporation and potential evapotranspiration data for Newfoundland has been noted by Yoxall (1980) and Banfield (1981; 1983). On the Avalon Peninsula, "Class A" pan evaporation data are available

TABLE 3.16 MEAN NUMBER OF OCCURRENCES OF FOG*

Month	Cape Race	St. John's
January	8	7
February	7	8
March	8	9
April	14	13
May	17	16
June	19	14
July	23	14
August	21	11
September	13	9
October	9	8
November	10	9
December	6	6
Year	155	123

* From Banfield (1983), visibility less than one *km* reported at some time during the day, normals, 1941-1970

for St. John's A only. On the basis of 5 years record, Banfield (1981; 1983) reported that mean annual pan evaporation was 640.1 *mm*. There is no mean monthly pan evaporation from November through April. Monthly pan evaporation peaks at 168.1 *mm* in July.

Empirical estimates of lake evaporation range form 480 *mm* on the south coast of the Island of Newfoundland to approximately 420 *mm* on the Northern Peninsula (Banfield, 1981). Banfield (1981) attributed the relatively higher pan evaporation at St. John's at least partly to stronger mean summer wind velocities. Banfield (1981; 1983) postulated that evaporation is reduced in upland areas due to lower air temperature and less solar radiation, despite stronger winds.

Yoxall (1980) adduced from the work of others that estimates of potential evapotranspiration range between 400-500 *mm* for the Island of Newfoundland. These estimates agree well with estimates of lake evaporation, and pan evaporation measured at Gander, Newfoundland, and Churchill Falls, Labrador (Banfield, 1981). However, they are substantially less than pan evaporation measured at St. John's. Yoxall (1980) and Banfield (1981; 1983) emphasized that estimates of potential evapotranspiration are impossible to verify owing to the present lack of suitable data.

Banfield (1981; 1983) reviewed average growth-season water deficit (Agriculture Canada, 1976). The procedure used estimated daily deficits from observed data on precipitation, potential evapotranspiration, consumptive use of water by plants, and water-holding capacity of soils. The growth season soil water deficit for the Avalon

Peninsula is between 50 *mm* and 100 *mm* (Banfield, 1981; 1983).

3.5.2 Runoff

Mean annual stream discharge and runoff are summarized for all gauged rivers on the Avalon Peninsula (Figure 3.13) in Table 3.17. Mean annual runoff ranges from a low of 1080 *mm* in the Waterford River catchment in St. John's, to a high of 1810 *mm* for the Northwest Brook catchment. Upland catchments of the southeast coastal regions have substantially greater runoff than those of the rest of the Avalon Peninsula.

Mean monthly stream discharge and runoff are summarized for Northwest Brook and Northeast Pond River in Table 3.18. Mean annual runoff at Northwest Brook is 57% greater than at Northeast Pond River. Mean monthly runoff at Northwest Brook exceeds Northeast Pond River in all months. Minimum monthly discharge occurs in July at both catchments. However, Northwest Brook experiences 180% greater runoff in July. At both catchments, the greatest monthly runoff occurs in April. Secondary runoff peaks occur in December at Northwest Brook, and in November at Northeast Pond River.

3.5.2.1 Water Balance Consideration

Yoxall (1980) concluded that due to the lack of instrumentally-obtained evaporation data in Newfoundland and the underrepresentation of precipitation values, an accurate assessment of the water balance of Newfoundland is not possible at this time. Solomon, et al. (1968) were first to note that precipitation at several locations on the Island is less than observed runoff. This has also been noted by

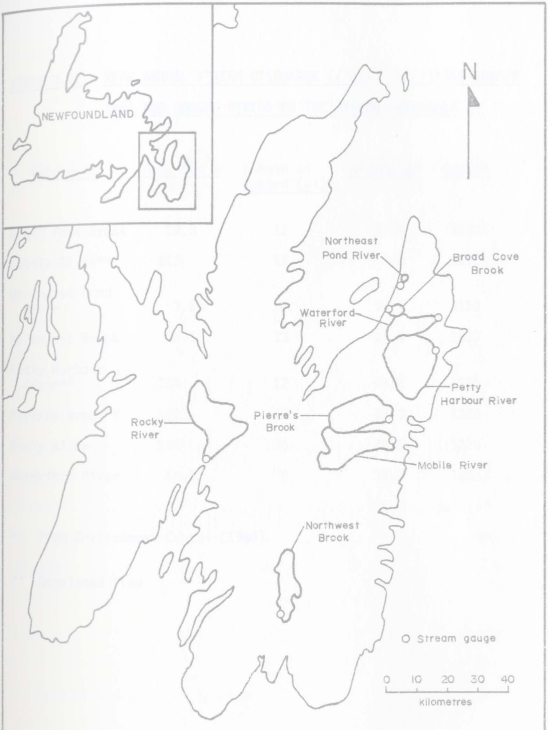

FIGURE 3.13 GAUGED RIVERS, AVALON PENINSULA

TABLE 3.17 MEAN ANNUAL STREAM DISCHARGE ($\ell\ sec^{-1}\ km^{-2}$)*AND RUNOFF (*mm*) FOR GAUGED RIVERS ON THE AVALON PENINSULA

Catchment	Area (km^2)	Length of Record (*yr*)	Discharge	Runoff
Broad Cove Brook	19.5	12	37.9	1200
Mobile River**	112	17	52.8	1670
Northeast Pond River	3.63	26	36.4	1150
Northwest Brook	53.3	13	57.4	1810
Petty Harbour River**	134	17	43.2	1360
Pierres Brook**	117	17	43.3	1370
Rocky River	285	30	38.6	1220
Waterford River	58.2	6	34.2	1080

* From Environment Canada (1980)

** Regulated Flow

TABLE 3.18 MEAN MONTHLY STREAM DISCHARGE ($\ell\ sec^{-1}\ km^{-2}$)* AND RUNOFF (*mm*) AT NORTHWEST BROOK AND NORTHEAST POND RIVER

Month	Northwest Brook		Northeast Pond River	
	Discharge	Runoff	Discharge	Runoff
January	65.9	176	39.7	106
February	69.4	168	40.5	98.0
March	65.3	175	41.6	111
April	78.6	204	65.6	170
May	57.6	154	49.0	131
June	39.0	101	24.0	62.1
July	28.5	76.4	10.2	27.3
August	40.3	108	19.8	53.1
September	46.5	121	19.0	49.3
October	65.7	176	34.7	93.0
November	65.7	170	49.6	129
December	69.8	187	46.6	125
Year	57.4	1810	36.4	1150

* From Environment Canada (1980)

Den Hartog and Ferguson (1975), and Banfield (1981, 1983). They attributed these discrepancies to undercatch by precipitation gauges.

From the data presented in Table 3.13 and Table 3.18, it is apparent that runoff observed at Northwest Brook is 356.8 *mm* greater than precipitation measured at the nearest precipitation station at St. Shotts. If it is assumed that the empirically estimated value of lake evaporation for the area of 480 *mm* (Banfield, 1981), less the mean growth season soil water deficit of between 50 *mm* and 100 *mm*, is equal to actual evapotranspiration, then it is estimated that actual mean annual precipitation over the Northwest Brook catchment area is between 2190 *mm* and 2240 *mm*. This estimate suggests that precipitation catch at St. Shotts could be as much as 35% less than that received over the nearby Northwest Brook catchment.

Banfield and Barnes (in prep.) noted that this discrepancy at Northwest Brook results from the inappropriate comparison of precipitation data collected at a low altitude coastal location with runoff data from an upland catchment inland. Realizing this difficulty, Solomon, et al. (1968) estimated the mean isohyetal map of Newfoundland by taking the influence of physiographic factors on precipitation into account. They estimated mean annual precipitation to be between 1520 *mm* and 1780 *mm*, substantially less than estimated above. Banfield and Barnes (in prep.) have demonstrated that under certain synoptic conditions which are common in spring and early summer, precipitation on coastal uplands in the Southern Avalon Peninsula is orographically enhanced by uplift of saturated airmasses over the coastal headlands. The release of potential instability was also found to be a contributing factor. It is concluded here that precipitation at St. Shotts is dramatically less than that actually incident on the Northwest Brook catchment. Both precipitation gauge undercatch as originally proposed by Solomon, et al. (1968), Den Hartog and Ferguson (1975), and Banfield (1981; 1983), and the orographic enhancement of precipitation by coastal uplands are contributing factors to this discrepancy.

Comparison of precipitation, evapotranspiration, and runoff between St. John's A and Northeast Pond River suggests that this discrepancy may not exist here. However, in this case, the precipitation gauge is located in an upland area in close proximity to the Northeast Pond River catchment with which it is compared.

CHAPTER 4

DATA PRESENTATION

4.1 OLD SAMS RIVER CATCHMENT

A number of hydrometeorological parameters were measured. The study period extended from May 18 to August 11, 1978. The following data were collected for most of this period:

(1) stream discharge;
(2) precipitation;
(3) temperature and relative humidity;
(4) bog water table depth; and
(5) pan evaporation.

The first three were measured continuously, whereas bog water table depth and pan evaporation were observed daily. Research design and methodology are discussed in Chapter 2 above.

4.1.1 Stream Discharge

Stream stage was recorded continually between 11:00 *hrs* NST, May 18, and 03:00 *hrs* NST, August 2, 1978. The stage record was abstracted manually from the recorder charts on a half-hourly basis. A Fortran computer program was used to determine stream discharge by relating it to stage with the established rating curve (Section 2.4.1). Half-hourly stream discharge data are listed in Appendix A.

Heavy precipitation experienced in the rain storm of June 9 and 10, 1978, resulted in an excessive amount of moisture entering the stage recorder housing. This washed the ink from the tracer and chart. With the exception of two short periods on June 15 and 17, the data were completely lost between 23:30 *hrs* NST, June 10, and 22:00 *hrs* NST, June 18, 1978. A similar loss of record occurred between 22:00 *hrs* NST, July 23, and 11:00 *hrs* NST, July 24.

Suitable data for an analysis to estimate this missing half-hourly data record are not available. However, it has been possible to develop a bivariate linear regression model to estimate daily discharge at Old Sams River from daily discharge at Northwest Brook (Figure 4.1). Daily discharge is expressed as specific runoff ($\ell\ sec^{-1}\ km^{-2}$). The standard error of the estimate of y, SEEy, is 9.30 $\ell\ sec^{-1}\ km^{-2}$ (23.7 $\ell\ sec^{-1}$). While the relationship is statistically significant at the 0.1% level of confidence, predicted values of y have large error limits. Differences in basin size and physical characteristics preclude the development of a more precise model of daily runoff. These estimated data are included in Section 5.3. However, data analysis does not rely upon their inclusion. It should be noted that discharge data, where analyzed in a water resources context, are expressed as runoff in *mm*.

4.1.2 Precipitation

Precipitation was recorded continually between 12:15 *hrs* NST, May 20, and 18:00 *hrs* NST, August 11, 1978. All precipitation during this period was liquid (rain, drizzle, and condensation). Half-hourly precipitation totals were abstracted from the recorder charts. These data are summarized in Appendix B.

In the period between 12:00 *hrs* NST, July 30, and 17:10 *hrs* NST, August 2, the recorder appears to have malfunctioned. The chart record shows uncharacteristic up and down movements. While only 0.6 *mm* of

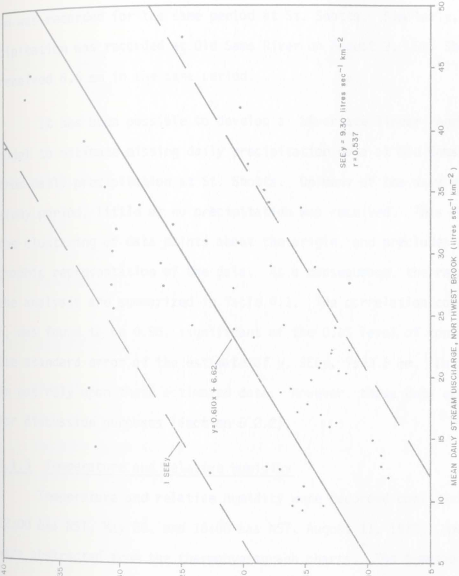

FIGURE 4.1 MEAN DAILY STREAM DISCHARGE, NORTHWEST BROOK VERSUS OLD SAMS RIVER

precipitation was recorded on July 30, a distinct stream discharge event, far in excess of what would be expected to result from such a small amount of precipitation was noted (Appendix A). A total of 7.4 *mm* was recorded for the same period at St. Shotts. Similarly, no precipitation was recorded at Old Sams River on August 2. St. Shotts received 6.6 *mm* in the same period.

It has been possible to develop a bivariate linear regression model to estimate missing daily precipitation data at Old Sams River from daily precipitation at St. Shotts. On many of the days during the study period, little or no precipitation was received. This results in the clustering of data points about the origin, and precludes meaningful graphic representation of the data. As a consequence, the results of the analysis are summarized in Table 4.1. The correlation coefficient, r, was found to be 0.95, significant of the 0.1% level of confidence. The standard error of the estimate of y, SEEy, is 3.3 *mm*. Data analyses do not rely upon these estimated data. However, these data are included for discussion purposes (Section 5.2.2).

4.1.3 Temperature and Relative Humidity

Temperature and relative humidity were recorded continually between 12:00 *hrs* NST, May 20, and 16:00 *hrs* NST, August 11, 1978. Hourly data were abstracted from the thermohygrograph charts. The temperature record is summarized in Appendix C. The relative humidity data were corrected for temperature error as per the manufacturer's specifications and are listed in Appendix D.

There is a considerable amount of missing data which resulted from technical difficulties with the instrument, especially in the first few

TABLE 4.1 BIVARIATE LINEAR REGRESSION STATISTICS, PRECIPITATION, ST. SHOTTS VERSUS OLD SAMS RIVER

Regression Equation ($y = 1.23\,x - 0.001$)

Slope = 1.23

y-intercept = -0.001

Standard error of the estimate of y = 3.3 *mm*

Other parameters

mean of x = 2.4 *mm*

mean of y = 3.0 *mm*

standard deviation of x = 8.6 *mm*

standard deviation of y = 10.6 *mm*

correlation coefficient, r = 0.95

weeks of operation. The most serious problem was experienced with the relative humidity tracer arm. In addition to this, as was experienced with the stage recorder, the extremely wet conditions prevailing in the rain storm of June 9 and 10, resulted in a substantial loss of record between June 9 and June 18.

It has been possible to develop a bivariate linear regression model to estimate missing daily temperature data at Old Sams River from daily temperature at St. Shotts (Figure 4.2). The correlation coefficient, r, is 0.92, significant at the 0.1% level of confidence. The standard error of the estimate of y, SEEy, is 1.7 C°. These data are included for discussion purposes only (Section 5.2.1).

4.1.4 Bog Water Table Depth

Bog water table depths were measured on eighteen days over the study period. These are summarized in Appendix E, Table E.1.

When it was not possible to make observations at each well some missing data were noted. For example, on June 28, wells 8, 10, 12B, 12C, 12D, 13, 14, and 15 were missed due to inclement weather. On July 11, August 2, and August 4 water table depths in wells 4 and 6 were recorded en route to the meteorologic station. Wells 12A, 12B, 12C, and 12D, were not operational until June 2, and this resulted in the lack of data before June 8.

In an effort to fill in the missing data noted in Table E.1, bivariate linear regression analyses were carried out to estimate missing values from observed values. The mean water table depths recorded at wells 4 and 6, $\bar{x}_{4,6}$, the two wells with the greatest number of ob-

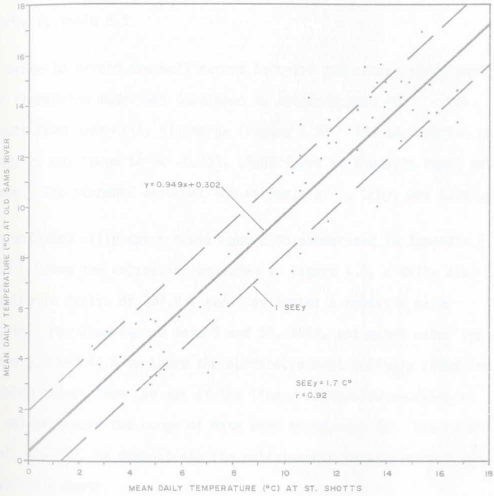

FIGURE 4.2 DAILY TEMPERATURE, ST. SHOTTS VERSUS OLD SAMS RIVER

servations, were used to develop predictive equations for wells with missing data. These are summarized in Appendix E, Table E.2. In spite of very small sample sizes, all correlation coefficients were significant at the 0.1% level of confidence. Standard errors were quite small, ranging between 0.70 and 1.7 *cm*. The completed data set is summarized in Appendix E, Table E.3.

In order to extend the well record to cover the entire study period, a linear regression model was developed to estimate mean daily water table depth from mean daily discharge (Figure 4.3). The correlation coefficient, r, was found to be -0.733, significant at the 1.0% level of confidence. The standard error of the estimate of y, SEEy, was 1.92 *cm*.

The extended daily water table record is summarized in Appendix E, Table E.4. Using the regression equation in Figure 4.3, a daily discharge value in excess of 137.9 $\ell\ sec^{-1}$ estimates a negative water table depth. For example, on June 9 and 10, 1978, estimated water table depths are 5.2 and 44.5 *cm* above the surface, a most unlikely situation. This problem arises from the use of the linear regression equation to predict values beyond the range of data used to develop it. The model is useful, however, to demonstrate the relationship between runoff and bog water table depth.

4.1.5 Pan Evaporation

Pan evaporation data were collected for one month between July 3, 1978, and August 4, 1978. Daily readings were made as frequently as possible. These data are summarized in Appendix F.

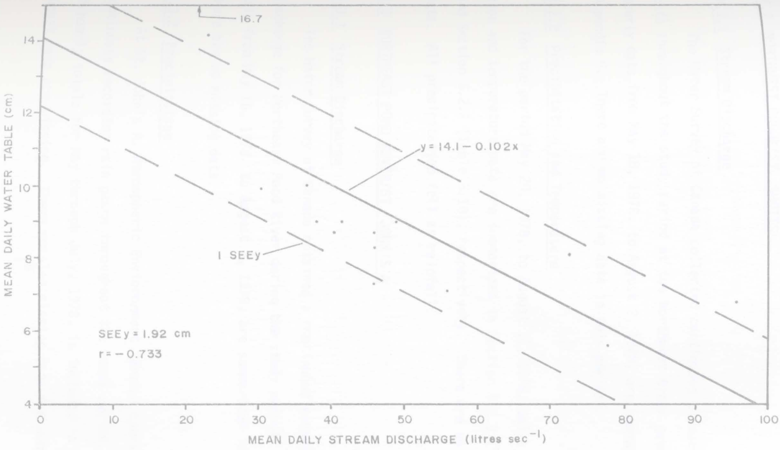

FIGURE 4.3 MEAN DAILY STREAM DISCHARGE VERSUS MEAN DAILY WATER TABLE DEPTH

4.2 NORTHWEST BROOK/ST. SHOTTS

4.2.1 Stream Discharge

The Water Survey of Canada collected continuous stream discharge data throughout the study period at the Northwest Brook gauging station. Hourly data from May 18, 1978, to August 2, 1978, are summarized in Appendix G. There are no missing data in this period.

4.2.2 Precipitation and Temperature

For the period May 20, 1978, to August 11, 1978, daily precipitation and temperature data are summarized in Section 5.2.1 (Table 5.8) and Section 5.2.2 (Table 5.10), respectively. There are no missing data. All precipitation fell as rainfall.

4.3 NORTHEAST POND RIVER/ST. JOHN'S A

4.3.1 Stream Discharge

The Water Survey of Canada obtained a continuous record of stream discharge for Northeast Pond River during the study period. Hourly data from May 18, 1978, to August 2, 1978, are summarized in Appendix H. There are no missing data.

4.3.2 Precipitation

At St. John's A, Atmospheric Envioronment Service operated a continuous recording rain gauge throughout the study period. A summary of hourly totals for May through July, 1978, is included in Appendix I. August data are missing. There arealso missing data for June 4 and 5.

In addition to the continuous recorder, a Canadian standard gauge was used to collect daily precipitation data. These data are summarized for the period from May 20, 1978, to August 11, 1978, in Section 5.2.2 (Table 5.10).

4.3.3 Temperature

Daily maximum, minimum, and mean temperature at St. John's A are summarized for the period May 20, 1978, to August 11, 1978, in Section 5.2.1 (Table 5.8). There are no missing data.

CHAPTER 5

ANALYSIS OF DATA

5.1 SEASONAL HYDROCLIMATOLOGICAL REPRESENTATIVENESS OF CONDITIONS PRECEEDING AND DURING THE STUDY PERIOD

5.1.1 St. Shotts and Northwest Brook

When compared with climatic normals the period from January through August, 1978 was for the most part warmer than average at St. Shotts (Table 5.1). In March, May, and August, mean monthly temperature was only slightly below the mean. Warmer than normal conditions prevailed in the remaining months, especially in April, June, and July, when mean monthly temperatures were 1.7, 0.8, and 1.0 standard deviations above the mean.

St. Shotts experienced an extreme range of monthly precipitation (Table 5.1). In January, 247.7 *mm* of precipitation fell, an amount in excess of two standard deviations above the mean. By contrast, February was exceptionally dry at 1.31 standard deviations below the mean. March was wetter than normal, with April even more so, having received 212.3 *mm* of precipitation, 1.46 standard deviations above the mean. On April 14, 1978, 81.3 *mm* of precipitation fell (Environment Canada, 1978), the greatest 24 hour amount on record (Environment Canada, 1982). Precipitation in May and June was normal, but July and August were quite dry.

Monthly discharge data for Northwest Brook are summarized for the same period in Table 5.2 Consistent with the precipitation record at

TABLE 5.1 ST. SHOTTS MONTHLY TEMPERATURE AND PRECIPITATION IN 1978, COMPARED WITH NORMALS*

Temperature

	Mean** (°C)	1978*** (°C)	Difference (C°)	Standard Deviation** (C°)	Difference (stand. dev.)
January	-2.1	-1.3	0.8	1.8	0.4
February	-2.5	-2.3	0.2	2.1	0.1
March	-1.6	-2.1	-0.5	1.0	-0.5
April	1.4	0.2	1.2	0.7	1.7
May	4.7	4.2	-0.5	1.1	-0.5
June	7.8	8.7	0.9	1.2	0.8
July	12.3	13.1	0.8	0.8	1.0
August	14.1	13.9	-0.2	0.7	-0.3

Precipitation

	Mean** (mm)	1978*** (mm)	Difference (mm)	Standard Deviation** (mm)	Difference (stand. dev.)
January	139.5	247.7	108.2	53.6	2.02
February	103.1	37.3	-65.8	50.3	-1.31
March	131.3	146.8	15.5	30.2	0.51
April	122.9	212.3	89.5	61.0	1.46
May	110.2	77.0	-33.2	56.1	-0.59
June	106.3	120.7	14.4	38.8	0.37
July	104.2	59.9	-44.3	42.6	-1.04
August	112.1	59.7	-52.4	52.9	-0.99

* (Environment Canada, 1982)
** Adjusted Normals 1972-1980
*** (Environment Canada, 1978)

TABLE 5.2 NORTHWEST BROOK MONTHLY STREAM DISCHARGE IN 1978, COMPARED WTIH NORMALS*

	Mean** ($\ell\ sec^{-1}\ km^{-2}$)	1978* ($\ell\ sec^{-1}\ km^{-2}$)	Difference ($\ell\ sec^{-1}\ km^{-2}$)	Standard Deviation** ($\ell\ sec^{-1}\ km^{-2}$)	Difference (stand. dev.)
January	65.9	124	58.1	38.1	1.52
February	69.4	24.8	-44.6	47.2	-0.94
March	65.3	67.2	1.9	29.7	0.06
April	78.6	115	36.4	47.1	0.77
May	57.6	98.9	41.3	22.3	1.85
June	39.0	65.9	26.9	24.1	1.12
July	28.5	17.3	-11.2	17.7	-0.63
August	40.3	10.3	-30.0	34.2	-0.88

* (Environment Canada, 1980)

** 1966-1979

nearby St. Shotts, Northwest Brook experienced a range of extremes in the period from January to August, 1978. With the exception of low flows in February, discharge was above average in the first six months of 1978. Discharge in January and May was the highest, and in June, it was the second highest on record (Environment Canada, 1980). Discharge in July and August, like precipitation, was well below normal; in August it was the lowest on record (Environment Canada, 1980).

Discharge was extremely high in May, while precipitation in that same period was well below normal. This apparent anomaly is explained by the fact that from April 28-30, 59.4 mm of precipitation fell (Environment Canada, 1978). Given that Northwest Brook has a 2-3 day lag time between peak precipitation and peak discharge (Section 5.4), it is likely that this precipitation contributed greatly to the record discharge observed in May.

The St. Shotts/Northwest Brook area experienced a relatively wet winter and spring in 1978, with, for the most, above average temperature, precipitation and discharge. In summer, there was a transition from this to relatively warm temperatures with below average precipitation and discharge.

5.1.2 St. John's A and Northeast Pond River

Unlike St. Shotts, St. John's experienced a winter and spring cooler than normal in 1978 (Table 5.3). Temperatures were particularly low in March and April, when mean monthly temperature was 0.8 and 1.1 standard deviations below the mean. Temperature in June was

*TABLE 5.3 ST. JOHN'S A MONTHLY TEMPERATURE AND PRECIPITATION 1978, COMPARED WITH NORMALS**

Temperature

	Mean** (°C)	1978*** (°C)	Difference (C°)	Standard Deviation** (C°)	Difference (stand. dev.)
January	-3.9	-3.6	0.3	2.0	-0.2
February	-4.5	-3.8	0.7	2.5	-0.3
March	-2.3	-3.6	-1.3	1.6	-0.8
April	1.2	-0.4	-1.6	1.4	-1.1
May	5.4	4.7	-0.7	1.4	-0.5
June	10.9	12.5	1.6	1.6	1.0
July	15.5	15.6	0.1	1.5	0.1
August	15.3	14.7	-0.6	1.5	-0.4

Precipitation

	Mean** (mm)	1978*** (mm)	Difference (mm)	Standard Deviation** (mm)	Difference (stand. dev.)
January	155.8	218.0	62.2	54.2	1.15
February	190.1	104.7	-35.4	48.2	-0.73
March	131.9	183.1	51.2	39.8	1.29
April	115.6	188.2	72.5	64.8	1.12
May	101.8	47.7	-54.1	38.5	-1.41
June	85.6	57.2	-28.6	36.5	-0.78
July	75.3	84.9	9.6	35.9	0.27
August	121.6	49.5	-72.1	64.0	-1.13

* (Environment Canada, 1982)
** 1951-1980
*** (Environment Canada, 1978)

considerably warmer than normal, but was normal in July and August.

With the exception of February, conditions wetter than normal prevailed at St. John's from January through April (Table 5.3). However, in this period, St. John's did not experience the extreme range of precipitation noted for St. Shotts, neither in absolute terms nor in terms of comparison with their respective normals. In contrast to St. Shotts, precipitation was extremely low in May, 1.41 standard deviations below the mean. Precipitation in June was much lower than normal, and in July, it was slightly higher than normal, much higher than at St. Shotts. In August, precipitation was quite low, 1.13 standard deviations below the mean.

Northeast Pond River did not experience as extreme a range in monthly discharge as observed for Northwest Brook (Table 5.4). Discharge was normal in January, March, and April, but it was well below normal in February. It was 1.02 standard deviations above the mean in May. Discharge was substantially below normal in June, in contrast to that noted at Northwest Brook. In July and August, discharge at Northeast Pond River was below normal, similar to conditions experienced at Northwest Brook.

As was noted for St. Shotts, precipitation at St. John's was extremely high in April, but a correspondingly high discharge value did not occur until May. However, 31.8 *mm* of rain fell on April 28-30, a substantial proportion of which may not have run off until early May. A total of 75.2 *mm* of precipitation fell as snow in the period April 12-17 (Environment Canada, 1978). While this snow melted before

TABLE 5.4 NORTHEAST POND RIVER MONTHLY DISCHARGE IN 1978, COMPARED WITH NORMALS*

	Mean** ($\ell\ sec^{-1}\ km^{-2}$)	1978* ($\ell\ sec^{-1}\ km^{-2}$)	Difference ($\ell\ sec^{-1}\ km^{-2}$)	Standard Deviation** ($\ell\ sec^{-1}\ km^{-2}$)	Difference (Stand. dev.)
January	39.7	57.3	17.6	29.0	0.61
February	40.5	13.2	-27.3	29.2	-0.93
March	41.6	39.2	-3.3	20.8	-0.16
April	65.6	76.3	10.7	30.8	0.35
May	49.0	75.2	26.2	25.8	1.02
June	24.0	11.6	-12.4	15.9	-0.78
July	10.2	6.1	-4.1	8.9	-0.46
August	19.8	3.0	-16.8	21.2	-0.79

* Environment Canada (1980)

** 1953-1979

the end of April at St. John's A, it is possible that given the extent of forest cover in the Northeast Pond River catchment, snowmelt runoff may have been substantially delayed into May.

The St. John's/Northeast Pond River area experienced a relatively cool, wet winter and early spring. While discharge remained high into May, it dropped well below normal during the summer. This was a result of low preciptiation and temperatures that were normal to above normal during most of the study period.

5.1.3 Old Sams River

The seasonal representativeness of the hydrometeorological record for the study period is difficult to assess because of the absence of historical record. However, the nearby St. Shotts and Northwest Brook stations provide a reasonable basis for comparison. In Section 4.1.3, correlation and bivariate linear regression analyses of daily temperature data demonstrate the statistically significant relationship between these two proximal stations (Figure 4.2). On the basis of this relationship, it is argued that, as was noted for St. Shotts, temperature at the Old Sams River catchment was slightly below normal in May, and well above normal in June and July. Similarly, it is reasonable to suggest that from January to the beginning of the study period, temperature was for the most part slightly warmer than normal.

Mean monthly temperature at Old Sams River and St. Shotts during the study period is summarized in Table 5.5. While temperatures are comparable, mean monthly temperature was slightly cooler at Old Sams River. This may be attributed to the higher altitude and more inland location of the Old Sams River station.

TABLE 5.5 MEAN MONTHLY TEMPERATURE (°C) AT OLD SAMS RIVER AND ST. SHOTTS, STUDY PERIOD, 1978

	Old Sams River	St. Shotts*
May (20-31)	4.0	4.6
June	8.9	8.7
July	12.8	13.1
August (1-10)	14.1	15.1

* Environment Canada (1978)

Monthly precipitation for Old Sams River and St. Shotts are summarized in Table 5.6. With the exception of June, when Old Sams River recorded 46.9% more precipitation than St. Shotts, the two stations received very similar amounts of precipitation. Correlation and bivariate linear regression analyses between data collected at the two stations were carried out in Section 4.1.2. The slope of the regression equation is 1.23 (Old Sams River being the dependent variable), and is indicative of the higher amounts of rainfall recorded at Old Sams River in June. The y-intercept is extremely close to the origin at -0.001.

Following the argument presented for temperature, it is postulated that as at St. Shotts, Old Sams River experienced slightly below normal precipitation in May. Quite dry conditions prevailed through July and August. However, it is apparent that the Old Sams River experienced above normal precipitation, much greater than at St. Shotts, in the month of June. Following a similar argument to that presented for temperature, it is suggested that with the exception of February, precipitation was well above normal from January to the beginning of the study period.

While a statistically significant relationship between discharge data collected at Northwest Brook and Old Sams River was established in Section 4.1.1 (Figure 4.1), error limits are quite large. Given the differences in drainage area and basin characteristics described in Chapter 3, disparities in discharge are not unexpected. However, the proximity of these two catchments and the demonstrated relationship of meteorologic factors suggests that it is not unreasonable to discuss

TABLE 5.6 MONTHLY PRECIPITATION (*mm*) AT OLD SAMS RIVER AND ST. SHOTTS, STUDY PERIOD, 1978

	Old Sams River	St. Shotts*
May (20-31)	17.8	18.1
June	177.2	120.6
July	60.5	60.0
August (1-11)	12.7	10.7

* Environment Canada (1978)

inter-basin similarities in seasonal discharge.

Table 5.7 summarizes mean monthly stream discharge for Old Sams River and Northwest Brook during the study period. While discharge in July and August are comparable, in May and June, discharge is substantially less at Old Sams River. As discussed below in Section 5.3, this difference may be attributed to consistent error in measurement, or it may have resulted from the use of estimated data for the period June 10 to June 18. However, as these basins did experience comparable meteorological conditions during the study period, discharge differences may also be attributed to differences in physical characteristics. On this basis it is argued that in terms of seasonal representativeness, Old Sams River experienced similar broad-scale patterns and magnitudes of discharge during the study period. Thus, it is suggested that, as at Northwest Brook, Old Sams River experienced unusually high discharge in May and June, with July and August well below normal. It is also suggested that with the exception of low flows in February, discharge was above normal from January to the beginning of the study period.

5.1.4 Summary

From the evaluation of seasonal hydroclimatogical representativeness above, it is concluded that the study period experienced a range of hydrometeorological conditions. All three catchments underwent a transition from warm (except Northeast Pond River which was slightly cooler than normal) and wet hydrometeorological conditions in winter and spring, to much drier than normal conditions in July and August. These catchments experience similar hydrometeorological conditions owing to similarities in the hydroclimatology of the Avalon Peninsula.

TABLE 5.7 MEAN MONTHLY STREAM DISCHARGE ($\ell\ sec^{-1}\ km^{-2}$) AT OLD SAMS RIVER AND NORTHWEST BROOK, STUDY PERIOD, 1978

	Old Sams River	Northwest Brook*
May (19-31)	24.1	32.0
June	47.6	65.9
July	16.1	17.1
August (1-3)	15.2	12.2

* Environment Canada (1978)

However, inter-basin comparisons indicate that the Avalon Peninsula does experience locally diverse hydrometeorological conditions.

5.2 ANALYSIS OF DAILY HYDROMETEOROLOGICAL DATA FOR THE STUDY PERIOD

5.2.1 Temperature

The maximum, minimum, and mean daily air temperatures recorded during the study period at Old Sams River, St. Shotts, and St. John's A are summarized in Table 5.8. As noted in Sections 5.1.1 and 5.1.3, owing primarily to their proximity, Old Sams River and St. Shotts experienced comparable temperatures during the study period. However, mean daily temperature is slightly cooler at Old Sams River. St. John's is substantially warmer than the other two stations; in the extreme case it was 2.8 C° warmer in the month of July. This is despite the fact that July and August temperatures were only near normal at St. John's (Table 5.3), but substantially warmer than normal at St. Shotts and Old Sams River (Table 5.1).

On July 21, temperatures reached as high as 26.3 °C in St. John's (Table 5.8). Maximum temperatures were much less at St. Shotts and Old Sams River, where extremes for the study period were 20.0 °C and 21.3 °C, respectively (Table 5.8).

The mean daily range of temperature at St. John's was much greater than at St. Shotts and Old Sams River (Table 5.9). St. Shotts experienced the smallest range of daily temperature. This was probably a result of the moderating maritime influences of the nearby Atlantic Ocean. The daily range of temperature was similarly moderated at Old Sams River, but its location 12 *km* inland made it less so.

TABLE 5.8 MAXIMUM, MINIMUM, AND MEAN DAILY TEMPERATURE (°C),* OLD SAMS RIVER, ST. SHOTTS,** AND ST. JOHN'S A,** STUDY PERIOD, 1978

Date	Old Sams River			St. Shotts			St. John's A		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
May 20	8.0	-1.1***	3.5	11.1	2.8	7.0	5.1	-1.5	1.8
May 21	7.5	0.7	4.1	7.8	-0.6	3.6	6.5	-1.8	2.4
May 22	6.5	1.0	3.8	6.7	2.8	4.8	9.3	2.7	6.0
May 23	5.7	-0.8	3.3	6.7	2.8	4.8	9.7	-0.7	4.5
May 24	6.3	-1.0	2.7	6.1	1.7	3.9	10.4	-1.4	4.5
May 25	10.2	0.8	5.5	8.3	1.7	5.0	16.1	0.2	8.2
May 26	10.0	-1.1	4.5	7.8	1.7	4.8	5.9	-1.3	2.3
May 27	6.1	2.7	4.4	6.7	-1.7	2.5	8.9	-1.2	3.9
May 28	5.9	0.1	3.0	6.7	3.9	4.8	5.0	-0.3	2.4
May 29	6.3	1.3	3.8	6.1	-0.6	2.8	3.4	-0.6	1.4
May 30	11.1	1.1	6.1	11.1	2.2	6.7	10.0	0.8	5.4
May 31	6.3	1.3	3.8	7.2	1.7	4.5	6.3	0.7	3.5
Mean (May 20-31)	7.5	0.4	4.0	7.7	1.5	4.6	8.1	-0.4	3.9

* Time of observation, 08:00 *hrs* NST

** Environment Canada (1978)

*** Extreme value for month underlined

TABLE 5.8 MAXIMUM, MINIMUM, AND MEAN DAILY TEMPERATURE (°C),* OLD SAMS RIVER, ST. SHOTTS,** AND ST. JOHN'S A,** STUDY PERIOD 1978 (cont'd)

Date	Old Sams River			St. Shotts			St. John's A		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
June 1	6.8	0.0	3.4	8.3	1.7	5.0	12.4	0.3	6.4
June 2	9.3	-2.1	3.6	8.9	1.7	5.3	4.4	-0.7	1.9
June 3	8.2†	2.0	5.1	8.3	-2.2	3.1	14.3	-0.8	6.8
June 4	10.6	6.4	5.7	8.9	2.8	5.9	15.1	6.6	10.9
June 5	7.0	0.8†	3.9	8.9	5.6	7.3	6.8	0.7	3.8
June 6	7.6	3.5†	5.6	7.8	1.7	4.8	4.3	0.6	10.1
June 7	10.4	-1.9†	4.3	7.2	3.3	5.3	14.8	1.8	8.3
June 8	7.5	3.3	5.4	6.7	1.7	4.2	17.1	3.0	10.1
June 9	10.6	5.8	8.2	10.6	5.0	7.8	15.9	6.9	11.4
June 10	10.0	3.1	6.6	8.3	6.7	7.5	16.2	5.0	10.6
June 11	--	--	(6.7)††	8.9	4.4	1.7	14.6	4.2	9.4
June 12	--	--	(7.7)	11.1	4.4	7.8	18.4	6.9	12.7
June 13	14.0†	--	(9.3)	12.8	6.1	9.5	23.4	8.3	15.9
June 14	14.1†	10.3†	12.2	12.2	8.9	10.6	25.2	13.4	19.3
June 15	--	--	(9.3)	10.6	8.3	9.5	15.7	7.2	11.5
June 16	--	--	(8.3)	10.6	6.1	8.4	16.0	4.2	10.1
June 17	--	--	(7.4)	15.0	0.0	7.5	9.9	1.6	5.8
June 18	16.1†	7.9†	12.0	13.9	1.7	7.8	11.4	1.6	6.5
June 19	16.8	7.1	12.0	15.0	7.8	11.4	24.8	7.8	16.3
June 20	15.0	9.2	12.1	14.4	6.7	10.6	22.0	12.4	17.2
June 21	16.5	10.6	13.6	16.7	10.0	13.4	25.7	10.8	18.3

† Some missing data
†† Bracketed values estimated from bivariate linear regression equation in Figure 4.3

TABLE 5.8 MAXIMUM, MINIMUM, AND MEAN DAILY TEMPERATURE (°C),* OLD SAMS RIVER, ST. SHOTTS,** AND ST. JOHN'S A,** STUDY PERIOD 1978 (cont'd)

Date	Old Sams River			St. Shotts			St. John's A		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
June 22	14.0	8.8	11.4	13.3	7.2	10.3	24.7	12.2	18.5
June 23	14.2	10.9	12.6	12.8	11.1	12.0	22.7	12.5	17.6
June 24	15.6	10.6	13.1	14.4	10.6	12.5	24.7	15.7	20.2
June 25	16.5	8.7	12.6	13.9	9.4	11.7	23.7	11.6	17.7
June 26	16.3	5.6	11.0	13.3	8.3	10.8	24.9	10.6	17.8
June 27	18.5	8.0	13.3	14.4	6.7	10.6	25.7	13.0	19.4
June 28	14.7	12.2	13.5	13.9	9.4	11.7	21.8	14.6	18.2
June 29	14.2	7.0	10.6	13.9	10.0	12.0	21.7	10.0	15.9
June 30	10.6	4.1	7.4	11.1	8.3	9.7	17.6	7.5	12.6
Mean (June)	M	M	8.9†	11.5	5.8	8.7	17.9	7.0	12.5
July 1	12.5	5.4	9.0	12.8	4.4	8.6	12.9	7.0	10.0
July 2	18.4	7.6	13.0	17.8	10.0	13.9	18.4	10.4	14.4
July 3	12.8	6.2	9.5	13.9	9.4	11.7	16.3	9.0	12.7
July 4	14.8	2.7	8.8	13.3	8.9	11.1	13.6	6.8	10.2
July 5	13.7	7.4	10.6	14.4	4.4	9.4	16.4	7.4	11.9
July 6	9.5	6.9	8.2	12.8	8.3	10.6	9.0	7.5	8.3
July 7	12.2	2.8	7.5	12.2	8.3	10.3	18.7	7.8	13.3
July 8	12.6	8.8	10.7	14.4	6.7	10.6	21.2	8.5	14.9
July 9	15.7	10.0	12.9	13.3	10.0	11.7	22.6	13.1	17.9
July 10	19.8	11.4	15.6	16.1	10.0	13.1	23.6	13.9	18.8
July 11	16.5	13.4	15.0	16.1	11.1	13.6	24.6	15.1	19.9
July 12	16.5	9.4	13.0	15.6	12.2	13.9	22.0	13.6	17.8

TABLE 5.8 MAXIMUM, MINIMUM, AND MEAN DAILY TEMPERATURE (°C),* OLD SAMS RIVER, ST. SHOTTS,** AND ST. JOHN'S A,** STUDY PERIOD 1978 (cont'd)

Date	OLD SAMS RIVER			St. Shotts			St. John's A		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
July 13	16.9	7.6	17.3	15.6	10.0	12.8	21.7	12.3	17.0
July 14	16.8	9.5	13.2	16.7	9.4	13.1	24.2	11.8	18.0
July 15	19.0	10.2	14.6	16.7	11.1	13.9	25.1	10.1	17.6
July 16	21.3	8.7	15.0	17.8	11.7	14.8	18.9	9.4	14.2
July 17	17.7	11.0	14.4	17.2	9.4	13.3	18.1	10.6	14.4
July 18	16.6	11.2	13.9	17.8	12.2	15.0	22.7	11.1	16.9
July 19	16.3	9.1	12.7	16.1	12.8	14.5	21.5	12.8	17.2
July 20	20.9	6.9	13.9	20.0	10.0	15.0	26.2	12.1	19.2
July 21	15.2	12.5	13.9	15.6	10.0	12.8	26.3	14.0	20.2
July 22	17.6	10.0	13.8	20.0	11.7	15.9	18.8	7.7	13.3
July 23	17.9	12.0	15.0	16.1	11.7	13.9	24.7	9.4	17.1
July 24	13.1	7.0	10.1	15.0	12.2	13.6	15.2	7.8	11.5
July 25	18.4	5.1	11.8	16.1	8.9	12.5	17.2	6.8	12.0
July 26	18.5	10.2	14.4	16.1	5.6	10.9	23.9	9.2	16.6
July 27	20.1	8.6	14.4	18.9	10.0	14.5	23.8	12.6	18.2
July 28	19.4	12.0	15.7	16.7	10.6	13.7	24.2	11.8	18.0
July 29	16.9	13.0	15.0	16.7	12.8	14.8	22.1	13.6	18.9
July 30	16.5	12.9	14.7	18.9	14.4	16.7	24.5	13.0	18.9
July 31	17.5	8.3	12.9	17.8	12.8	15.3	21.6	6.1	13.9
Mean (July)	16.5	9.0	12.8	16.1	10.0	13.1	20.7	10.4	15.6
August 1	17.9	9.0	13.5	17.8	10.0	13.9	17.6	3.8	10.7
August 2	16.0	11.9	14.0	16.1	11.7	13.9	18.9	10.8	13.9
August 3	19.4	7.4	13.4	20.0	13.3	16.7	20.7	12.1	16.4

TABLE 5.8 MAXIMUM, MINIMUM, AND MEAN DAILY TEMPERATURE (°C),* OLD SAMS RIVER, ST. SHOTTS,** AND ST. JOHN'S A,** STUDY PERIOD 1978 (cont'd)

Date	Old Sams River			St. Shotts			St. John's A		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
August 4	16.0	13.9	15.0	16.7	12.2	14.5	23.4	13.0	18.2
August 5	18.0	9.5	13.8	17.2	13.9	15.6	24.5	13.9	19.2
August 6	20.1	13.8	17.0	18.9	11.7	15.3	25.6	11.5	18.6
August 7	18.8	6.9	12.9	16.7	13.8	15.3	24.4	10.1	17.3
August 8	16.1	9.8	13.0	16.7	13.9	15.3	21.7	9.7	15.7
August 9	17.7	10.1	13.9	18.3	11.7	15.0	23.9	11.1	17.5
August 10	16.3	15.5	14.9	17.2	13.9	15.6	25.1	14.5	19.8
Mean (August 1-10)	17.6	12.6	15.1	17.6	10.6	14.1	22.6	11.1	16.9

TABLE 5.9 MEAN DAILY RANGE OF MAXIMUM AND MINIMUM TEMPERATURES (C°)*

	Old Sams River	St. Shotts	St. John's A
May 20-31	12.2	12.8	17.9
June	M**	18.9	26.5
July	18.6	15.6	20.2
August 1-10	13.2	10.0	21.8

* Derived from Table 5.8

** M represents missing data

St. John's is sheltered from the prevailing southwest to westerly spring and summer winds, whereas St. Shotts and Old Sams River experience these winds directly off the sea, frequently bringing seasonally cool maritime conditions.

5.2.2 Precipitation

As discussed in Section 5.1.3, there is a statistically significant correlation between daily precipitation at Old Sams River and St. Shotts. However, the daily record reveals a considerable amount of variation among these two stations and St. John's (Table 5.10).

Table 5.11 lists the number of days with measureable precipitation recorded at each station. Measureable precipitation was observed on 64% of the days at Old Sams River, but on only 43% of the days at St. Shotts. There is some concern that this difference may be a result of the use of different types of precipitation gauges. However, the Canadian standard gauge used at St. Shotts is sensitive to 0.2 mm (Environment Canada, 1982); the Sangamo tipping-bucket rain gauge used at Old Sams River has the same sensitivity. The different catch characteristics of the two gauges and possible differences in exposure and site location may also account for the observed difference in the frequency of precipitation. However, it is more likely that this difference is primarily attributable to the phenomenon noted by Banfield (1981; 1983), whereby conditions of low cloud cover at coastal locations are accompanied by fog and drizzle in upland catchments further inland (see Section 3.5.1.3).

Further analysis suggests that differences in recorded precipitation

TABLE 5.10 DAILY PRECIPITATION (*mm*),* OLD SAMS RIVER, ST. SHOTTS,** AND ST. JOHN'S A,** STUDY PERIOD, 1978

Date	Old Sams River	St. Shotts	St. John's A
May 20	0.4	T***	2.2
May 21	0.2	2.3	T
May 22	0.0	0.0	0.3
May 23	0.0	0.0	T
May 24	0.0	0.0	0.0
May 25	3.4	0.0	2.8
May 26	0.2	0.0	0.0
May 27	1.4	8.9	0.2
May 28	6.2	0.8	16.4
May 29	5.8	6.1	5.8
May 30	0.2	0.0	0.6
May 31	0.0	0.0	0.4
Total (May 20-31)	17.8	18.1	28.7
June 1	0.0	0.0	T
June 2	0.0	0.0	0.0
June 3	0.4	0.0	0.0
June 4	9.6	7.9	9.2
June 5	8.0	10.9	0.2
June 6	0.0	0.0	0.2
June 7	0.0	0.0	0.0
June 8	0.0	0.0	0.0
June 9	91.4	65.5	14.5
June 10	13.0	9.9	4.2
June 11	0.0	0.0	0.0
June 12	0.0	0.0	0.0
June 13	0.2	0.0	0.0
June 14	13.4	14.0	T
June 15	2.8	2.8	8.8
June 16	0.0	0.0	0.0
June 17	0.0	0.0	0.0
June 18	0.0	0.0	0.0
June 19	0.2	0.0	0.0
June 20	1.6	2.0	T
June 21	0.4	T	0.0
June 22	6.8	0.0	0.6
June 23	7.6	1.5	1.6
June 24	6.4	4.6	5.1
June 25	0.0	0.0	T
June 26	0.0	0.0	0.0

* Time of observation, 08:00 *hrs* NST
** Environment Canada (1978)
*** T represents trace

TABLE 5.10 DAILY PRECIPITATION (*mm*),* OLD SAMS RIVER, ST. SHOTTS,** AND ST. JOHN'S A,** STUDY PERIOD, 1978 (cont'd)

Date	Old Sams River	St. Shotts	St. John's
June 27	0.0	0.0	0.0
June 28	13.6	0.0	9.9
June 29	1.6	1.5	2.9
June 30	0.2	0.0	0.0
Total (June)	177.2	120.6	57.2
July 1	0.4	T	0.0
July 2	0.6	0.8	0.0
July 3	0.0	0.0	0.0
July 4	0.2	0.0	3.2
July 5	8.2	6.4	26.3
July 6	2.4	2.3	0.0
July 7	0.2	T	0.0
July 8	0.2	0.0	0.0
July 9	0.2	1.0	0.0
July 10	0.2	T	0.0
July 11	3.6	2.0	0.0
July 12	0.4	T	2.0
July 13	0.0	0.0	0.0
July 14	0.2	0.0	0.0
July 15	0.0	0.0	0.0
July 16	0.0	0.0	0.0
July 17	12.6	24.6	T
July 18	9.4	1.5	13.2
July 19	0.0	0.0	T
July 20	0.0	0.0	0.0
July 21	3.8	3.8	0.5
July 22	0.2	0.0	T
July 23	5.8	8.9	1.0
July 24	1.8	0.5	16.5
July 25	0.0	0.0	T
July 26	0.0	0.0	0.0
July 27	0.2	0.0	0.0
July 28	0.6	0.8	0.0
July 29	0.2	T	2.0
July 30	(9.1)†	7.4	20.2
July 31	(0.0)	0.0	0.0
Total (July)	(60.5)	60.0	84.9

† Bracketed values estimated from regression equation in Figure 4.2, or in the case of totals, includes some estimated data

TABLE 5.10 DAILY PRECIPITATION (*mm*),* OLD SAMS RIVER, ST. SHOTTS,** AND ST. JOHN'S A,** STUDY PERIOD, 1978 (cont'd)

Date	Old Sams River	St. Shotts	St. John's A
August 1	(0.0)	0.0	0.0
August 2	(8.1)	6.6	12.2
August 3	0.2	0.0	2.0
August 4	4.0	3.6	2.2
August 5	0.2	0.0	T
August 6	0.2	0.5	0.0
August 7	0.0	0.0	1.0
August 8	0.0	0.0	0.0
August 9	1.8	0.0	0.0
August 10	0.0	0.0	0.0
August 11	0.0	0.0	0.0
Total (August 1-11)	(14.5)	10.7	17.4

TABLE 5.11 DAYS WITH MEASURABLE PRECIPITATION, OLD SAMS RIVER, ST. SHOTTS, AND ST. JOHN'S A, STUDY PERIOD, 1978*

	Old Sams River	St. Shotts	St. John's A
May 20-31	8	5	10
June	17	11	15
July	22	17	14
August 1-11	6	3	5
Total	53	36	44
Percent	64	43	53

* Derived from Table 5.10.

are real and did not arise as a result of instrumental error. In particular, during the month of June, the Old Sams River received 56.6 *mm* more precipitation than St. Shotts (Table 5.10). During a number of discrete events, Old Sams River received substantially more precipitation: on May 25, June 9-10, June 22-24, and June 28 (Table 5.10). In fact, on May 25, June 22, and June 28, substantial precipitation was received at Old Sams River with no concomitant rainfall recorded at St. Shotts. Banfield and Barnes (in preparation) have noted that during the three events in June, very similar synoptic conditions prevailed, whereby warm sectors with southwesterly airflow from the Atlantic Ocean were accompanied by high relative humidity and temperature. At the same time, potential instability was noted in the analyses of upper air at St. John's. Such conditions can give rise to orographic enhancement of precipitation which occurs when an air mass is forced up over an upland terrain such as that found in the St. Shotts area.

Further study of this phenomenon is warranted. The excess of runoff over precipitation noted in Section 3.5.2.1 for several Avalon Peninsula drainage basins is probably attributable at least in part to widespread orographic influence in the region. The lack of satisfactory precipitation network in upland areas has given rise to this anomaly.

The difference in precipitation between St. Shotts and Old Sams River on May 27 and 28 (Table 5.10) can be attributed to spatial and temporal variations between them. The Old Sams River continuous record shows that the main portion of the event occurred there immediately after the time of observation (08:00 *hrs* NST) at St. Shotts.

As Noted in Section 5.1.2, precipitation at St. John's was very low in May and moderately low in June. However, in late May, St. John's was wetter than the two southern stations by virtue of one major precipitation event on May 28 (Table 5.10). In June, St. John's received only 47% of that recorded at Old Sams River. Unlike the dry July experienced at the two southern stations, precipitation at St. John's was 42% greater and slightly above normal for that month.

It would appear from storms recorded on May 28, June 9-10, June 22-24, July 5-6, July 24, and July 30 (Table 5.10), that in both amount and timing, precipitation at St. John's is not always consistent with that recorded at Old Sams River and St. Shotts. While St. John's appears to be affected by the same general weather patterns, it is in the rainshadow of the southern Avalon Peninsula during the southwesterly airflow which prevails in spring and summer (Banfield and Barnes, in preparation). This is particularly evident in the major event of the study period, June 9-10, when Old Sams River received 6.25 times more precipitation than St. John's (Table 5.10). A reciprocal condition can occur in winter, when the Avalon Peninsula often receives severe storms from northern and eastern points (Banfield 1981; 1983).

5.2.3 Relative Humidity

As summarized in Appendix D, relative humidity recorded during the study period at Old Sams River was frequently high. On fine days, however relative humidity dropped significantly in the diurnal pattern typical for Newfoundland (Banfield 1981; 1983). On such occasions, it fell from an overnight high at or close to 100% to as low as

50% to 70% by mid-afternoon. The lowest relative humidity was recorded at 17:00 *hrs* on June 2, when it fell to 49%. Following this mid-day low, relative humidity rose sharply to about 100%. Typically, it remained between 90% and 100% overnight.

During the study period, moist conditions were common. Relative humidity often remained above 90% for days. On one occasion, it remained above 90% for a period in excess of 5 days, from 21:00 *hrs* NST, June 19, to 9:00 *hrs* NST, June 25.

A review of relative humidity data in Appendix D reveals a close inverse relationship between relative humidity and temperature. This relationship is a reflection of the temperature dependence of relative humidity, and follows the distinct diurnal pattern of temperature.

5.2.4 <u>Evaporation</u>

Summarized in Appendix F, pan evaporation totalled 81.46 *mm* at Old Sams River for the one month observation period between July 3 and August 3. Pan evaporation exceeded precipitation for the same period (67.8 *mm*) by 20%. Monthly "Class A" pan evaporation recorded at St. John's A for July (offset by 3 days) was 89.5 *mm* (Environmental Canada, 1978). This is slightly greater, but it is a comparable amount. As noted in Section 5.2.1,mean daily temperature was 2.8 C° warmer at St. John's than at Old Sams River in July. The greater amount of pan evaporation at St. John's may be attributed to this difference.

It is recognized that relative humidity and wind are also major factors in determining the rate of evaporation. The slight difference in pan evaporation between stations is not necessarily attributable solely to higher temperature. Relative humidity was very high at Old Sams River, whereas given the warmer conditions experienced there, St. John's probably experienced lower relative humidity.

During the study period, it was observed that on clear days with concomitant low relative humidity, wind was frequently high and onshore in direction. It appears that a mid-day onshore wind occurs here with regularity. This land-sea breeze phenomenon was described by Banfield (1981; 1983) for coastal areas on the Island of Newfoundland. Its existence in the Old Sams River area may explain why despite substantially cooler temperatures in July, only slightly less pan evaporation was observed there than at St. John's.

5.2.5 Bog Water Table

The mean, standard deviation, and number of observations for each bog water table well, including predicted missing data are summarized in Table 5.12. Mean bog water table depth for the duration of the study period ranged from 4.2 *cm* at well number 2, to 18.4 *cm* at well number 9. The standard deviation varied from 1.9 *cm*, also at well 2, to 3.7 *cm* at well 12. These data indicate a surprisingly small amount of variation given the range of hydrometeorologic conditions experienced during the study period. The mean range of water table depths for all wells throughout the observation period was 11.2 *cm*, and the mean maximum and minimum depths were 16.2 and 5.6 *cm*, respectively.

For all wells, the maximum water table depth for the study period was recorded on July 17. On the following day the maximum temperature was 21.3 °C, the warmest temperature recorded during the study period.

TABLE 5.12 MEAN DEPTH OF BOG WATER TABLE DURING STUDY PERIOD*

Well Number	Mean Depth (cm)	Standard Deviation (cm)	Number of Observations	Maximum (cm)	Minimum (cm)	Range (cm)
1	9.2	2.9	18	16.9	5.1	11.8
2	4.2	1.9	18	9.3	1.7	7.6
3	4.7	2.3	18	11.1	1.5	9.6
4	9.1	2.8	18	16.8	4.1	12.7
5	8.5	2.6	18	15.5	4.7	10.8
6	6.1	2.6	18	13.6	2.3	11.3
7	10.7	2.7	18	18.1	6.9	11.2
8	6.8	3.0	18	15.4	2.9	12.5
9	18.4	3.4	18	27.9	13.0	14.9
10	6.4	2.2	18	13.4	4.5	8.9
11	10.1	2.8	18	16.9	5.0	11.1
12	11.7	3.7	18	20.3	5.6	14.7
12A	8.0	2.8	18	16.0	4.3	11.7
12B	7.2	2.6	18	14.3	3.5	10.8
12C	14.7	2.6	18	22.4	11.7	10.7
12D	5.9	2.4	18	12.7	3.1	9.6
13	7.6	2.5	18	14.6	5.0	9.6
14	14.7	3.1	18	23.3	11.6	11.7
15	11.8	2.6	18	19.7	9.1	10.6
Mean	9.3			16.2	5.6	11.2
Standard deviation				5.6	3.4	1.8

* Derived from Table E.3, Appendix E; includes some predicted values

Only 0.6 *mm* of rainfall was received during the previous five days. Given that the month of July was much warmer and drier than normal (Section 5.1.3), the maximum water table depths recorded during the study period were remarkably shallow.

The deepest water table depth, 27.9 *cm*, was observed on July 17 at well number 9 (Appendix E, Table E.1). This was the only occasion when the water table depth dropped below the critical 25 *cm* depth (see Section 1.2.4) identified by Robertson, et al. (1968).

The shallowest water table depth recorded during the study period was 1.5 *cm*, recorded on June 23 at well number 3 (Table E.1, Appendix E). Given that observations were manual and were not made during inclement weather, particularly during rainstorms, it is expected that water table may have approached or even exceeded the bog surface level on some occasions.

The bivariate linear regression model derived in Section 4.1.4 to estimate daily basin water table depth from daily stream discharge (Table E.4, Appendix E) may be a useful tool for estimating missing water table data. Using this model, a daily discharge amount in excess of 137.9 $\ell\ sec^{-1}$ yields a negative water table depth. This is not unreasonable as the water table can often rise above the surface in bogs. However, the slope of the equation would change at this point because the water table could not rise a great deal above the surface without rainfall running off as if it had been intercepted by a sloping impervious surface. Below 137.9 $\ell\ sec^{-1}$, the model is useful in predicting the overall basin bog water table within ±3.84 *cm* at the

95.5 percent level of confidence (±2 SEE y). In future, it would be useful to determine the relationship between bog water table and discharge above the critical 137.9 $\ell\ sec^{-1}$ discharge.

Assuming that predicted water table depths were equal to zero when discharge was greater than 137.9 $\ell\ sec^{-1} km^{-2}$, the range of mean basin water table depth during the study period was only 16.2 *cm*, 5.0 *cm* greater than the mean range of water table depths actually observed (Table 5.12). This re-emphasizes the small range of water table fluctuations observed, despite the warmer and drier than normal conditions experienced during the study period.

The period of 34 days from June 13 until July 17 underwent a transition from the highest to the lowest water table depths observed (Table E.4, Appendix E). The net rate of water table decline in this period was 4.9 $mm\ day^{-1}$. During the very dry five-day period preceeding July 17, when only 0.6 *cm* of rain fell, actual observed mean basin water table dropped from 9.0 *cm* to 16.7 *cm* below the surface, a rate of 15.4 $mm\ day^{-1}$ (Table E.4, Appendix E).

5.3 ANALYSIS OF DAILY RUNOFF DATA FOR THE STUDY PERIOD

Daily runoff, precipitation, temperature, and bog water table depth for the Old Sams River are summarized for the study period in Figure 5.1. These runoff data are compared with that record for Northwest Brook and Northeast Pond River in Table 5.13. Daily runoff at Northwest Brook is presented in Figure 5.2, along with daily precipitation at Old Sams River, the closest station with a continuous record for the study period. Daily runoff at Northeast Pond River, and

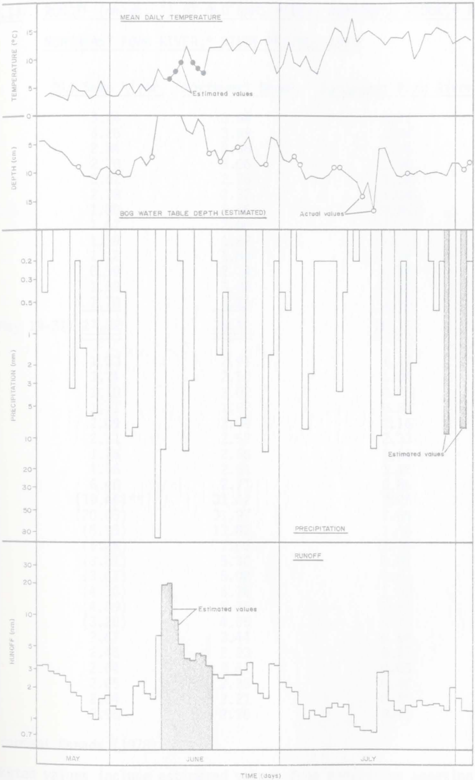

FIGURE 5.1 DAILY RUNOFF AND PRECIPITATION, MEAN DAILY TEMPERATURE, AND DAILY BOG WATER TABLE DEPTH, OLD SAMS RIVER

TABLE 5.13 RUNOFF (*mm day*$^{-1}$) AT OLD SAMS RIVER, NORTHWEST BROOK,* AND NORTHEAST POND RIVER,* STUDY PERIOD, 1978

Date	Old Sams River	Northwest Brook	Northeast Pond River
May 19	3.24	3.84	3.71
May 20	3.28	3.69	3.54
May 21	2.84	3.38	2.94
May 22	2.70	3.06	1.90
May 23	2.62	2.76	1.38
May 24	2.28	2.37	1.04
May 25	1.80	2.06	0.86
May 26	1.67	2.00	0.81
May 27	1.19	1.82	0.73
May 28	1.12	1.89	1.38
May 29	0.99	2.38	2.94
May 30	1.59	3.03	2.76
May 31	1.70	3.21	2.16
Total (May 19-31)	27.02	35.49	26.15
June 1	1.33	2.91	1.47
June 2	1.24	2.50	1.04
June 3	1.10	2.07	0.86
June 4	1.11	1.92	0.81
June 5	2.09	2.09	2.16
June 6	2.31	2.52	2.33
June 7	1.76	2.66	1.64
June 8	1.55	2.51	1.12
June 9	6.40	2.71	0.86
June 10	(19.44)**	31.02	2.25
June 11	(20.05)	31.97	2.85
June 12	(8.95)	13.82	1.56
June 13	(5.24)	7.66	1.04
June 14	(3.81)	5.30	0.81
June 15	(3.67)	5.08	0.95
June 16	(4.30)	6.26	1.12
June 17	(4.09)	5.76	0.95
June 18	(3.20)	4.35	0.73
June 19	2.67	3.44	0.64
June 20	2.45	2.93	0.57
June 21	2.64	2.61	0.53
June 22	2.65	2.38	0.48
June 23	2.64	2.21	0.43
June 24	2.95	2.26	0.43

* Environment Canada (1978)

** Bracketed values include estimated values from regression equation in Figure 4.1, or in the case of totals, includes estimated data

TABLE 5.13 RUNOFF (*mm day*$^{-1}$) AT OLD SAMS RIVER, NORTHWEST BROOK,* AND NORTHEAST POND RIVER,* STUDY PERIOD, 1978 (cont'd)

Date	Old Sams River	Northwest Brook	Northeast Pond River
June 25	3.44	3.35	0.43
June 26	2.16	4.10	0.38
June 27	1.75	3.61	0.35
June 28	1.56	2.95	0.34
June 29	3.39	2.64	0.38
June 30	3.25	2.69	0.41
Total (June)	(123.32)	168.28	29.92
July 1	2.22	2.79	0.41
July 2	1.99	2.68	0.38
July 3	1.81	2.35	0.35
July 4	1.37	2.09	0.34
July 5	0.99	1.92	0.31
July 6	1.20	1.80	0.48
July 7	1.07	1.77	2.59
July 8	1.02	1.75	1.90
July 9	1.26	1.71	1.04
July 10	1.40	1.65	0.73
July 11	1.28	1.55	0.62
July 12	1.36	1.49	0.57
July 13	1.08	1.41	0.48
July 14	0.83	1.29	0.41
July 15	0.77	1.18	0.35
July 16	0.77	1.11	0.34
July 17	0.73	1.03	0.29
July 18	2.76	1.24	0.34
July 19	2.81	1.65	0.34
July 20	1.47	1.62	0.34
July 21	1.19	1.47	0.34
July 22	1.13	1.38	0.31
July 23	1.32	1.24	0.29
July 24	1.29	1.18	0.29
July 25	1.48	1.09	0.31
July 26	1.31	0.98	0.29
July 27	1.35	0.88	0.29
July 28	1.39	0.84	0.26
July 29	1.32	0.80	0.24
July 30	1.18	0.83	0.31
July 31	1.96	1.06	0.54
Total (July)	43.11	45.83	16.08

TABLE 5.13 RUNOFF (*mm day*$^{-1}$) AT OLD SAMS RIVER, NORTHWEST BROOK,* AND NORTHEAST POND RIVER,* STUDY PERIOD, 1978 (cont'd)

Date	Old Sams River	Northwest Brook	Northeast Pond River
August 1	1.56	1.11	0.60
August 2	1.19	1.02	0.50
August 3	1.18	1.00	0.54
Total (August 1-3)	3.93	3.13	1.64

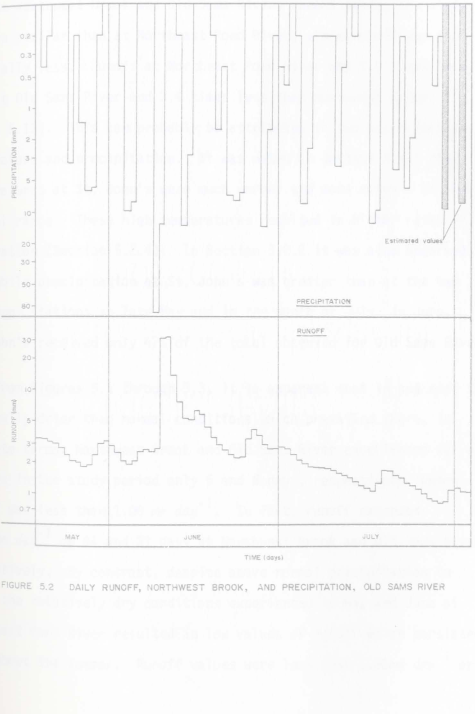

FIGURE 5.2 DAILY RUNOFF, NORTHWEST BROOK, AND PRECIPITATION, OLD SAMS RIVER

daily precipitation and temperature at St. John's A are presented in Figure 5.3. These runoff data were derived from Appendices A, G, and H, and are expressed in units of *mm* day^{-1}.

At Northwest Brook and Old Sams River, runoff during the study is more similar than at Northeast Pond River, where runoff was substantially less. Runoff at Northeast Pond River was 2.7 times less than at Old Sams River and 3.4 times less than Northwest Brook (Table 5.13). This can probably be attributed to two major factors, temperature and precipitation. It was noted in Section 5.2.1 that temperatures at St. John's were much warmer and more extreme in their diurnal range. These high temperatures resulted in higher rates of evaporation (Section 5.2.4). In Section 5.2.2 it was also observed that while precipitation at St. John's was greater than at the two southern stations in late May and in the month of July, in June, St. John's received only 47% of the total observed for Old Sams River.

From Figures 5.1 through 5.3, it is apparent that in spite of the seasonally drier than normal conditions which prevailed there, in absolute terms, Northwest Brook and Old Sams River experienced out of 76 days in the study period only 5 and 6 days, respectively, where runoff was less than 1.00 *mm* day^{-1}. In fact, runoff exceeded 2.00 *mm* day^{-1} on 44 and 31 days at Northwest Brook and Old Sams River, respectively. By contrast, despite above normal precipitation in July, the relatively dry conditions experienced in May and June at Northeast Pond River resulted in low values of runoff which persisted throughout the summer. Runoff values were less than 1.00*mm* day^{-1} or

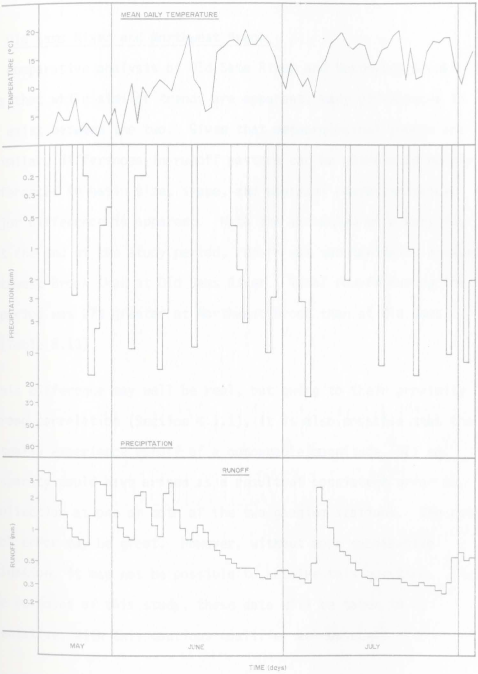

FIGURE 5.3 DAILY RUNOFF, NORTHEAST POND RIVER, AND DAILY PRECIPITATION AND MEAN DAILY TEMPERATURE, ST. JOHN'S

53 of the 76 days in the study period. Runoff exceeded 2.00 *mm day*$^{-1}$ on 11 days only.

5.3.1 Old Sams River and Northwest Brook

A comparative analysis of Old Sams River and Northwest Brook reveals that while similar trends are apparent, many differences in runoff exist between the two. Given that meteorological inputs are very similar, differences in runoff pattern can be attributed mainly to differences in basin size, shape, and physical characteristics. One major difference is apparent. With the exception of a very few days at the end of the study period, runoff was substantially greater at Northwest Brook than at Old Sams River. Total runoff during the study period was 27% greater at Northwest Brook than at Old Sams River (Table 5.13).

This difference may well be real, but owing to their proximity and strong correlation (Section 4.1.1), it is also possible that the two actually experience runoff of a comparable magnitude. If so, the disparity could have arisen as a result of consistent error in data collection at one or both of the two gauging stations. The potential for such error may be great. However, without more substantive investigation, it may not be possible to resolve this question. Thus, for the purposes of this study, these data will be taken to be representative, with this cautious qualifier acknowledged.

A major proportion of this inter-basin difference in runoff arises as a result of the June 9-10 precipitation event. At Old Sams River, missing data for the period June 10-18 were estimated using the bivariate linear regression model which is derived in section 4.1.1 (Figure 4.1). Runoff during this period was 1.48 times, or 35.3 mm, greater at Northwest Brook than estimated for the Old Sams River (Table 5.13). This accounts for 56% of the total difference in runoff between stations during the study period. However, it remains that with the exception of the last 12 days of the study period, runoff was consistently higher at Northwest Brook.

Figure 5.4 emphasizes the similarity in runoff response by representing graphically cumulative runoff from these two catchments. Until July 23, with few exceptions, cumulative daily runoff increased at a greater rate at Northwest Brook. Subsequently, cumulative daily runoff increased at a greater rate at Old Sams River. Despite these differences, the shape of the cumulative runoff curves is quite similar.

The Northwest Brook catchment, 20.9 times greater in drainage area, can be expected to experience less pronounced peaks in its hydrograph than the much smaller Old Sams River catchment. At Northwest Brook, the more gradual decrease in runoff experienced during recession through most of the study period may be a result of the greater time base of its hydrograph. Delayed contribution of antecedent moisture as base flow was not unexpected in light of the fact that as noted in Section 5.1.1, discharge there was the highest and second highest on record in the months of May and June, respectively.

At odds with the above, daily runoff at the Old Sams River exceeded that recorded at Northwest Brook on July 23, and continued to do so for the remaining 12 days of the study period. Such resilience

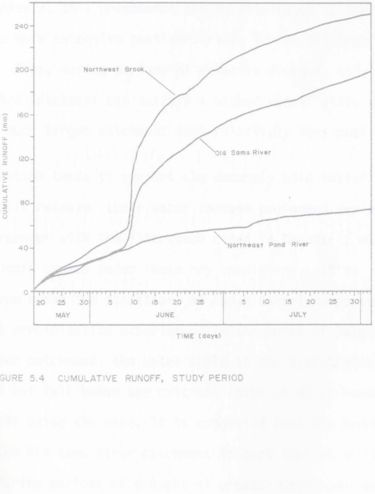

FIGURE 5.4 CUMULATIVE RUNOFF, STUDY PERIOD

in the recession curve is uncharacteristic for a small drainage basin, especially during periods of below normal precipitation and stream discharge,and high evaporation. This suggests that through unusually dry periods, despite its much smaller drainage area, the Old Sams River catchment is capable of sustaining much higher yeilds than the Northwest Brook catchment. Taking into consideration both the hydrological characteristics of peat discussed in Chapter 1 and the apparent similarities in the physical character of these two catchments outlined in Chapter 3, this phenomenon can be attributed to the influence of the more extensive peatland tracts in the Old Sams River drainage basin. Thus, during periods of relative drought, this peatland-dominated catchment can sustain a higher runoff yield than the similar but much larger catchment with relatively less peatland.

This observation tends to support the commonly held belief that peatlands gradually release their water through prolonged dry periods, and is in disagreement with the literature cited in Chapter 1 which suggests that runoff ceases under these dry conditions. It is apparent that even under the conditions of above normal temperature and below normal precipitation experienced in the month of July for the Old Sams River catchment, the water table in the hydrologically-active layer did not fall below the critical level at which runoff would cease. This being the case, it is suggested that the hydroclimatology of the Old Sams River catchment is such that at no time, except perhaps during periods of drought of greater magnitude than that experienced during the study period, does runoff cease from its peatlands. Thus, typically, the peatland of the Old Sams River catchment regulates runoff during dry periods, maintaining streamflow relatively higher than in adjacent catchments with little or no peatland.

5.3.2 Northeast Pond River

Although 1.42 times greater in drainage area than Old Sams River, and perhaps as a result of its lesser time of concentration (Section 3.2.2), Northeast Pond River demonstrated a more dramatic response in daily runoff following precipitation events (Figures 5.1 and 5.3). Between events, runoff at Northeast Pond Brook recedes to much lower levels, especially during dry periods. For example, during the relatively warm and dry period between July 7 and 17, in response to the 17.9 *mm* rainfall on July 5, runoff at Northeast Pond River declined 2.30 $mm\ day^{-1}$ from a peak of 2.59 $mm\ day^{-1}$ on July 7, to 0.29 $mm\ day^{-1}$ on July 17. At Old Sams River, despite receiving much less rainfall (Figure 5.1), runoff dropped only 0.30 $mm\ day^{-1}$ from 1.07 $mm\ day^{-1}$ on July 6, to 0.77 $mm\ day^{-1}$ on July 17. During this period, the warmest day and lowest runoff were recorded at Old Sams River.

These data also illustrated the regulation of streamflow demonstrated by Old Sams River in relatively dry periods. As discussed in Section 5.3.1, this characteristic can be attributed to the hydrologic control exercised by its extensive tracts of peatland.

5.4 HYDROGRAPH ANALYSES

During the study period, the Old Sams River experienced ten (10) discrete events in which precipitation generated an increase in streamflow. Three of these cannot be adequately assessed due to the missing data noted in Sections 4.1.1 and 4.1.2. These events occurred on June 15, July 24, and July 30, 1978. Four of the remaining seven are subdivided further on the basis of polymodal precipitation and/or complex hydrographs which occurred at Old Sams River. At Northwest Brook, only six of these remaining seven precipitation events resulted in a streamflow response. Similarly, only six of these were large enough to generate a streamflow response at Northeast Pond River.

For the purpose of comparative analysis, for each discrete event and their respective subdivisions, several hydrograph characteristics have been derived from hourly data in the appropriate Appendices. For the assessment of antecedent streamflow conditions and streamflow response to precipitation, the pre-rise discharge and the range of discharge from pre-rise to peak discharge are included. For the characterization of hydrographs, the lag time from peak hourly precipitation to peak hourly discharge, and the lag time from the centroid of precipitation (when 50% of the total had fallen) to mid-peak discharge are also included. This latter measure is necessary in order to more accurately reflect the lag times for events which demonstrate non-dramatic streamflow response to precipitation. For example, in several instances, discharge peaked and remained at the same level for several hours before the hydrograph began to recede. In other cases, the temporal distribution of precipitation was often heavily skewed; the peak hourly precipitation and centroid of precipitation often occurred several hours apart.

The following sections present inter-basin comparative analyses of these hydrograph characteristics for each event. To facilitate these analyses, stream discharge is expressed as specific runoff in units of $\ell\ sec^{-1} km^{-2}$.

5.4.1 Event 1

Event 1 extended from May 28 to June 3. Figure 5.5 summarizes discharge, precipitation, temperature, and relative humidity for the Old Sams River, and compares these with discharge at Northwest Brook and Northeast Pond River, and with precipitation at St. John's. It is subdivided into two events, 1A and 1B, on the basis of the two separate precipitation events recorded at both Old Sams River and St. John's. Hydrograph characteristics for all catchments are summarized in Table 5.14. The bimodal precipitation observed did not result in a complex hydrograph at Northwest Brook. Hydrograph characteristics are not subdivided for event 1.

In event 1A (Figure 5.5 and Table 5.14) Northeast Pond River, over a similar time base, received approximately twice as much precipitation as Old Sams River. As a result, Northeast Pond River experienced a more pronounced streamflow response, with its range of discharge quadrupling that recorded for Old Sams River. However, both measures of lag time were much longer at Northeast Pond River, much more so than could be attributed to the slight differences in their respective

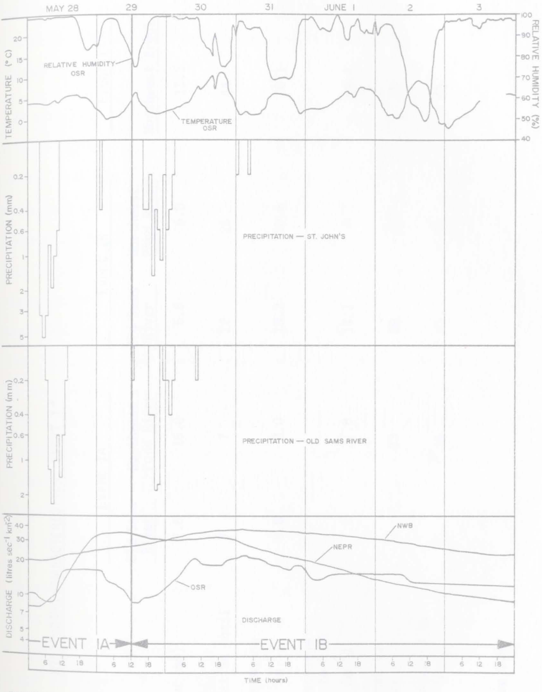

FIGURE 5.5 HYDROMETEOROLOGICAL PARAMETERS, EVENT I

TABLE 5.14 HYDROGRAPH CHARACTERISTICS, EVENT 1*

	Event 1A		Event 1B		Event 1
	Old Sams River	Northeast Pond River	Old Sams River	Northeast Pond River	Northwest Brook
Precipitaton (*mm*)	7.6	16.0	5.6	6.0	13.2
Duration of Precipitation (*hrs*)	7	7	22	25	44
Pre-rise Discharge ($\ell\ sec^{-1}\ km^{-2}$)	8.8	8.0	10.2	30.6	20.1
Range of Discharge Pre-rise to Peak ($\ell\ sec^{-1}\ km^{-2}$)	7.0	27.8	14.1	2.2	18.4
Lag Time, Peak to Peak (*hrs*)	3	23	30	21	65
Lag Time, Centroid to Mid-peak (*hrs*)	10	24	30	19	63

* See Figure 5.5

drainage areas (Table 5.14). In fact, given the physiography of these two catchments as outlined in Section 3.2, it was expected that Northeast Pond River would demonstrate a more rapid response to precipitation.

At odds with this, the Old Sams River catchment showed a relatively rapid streamflow (Figure 5.5 and Table 5.14). Prior to the event, pre-rise discharge was at a relatively low but comparable level in each catchment. On May 28, the mean bog water table depth throughout the Old Sams River catchment is estimated to have been 10.7 *cm* (Table E.4, Appendix E), slightly greater than the mean for the study period, 9.3 *cm* (Table 5.12). Given the drier than normal hydrometeorological conditions which prevailed during the study period (Section 5.1), this peatland-dominated catchment could be expected to absorb most of the moisture received during such a small precipitation event (i.e., 7.6 *mm* in 7 *hrs*). However, it is apparent that despite these drier than normal hydrometeorological conditions, the Old Sams River catchment displayed runoff characteristics typical of a wet hydrologically-active layer and demonstrated relatively rapid streamflow response to precipitation.

In event 1B, despite receiving a similar pattern and amount of precipitation, the Old Sams River catchment experienced almost twice as great a range of discharge, pre-rise to peak, than that experienced at Northeast Pond River (Figure 5.5 and Table 5.14). Antecedent moisture conditions, as indicated by precipitation (event 1A) and pre-rise discharge (event 1B), were much wetter at Northeast Pond River. Although by definition, lag times were greater at Old Sams River, these values are somewhat misleading. As can be seen in Figure 5.5, there was a decline in discharge in the rising limb of the hydrograph between 12:00 *hrs* and 21:00 *hrs* on May 30. As a consequence, peak discharge was delayed for several hours until 02:00 *hrs* on May 31. It is sufficient to say at this point that this hydrograph depression occurred as a result of an evapotranspiration-induced phenomenon which is discussed in detail in Section 5.5 below. It is postulated that without this hydrograph depression, discharge would have peaked much earlier, with lag times of similar or perhaps even shorter duration than noted at Northeast Pond River (Table 5.14). This suggestion is supported by the relatively steeper rising limb of the hydrograph observed at Old Sams River (Figure 5.5).

Despite the more pronounced and rapid streamflow response to precipitation at Old Sams River in event 1B, the rate of recession was much less there than at Northeast Pond River (Figure 5.5). From 18:00 *hrs* on June 1, discharge was less at Northeast Pond River than at Old Sams River, and continued to decrease more rapidly through June 3. Analysis of daily runoff in Section 5.3 documents this phenomenon, and suggests that the extensive tracts of peatland in the Old Sams River catchment are responsible for the regulation of streamflow and the gradual release of water through dry periods.

The simple hydrograph recorded at Northwest Brook for event 1 (Figure 5.5) offers little opportunity for comparative analysis with the complex hydrographs noted for the other two catchments. As expected from discussions in Section 3.2, lag times were from three to five times greater and the range in discharge from pre-rise to peak was much less. Pre-rise discharge was greater owing to antecedent moisture conditions and also the broader time base of its hydrographs. All of these characteristics can be attributed to the larger drainage area of the catchment.

5.4.2 Event 2

Event 2 extended from June 4 to June 8. Figure 5.6 summarizes the relevant data for the Old Sams River and compares them with that recorded for Northwest Brook and Northeast Pond River. As noted in Section 4.3.2, hourly precipitation data for St. John's are missing. However, daily totals of 9.2 *mm*, 0.2 *mm*, and 0.2 *mm* were recorded there on June 4, 5, and 6 respectively (Table 5.10).

On the basis of the complex hydrograph observed at Old Sams River, the event is subdivided into two events, 2A and 2B. Simple hydrographs were recorded at Northwest Brook and Northeast Pond River. Hydrograph characteristics for all catchments are summarized in Table 5.15. The missing precipitation data preclude complete hydrograph analysis at Northeast Pond River. For comparative purposes, hydrograph characteristics for the Old Sams River are also included as if the hydrograph was simple.

The lag times observed for both events at Old Sams River were very short, despite relatively low pre-rise discharge (Figure 5.6 and Table 5.15). However, the hydrograph peaks in both events were very much flattened, remaining at 16.6 $\ell\ sec^{-1} km^{-2}$ for six *hrs* in event 2A,

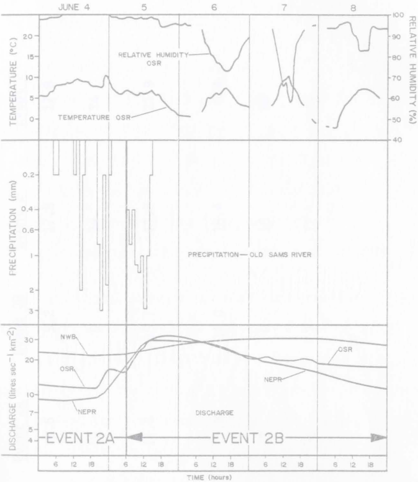

FIGURE 5.6 HYDROMETEOROLOGICAL PARAMETERS, EVENT 2

TABLE 5.15 HYDROGRAPH CHARACTERISTICS, EVENT 2*

	Old Sams River			Northwest Brook	Northeast Pond River
	Event 2A	Event 2B	Event 2	Event 2	Event 2
Precipitation (*mm*)	8.6	9.2	17.8	17.8	9.6
Duration of Precipitation (*hrs*)	19	9	34	34	M**
Pre-rise Discharge ($\ell\ sec^{-1}\ km^{-2}$)	11.3	15.7	11.3	21.9	8.8
Range of Discharge Pre-rise to Peak ($\ell\ sec^{-1}\ km^{-2}$)	5.3	14.0	18.4	9.4	23.7
Lag Time, Peak to Peak (*hrs*)	2	0	15	68	M
Lag Time, Centroid to Mid-peak (*hrs*)	4	7	12	61	M

* See Figure 5.6
** Missing data

and at 29.7 $\ell\ sec^{-1} km^{-2}$ for 16 *hrs* in event 2B.

Assuming a simple hydrograph was recorded at Old Sams River in event 2, lag times were approximately one fifth to one quarter that recorded at Northwest Brook, where peak discharge occurred two days later and the range of discharge was approximately half that recorded for the Old Sams River (Table 5.15).

Total precipitation at St. John's was only half that recorded at the Old Sams River station (Table 5.15). Unlike Old Sams River, most of the precipitation, 9.2 *mm*, fell before the time of observation, 08:00 *hrs* NST, June 5 (Table 5.10). This indicates that precipitation here was primarily limited to that recorded as event 2A at Old Sams River. Despite this, discharge did not peak until 19:00 *hrs* NST, June 5, well after the peak associated with event 2A at Old Sams River.

The range of discharge, pre-rise to peak, was greatest at Northeast Pond River, where only half the amount of precipitation received at Old Sams River fell (Table 5.15). Interpretation of this observation was difficult in the absence of hourly preciptiation data at St. John's. However, it is relevant here to consider the relative rates of recession at these two catchments. As noted in event 1B (Section 5.4.1), the rate of recession through June 7 and 8 is much less at Old Sams River. This, and the fact that a greater range of discharge, pre-rise to peak, was observed at Northeast Pond River in response to much less rainfall, suggests that although streamflow response is apparently more rapid at Old Sams River, its extensive tracts of peatland are responsible for the regulation of streamflow through relatively dry periods. Again, this notion is supported by the analysis of daily runoff in Section 5.3.

5.4.3 Event 3

Event 3 extended from June 9 through June 14. Figure 5.7 summarizes the relevant data for the Old Sams River, and compares these with discharge at Northwest Brook and Northeast Pond River, and with precipitation at St. John's. Although a substantial portion of the discharge data at Old Sams River is missing, as noted in Section 4.3.2, the hydrograph is complete until several hours past its peak. These data are subdivided into two separate events, 3A and 3B, on the basis of the two distinct precipitation events observed at both the Old Sams River and St. John's. Hydrograph characteristics are summarized in Table 5.16. A complex hydrograph was noted for the Old Sams River only. As a consequence, hydrograph characteristics for the Old Sams River are included for the subdivided events 3A and 3B, and also as if it were a simple hydrograph.

The intensive precipitation observed for event 3A at the Old Sams River resulted in a dramatic streamflow response (Figure 5.7 and Table 5.16). The lag time determined by both methods was five *hrs*. The heavy precipitation in event 3B resulted in an even more rapid streamflow response, with lag times of four *hrs* and three *hrs* for the peak to peak and centroid to mid-peak methods, respectively. When interpreted as a simple hydrograph, the lag times at Old Sams River are comparable to those determined for events 3A and 3B. The range of discharge is 246 $\ell\ sec^{-1} km^{-2}$, the same as that noted for event 3B.

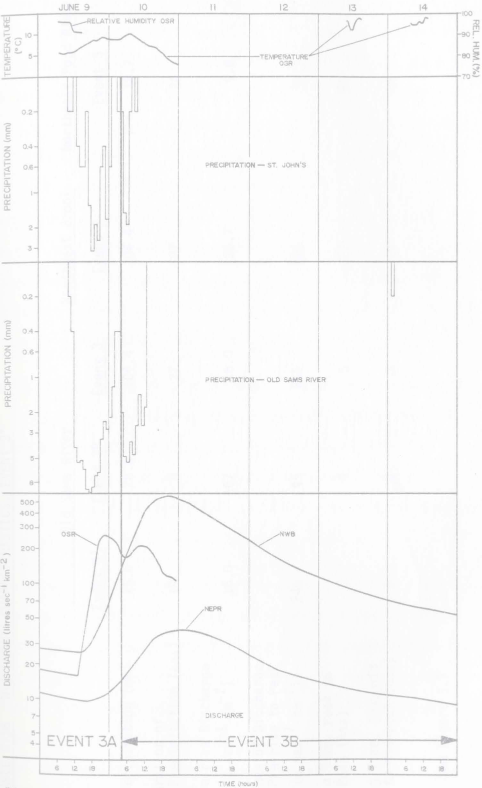

FIGURE 5.7 HYDROMETEOROLOGICAL PARAMETERS, EVENT 3

TABLE 5.16 HYDROGRAPH CHARACTERISTICS, EVENT 3*

	Old Sams River			Northwest Brook	Northeast Pond River
	Event 3A	Event 3B	Event 3	Event 3	Event 3
Precipitation (*mm*)	75.6	28.8	104.4	104.4	18.7
Duration of Precipitation (*hrs*)	18	9	27	27	24
Pre-rise Discharge ($\ell\ sec^{-1}\ km^{-2}$)	16.0	167	16.0	25.7	9.6
Range of Discharge Pre-rise to Peak ($\ell\ sec^{-1}\ km^{-2}$)	246	45	246	541	30.3
Lag Time, Peak to Peak (*hrs*)	5	4	5	27	31
Lag Time, Centroid to Mid-peak (*hrs*)	5	3	3	25	28

* See Figure 5.7

At Northwest Brook, the intensive precipitation in event 3 resulted in lag times of 27 *hrs* and 25 *hrs* for the peak to peak and centroid to mid-peak methods, respectively (Figure 5.7 and Table 5.16). This is less than half that recorded for events 1 and 2 (Table 5.14 and Table 5.15). The range of discharge at Northwest Brook is more than twice as great as that at Old Sams River. This is contrary to what one would expect for this substantially larger stream. It is presumed that discharge at the Old Sams River was actually much greater than that estimated by the rating curve (Figure 2.4). During this exceptional event, stage was much greater than would allow reasonable extrapolation of the data used in the formulation of the stage-discharge relationship (Section 2.4.1).

The lag times and range of discharge at Northeast Pond River (Table 5.16) are very similar to those recorded there during the comparable precipitation and pre-rise discharge conditions in event 1A (Table 5.14). However, the relatively small amount of precipitation recieved at Northeast Pond River precludes reasonable comparison with Old Sams River and Northwest Brook.

As has been noted for the two earlier events, Old Sams River experienced relatively rapid streamflow response to precipitation. This would appear to support the literature which suggests that peatlands experience spate-like runoff in wet conditions (Baden and Eggelsmann, 1968; Burke, 1972; and Goode, et al., 1977). However, the magnitude of preciptiation in event 3 was so great that it is difficult to attribute this dramatic response to anything but the intensity of the rainfall. Thus, it is not possible to make reasonable conclusions regarding the role of peatland in determining streamflow response in this event, especially in view of the sixfold difference in precipitation between Old Sams River and St. John's.

5.4.4 Event 4

Event 4 extended from June 22 to June 27. Figure 5.8 summarizes the relevant data for the Old Sams River, and compares these with discharge at Northwest Brook and Northeast Pond River, and with precipitation at St. John's. Precipitation during this period was intermittent and generally of low intensity. Three distinct precipitation events occurred between June 22 and June 25. On this basis, these data are subdivided into events 4A, 4B, and 4C. Hydrograph characteristics are summarized in Table 5.17. At Old Sams River, a streamflow response to precipitation was observed for all three events. At Northwest Brook and Northeast Pond River, there was a single streamflow response to the precipitation observed in events 4B and 4C. At Northeast Pond River, there was no streamflow response to precipitation in event 4A. The complexity of the Old Sams River hydrograph again demonstrates the relatively rapid streamflow response to precipitation observed there.

At Old Sams River (Table 5.17), lag times were comparable to those noted for the similar conditions which prevailed in events 1A and 1B (Table 5.14). The range of discharge, pre-rise to peak in events 4B and 4C was also similar to that recorded for events 1A and 1B, despite pre-rise discharge values approximately three times greater. Although the range of discharge in event 4A was small in

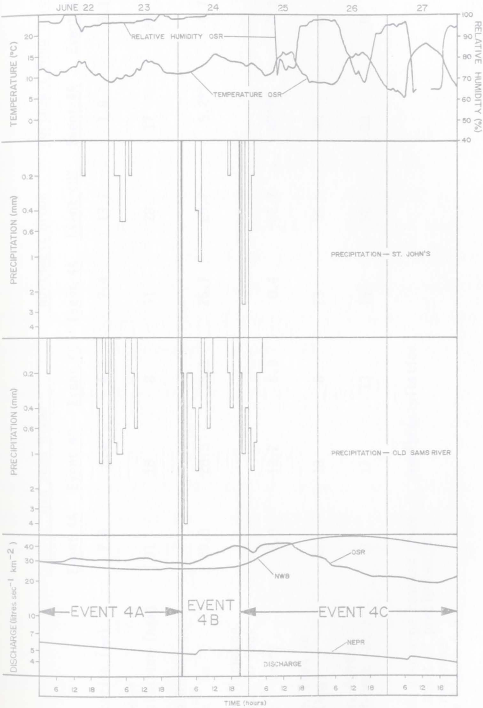

FIGURE 5.8 HYDROMETEOROLOGICAL PARAMETERS, EVENT 4

TABLE 5.17 HYDROGRAPH CHARACTERISTICS, EVENT 4†

	Old Sams River			Northwest Brook		Northeast Pond River	
	Event 4A	Event 4B	Event 4C	Event 4A	Event 4BC	Event 4A	Event 4BC
Precipitation (*mm*)	7.4	8.4	4.8	7.4	13.2	1.8	5.1
Duration of Precipitation (*hrs*)	31	18	8	31	28	17	20
Pre-rise Discharge ($\ell\ sec^{-1}\ km^{-2}$)	29.8	28.3	35.1	25.7	25.7	5.2**	4.7
Range of Discharge Pre-rise to Peak ($\ell\ sec^{-1}\ km^{-2}$)	2.0	12.2	6.9	0.4	22.7	NR***	0.3
Lag Time, Peak to Peak (*hrs*)	11	18	8	23	56	NR	0*
Lag Time, Centroid to Mid-peak (*hrs*)	8	17	13	19	52	NR	0

* Peak discharge reached prior to peak precipitation
** At start of precipitation
*** No response
† See Figure 5.8

comparison to that in event 1A, this can be accounted for by differences in the duration of precipitation.

Northwest Brook experienced a relatively rapid streamflow response to precipitation in event 4A (Table 5.17), with the lesser lag times than were recorded for the more intense event 3. However, at 0.4 $\ell\ sec^{-1} km^{-2}$, the pre-rise to peak range of discharge was insignificant. With event 4BC, a more characteristic, longer lag time was observed. This was accompanied by a more substantial range of discharge. In comparison with event 1 in which the same amount of precipitation was received (Table 5.14), a slightly greater range of discharge was observed in event 4BC. This probably resulted from the slightly higher pre-rise discharge and substantially shorter duration of precipitation recorded for event 4BC.

Northeast Pond River did not experience a streamflow response to the precipitation recorded in event 4A. A very small streamflow response was recorded in event 4BC. The small amount of precipitation as compared to that received at Old Sams River probably contributed to the lack of streamflow response. However, it is more likely that this precipitation served to satisfy soil-moisture and evapotranspiration deficits.

Inter-basin comparison for event 4 indicates that the Old Sams River, under conditions of relatively high antecedent streamflow, demonstrated relatively rapid streamflow response to precipitation. However, the magnitude and lag time of the streamflow response does not appear to differ greatly from similar precipitation events which occurred during drier antecedent streamflow conditions (event 1). In comparison with Old Sams River, Northwest Brook experienced a more subdued response with a lesser peak in discharge. Northeast Pond River, under drier antecedent streamflow conditions than in event 1, showed little or no response to these low intensity precipitation events. As with the previous three events, Old Sams River catchment had a more complex hydrograph, a reflection of its more rapid runoff characteristics.

Events 1 through 4 occurred over a range of antecedent streamflow conditions. Streamflow response to low intensity and small magnitude precipitation events at Old Sams River was not radically different through a range of pre-rise discharge conditions. The fact that antecedent streamflow conditions do not appear to have affected hydrograph characteristics during even relatively dry, low flow periods, indicates that the peatland-dominated Old Sams River catchment did not in comparison with Northwest Brook and Northeast Pond River, attenuate streamflow response to precipitation.

5.4.5 Event 5

Event 5 extended from June 28 to July 4. Figure 5.9 summarizes the relevant data for the Old Sams River and compares these with discharge at Northwest Brook and Northeast Pond River, and with precipitation at St. John's. Hydrograph characteristics are summarized for all three catchments in Table 5.18.

The Old Sams River, as with the previous four events, demonstrated a relatively rapid streamflow response to precipitation (Figure 5.9 and

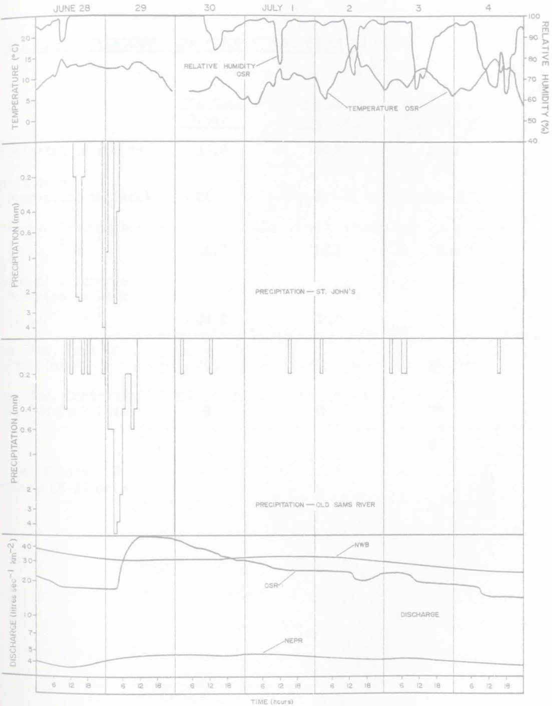

FIGURE 5.9 HYDROMETEOROLOGICAL PARAMETERS, EVENT 5

TABLE 5.18 HYDROGRAPH CHARACTERISTICS, EVENT 5*

	Old Sams River	Northwest Brook	Northeast Pond River
Precipitation (*mm*)**	15.0	15.0	12.8
Duration of Precipitation (*hrs*)	26	26	15
Pre-rise Discharge ($\ell\ sec^{-1}\ km^{-2}$)	16.7	30.8	3.6
Range of Discharge Pre-rise to Peak ($\ell\ sec^{-1}\ km^{-2}$)	33.1	2.0	1.1
Lag Time, Peak to Peak (*hrs*)	9	51	20
Lag Time, Centroid to Mid-peak (*hrs*)	8	54	30

* See Figure 5.9
** June 28-29 only

Table 5.18). Lag times are nine and eight *hrs* for peak to peak and centroid to mid-peak, respectively. Despite a pre-rise discharge value mid-way between Northwest Brook and Northeast Pond River, the range of discharge at Old Sams River was 17 and 30 times greater, respectively. The substantial difference between pre-rise discharge at Northwest Brook and Old Sams River may explain, to some extent, the relatively small streamflow response noted at Northwest Brook. As noted in Section 5.4.4, it is apparent that through a range of hydrometeorologic conditions, streamflow response to precipitation was consistently more rapid at Old Sams River in comparison with the other two catchments.

5.4.6 Event 6

Event 6 extended from July 5 to July 10. Figure 5.10 summarizes the relevant data for the Old Sams River, and compares these with discharge at Northwest Brook and Northeast Pond river, and with precipitation at St. John's. Hydrograph characteristics are summarized in Table 5.19.

The peculiar hydrograph shape recorded for event 6 at the Old Sams River is unusual and gives rise to some concern that these data may be in error. Hydrograph recession on July 7 was dramatic and unprecedented during the study period. A secondary peak in discharge on July 9 was not accompanied by precipitation. Careful scrutiny of the stage and precipitation charts indicates no evidence of equipment malfunction. This suggests that these data are not in error.

There is a plausible explanation for these apparently

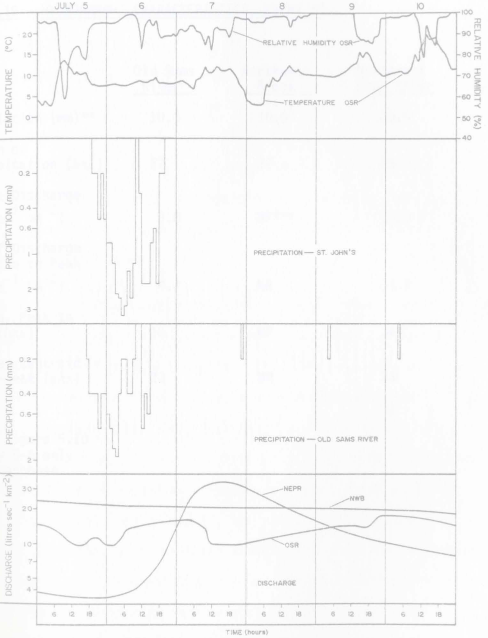

FIGURE 5.10 HYDROMETEOROLOGICAL PARAMETERS, EVENT 6

TABLE 5.19 HYDROGRAPH CHARACTERISTICS, EVENT 6*

	Old Sams River	Northwest Brook	Northeast Pond River
Precipitation (*mm*)**	10.6	10.6	29.5
Duration of Precipitation (*hrs*)	22	22	25
Pre-rise Discharge ($\ell\ sec^{-1}\ km^{-2}$)	9.8	NR***	3.3
Range of Discharge Pre-rise to Peak ($\ell\ sec^{-1}\ km^{-2}$)	6.4	NR	31.7
Lag Time, Peak to Peak (*hrs*)	18	NR	34
Lag Time, Centroid to Mid-peak (*hrs*)	23	NR	33

* See Figure 5.10
** July 5-6 only
*** No response

anomalous data which pertains to the interrelationships between water table, evapotranspiration, and streamflow. Throughout the study period, during periods of recession, the Old Sams River experienced a diurnal fluctuation in streamflow. This phenomenon is analyzed in Section 5.5. It is sufficient at this point to note that the dramatic streamflow recession on mid-day July 7 was accompanied by a substantial increase in temperature and decrease in relative humidity. It is postulated that the secondary hydrograph peak on July 9 represents a delayed resumption of the recession curve. In the interim period, the hydrograph was suppressed by a substantial evapotranspiration-induced moisture demand in the hydrologically-active layer.

Accepting the above hypothesis, the hydrograph characteristics at Old Sams River (Figure 5.10) are treated as a simple hydrograph for the period July 5 to July 7 (Table 5.19). The secondary peak on July 9 is ignored, facilitating an inter-basin comparison of hydrograph characteristics. As a result of low intensity and long duration precipitation, and low pre-rise discharge, the Old Sams River experienced a relatively subdued response, similar to that noted for event 1B (Table 5.14), and events 4A, 4B, and 4C (Table 5.17). However, in comparison with Northwest Brook where there was no streamflow response, Old Sams River demonstrated a more dramatic streamflow response to precipitation. Similarly, despite much greater precipitation recorded at St. John's, Old Sams River demonstrated a more rapid streamflow response to precipitation than experienced at Northeast Pond River. Again, as noted for previous events, streamflow response is more rapid and pronounced at Old Sams River.

Event 6 was the largest precipitation event recorded at St. John's during the study period, with approximately three times that recorded for the same period at Old Sams River. Both lag time and range of discharge were comparable to that recorded in event 3, when 37% less precipitation fell over a similar period. The relatively lesser streamflow response in event 6 is attributed to the much drier hydrometeorologic conditions preceding the event, including a very low pre-rise discharge, 3.3 $\ell\ sec^{-1} km^{-2}$.

5.4.7 Event 7

Event 7 extended from July 18 to July 22. Figure 5.11 summarizes the relevant data for the Old Sams River and compares these with discharge at Northwest Brook and Northeast Pond River, and with precipitation at St. John's. Hydrograph characteristics are summarized in Table 5.20.

Of all the events recorded at Old Sams River, event 7 offers the best opportunity for the investigation of streamflow response to precipitation under extremely dry conditions. As noted in Section 5.3 (Figure 5.1 and Table 5.13), daily streamflow was the lowest for the study period on the day preceding event 7, July 17. The highest temperature during the study period (Table 5.8) and the greatest bog water table depth (Appendix E, Table E.4) were also recorded on July 17. Not only was July 17 the day of greatest hydrometeorological extremes in the study period, discussion of the seasonal hydroclimatological representativeness in Section 5.1 revealed that conditions in the month

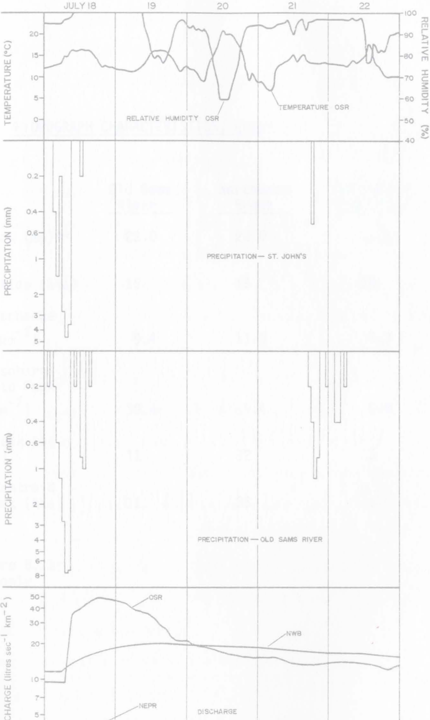

FIGURE 5.11 HYDROMETEOROLOGICAL PARAMETERS, EVENT 7

TABLE 5.20 HYDROGRAPH CHARACTERISTICS, EVENT 7*

	Old Sams River	Northwest Brook	Northeast Pond River
Precipitation (*mm*)**	22.0	22.0	13.2
Duration of Precipitation (*hrs*)	15	15	10
Pre-rise Discharge ($\ell\ sec^{-1}\ km^{-2}$)	9.4	11.5	3.3
Range of Discharge Pre-rise to Peak ($\ell\ sec^{-1} km^{-2}$)	39.4	8.4	0.8
Lag Time, Peak to Peak (*hrs*)	11	32	3
Lag Time, Centroid to Mid-peak (*hrs*)	11	35	6

* See Figure 5.11
** July 18 only

of July were similarly extreme in comparison with hydroclimatic normals. Mean daily temperature was 1.0 standard deviations above the mean, monthly precipitation was 1.04 standard deviations below the mean, and monthly stream discharge at nearby Northwest Brook was 0.63 standard deviations below the mean.

Hydrograph characteristics for event 7 at Old Sams River are, with the above observations in mind, indicative of streamflow response under exceptionally warm and dry conditions. Perhaps as a result of these conditions, lag times (Table 5.20) are slightly longer than noted for several lesser precipitation events, i.e. events 1A, 2A, 2B, 4A, and 5. However, in event 7, streamflow response was very similar to that recorded for event 3B (Table 5.16). Pre-rise discharge in event 3 was very high, 167 $\ell\ sec^{-1} km^{-2}$, in comparison with only 9.4$\ell\ sec^{-1} km^{-2}$ in event 7. A total of 28.8 *mm* of precipitation fell in event 3B, only 6.8 *mm* more than in event 7. Despite these dramatically different antecedent moisture conditions, the range of discharge, pre-rise to peak, in response to these similar magnitude precipitation events was 45 $\ell\ sec^{-1} km^{-2}$ and 39.4 $\ell\ sec^{-1} km^{-2}$ for event 3B and event 7, respectively. The longer lag times in event 7, when compared with event 3B, can be attributed to three factors:

(1) lower pre-rise discharge;

(2) temporal displacement of the hydrograph peak as a result of the secondary peak in precipitation (Figure 5.11); and

(3) the duration of precipitation which was approximately 1.5 times greater.

In further discussion of event 7, although lesser intensities and a smaller total amount of precipitation was noted at St. John's, a substantial amount of precipitation was received there (Table 5.20). Despite this, warm and dry conditions accompanied by low antecedent streamflow resulted in a relatively insignificant streamflow response. The intense, short-duration precipitation event (Figure 5.11) did, however, result in a relatively short lag time.

5.4.8 Summary

The above observations confirm that the Old Sams River demonstrated similar streamflow response to precipitation under both wet and extremely dry conditions. Thus, through a range of antecedent moisture conditions, this peatland-dominated catchment does not appear to regulate streamflow response to precipitation. In fact, the observed streamflow response in the study period would indicate that at no time did the hydrologically-active layer become sufficiently dry to absorb precipitation and significantly delay streamflow response. However, in focusing on the daily rates of recession in Section 5.3, it is apparent that relative to the other catchments, this peatland-dominated catchment did, in the drier than normal conditions of the study period, gradually release moisture through prolonged dry periods. This duality in the effect of peatland on streamflow response to precipitation may partly resolve the contradictions in the literature where peatlands are described as spate-like on the one hand, and sponge-like on the other.

5.5 DIURNAL EVAPOTRANSPIRATION-INDUCED HYDROGRAPH DEPRESSIONS, OLD SAMS RIVER CATCHMENT

During the study period, a unique phenomenon was frequently observed to occur on the hydrograph from the Old Sams River. On 22 of the 76 days in the study period, there was a dramatic diurnal fluctuation in temperature and relative humidity. Typically, on the morning of these days, discharge decreased dramatically in unison with a decrease in relative humidity and a corresponding increase in temperature. In the evening, discharge was observed to increase to a level greater than observed during the mid-day hydrograph depression, at which time temperature decreased and relative humidity increased. These hydrograph depressions corresponded with meteorologic conditions which were conducive to evapotranspiration, and were primarily, but not necessarily, restricted to the recession phase of the hydrograph.

This phenomenon was noted on May 22-25, and 27 (Figure 5.12); May 30-31 (Figure 5.5); June 7 (Figure 5.6); June 19 (Figure 5.13); June 27 (Figure 5.8); July 2 (Figure 5.9); July 5 and 7 (Figure 5.10); July 13-17 (Figure 5.14); and July 25-28 (Figure 5.15). In a majority of these instances, these depressions occurred during the recession phase of the hydrograph. However, on May 30 (Figure 5.5) and from July 5-9 (Figure 5.10), these depressions were observed on the rising limb, crest, and falling limb segments of the hydrograph when post-precipitation meteorological conditions were conducive to evapotranspiration.

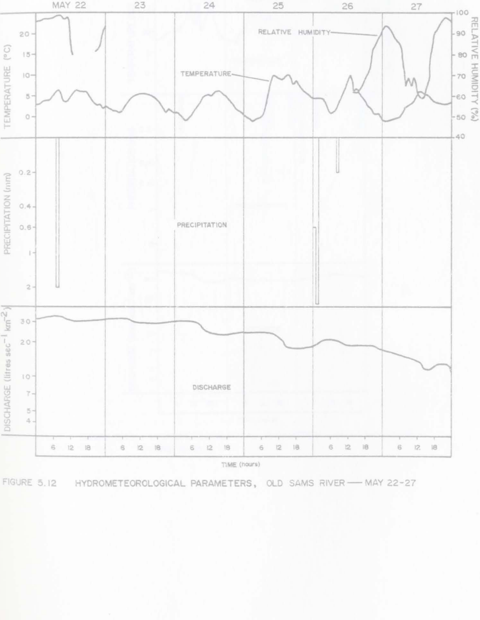

FIGURE 5.12 HYDROMETEOROLOGICAL PARAMETERS, OLD SAMS RIVER — MAY 22-27

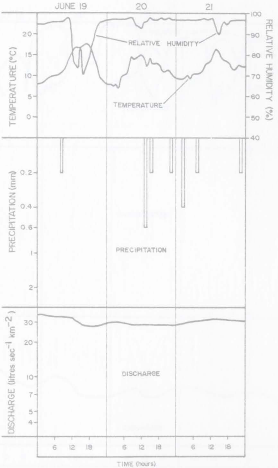

FIGURE 5.13 HYDROMETEOROLOGICAL PARAMETERS, OLD SAMS RIVER— JUNE 19-21

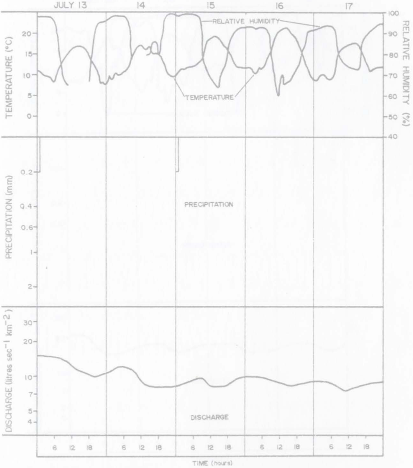

FIGURE 5.14 HYDROMETEOROLOGICAL PARAMETERS, OLD SAMS RIVER — JULY 13-17

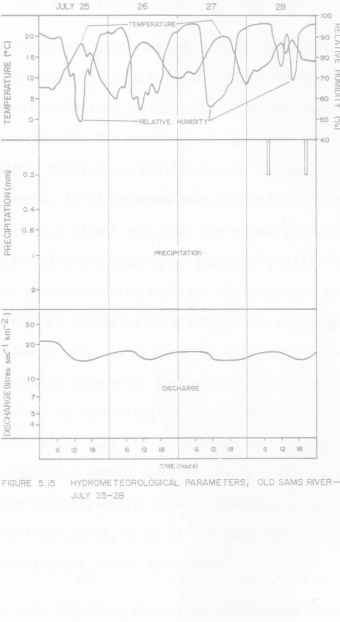

FIGURE 5.15 HYDROMETEOROLOGICAL PARAMETERS, OLD SAMS RIVER— JULY 25-28

On a number of other days, the falling limb and recession phase of the hydrograph experienced dramatic breaks in slope corresponding to periods of increasing and decreasing rates of evapotranspiration. For example, this phenomenon was observed on May 26 (Figure 5.12); June 1 and 2 (Figure 5.5); June 6 (Figure 5.6); June 26 (Figure 5.8); June 30 and July 1, 3, and 4 (Figure 5.9); and July 19-22 (Figure 5.11).

For the duration of the study period, this phenomenon was not apparent in the hydrographs at both Northwest Brook and Northeast Pond River. These diurnal variations in streamflow have not been described in the literature concerning the hydrology of peatland, and as such, were not anticipated. However, at Brishie Bog in the Southern Uplands of Scotland, (Tomlinson, 1979) observed that during drier conditions, the water table fell at a slower rate than during wet periods, and proceeded in regular pulses, producing a stepped effect in its decline. Each step occurred during daylight hours and was followed by a tread in water table recession at night. It is suggested that this stepwise decline in water table occurred as a result of the same conditions which produced hydrograph depressions at Old Sams River. As runoff from peatland is controlled by the hydrologically-active layer (Sections 1.2.2 and 1.2.3), it is apparent that diurnal fluctuations in evaporative demand can effectively alter the runoff process in the hydrologically-active layer, producing stepwise decline in water table (Tomlinson,1979), or as at Old Sams River, resulting in dramatic diurnal fluctations in the hydrograph.

In accordance with the above discussion, short-term diurnal fluctuations of shallow water tables have been reported in fens by

Godwin (1931), and in non-peatland areas by Meyboom (1965), Troxell (1936), Ward (1975), and White (1932). Ward (1975) attributed this to diurnal fluctuations in rates of evapotranspiration. He reported that these variations are interrupted by periods of rainfall and/or reduced evapotranspiration and it was suggested that this regular diurnal rhythm is maintained through much of the summer.

In an attempt to quantify the characteristics of these evapotranspiration-induced depressions in the hydrograph, a number of simple measures have been derived to facilitate analysis. These include the previous overnight recovery discharge (PORD), the minimum evapotranspiration depressed discharge (EDD), and the recovery discharge (RD) recorded overnight following the EDD. The EDD is also expressed as a percentage of both the PORD and the RD. The lag time from the EDD to the RD is also included. Table 5.21 summarizes these characteristics for the 22 days in which the evapotranspiration-induced depressions in the hydrograph were observed to occur.

Values of PORD range from 8.9 $\ell\ sec^{-1} km^{-2}$ to 33.1 $\ell\ sec^{-1} km^{-2}$ (Table 5.21). Values of EDD range from 7.3 $\ell\ sec^{-1} km^{-2}$ to 29.8 $\ell\ sec^{-1} km^{-2}$. Values of RD range from 8.9 $\ell\ sec^{-1} km^{-2}$ to 32.2 $\ell\ sec^{-1} km^{-2}$. Based on the data for the study period, it appears that an evapotranspiration-induced depression can be detected through a range of moderate to very low discharge conditions. EDD, expressed as a percentage of PORD, ranged from 60.5% to 91.7%. In fact, in a matter of hours, discharge decreased to values of EDD which were as low as 60.5% of PORD, a dramatic 39.5% decrease. These conditions occurred under baseflow recessional conditions, at a time when such dramatic recession was not

TABLE 5.21 ANALYSES OF DIURNAL EVAPOTRANSPIRATION-INDUCED DEPRESSIONS IN THE HYDROGRAPH

Date	Previous Over-Night Recovery Discharge, PORD $(\ell\ sec^{-1} km^{-2})$	Evapotranspiration Depressed Discharge EDD $(\ell\ sec^{-1} km^{-2})$	Recovery Discharge, RD $(\ell\ sec^{-1} km^{-2})$	EDD as Percentage of PORD	EDD as Percentage of RD	Lag Time, EDD to RD (hrs)
May 22	33.1	29.8	32.2	90.0	92.5	13.5
May 23	32.2	29.1	30.6	90.4	95.1	4.5
May 24	30.6	23.4	24.2	76.5	96.7	0.5
May 25	24.2	17.8	21.0	73.6	84.8	4.0
May 27	17.2	11.6	13.0	67.4	89.2	0.5
May 30	21.4	18.6	22.9	86.9	81.2	6.0
May 31	22.9	17.2	18.6	75.1	92.5	0.5
June 7	21.8	20.0	20.9	91.7	95.7	0.5
June 19	34.6	27.9	29.8	80.6	93.6	2.5
June 27	21.5	19.2	21.5	89.3	89.3	6.0
July 2	24.4	20.1	23.6	82.4	85.2	6.0
July 5	14.5	9.8	11.3	67.6	86.7	1.0
July 7	16.2	9.8	17.8*	60.5	55.1	48.0
July 13	15.1	9.9	12.2	65.6	81.1	7.0
July 14	12.2	8.1	9.9	66.4	81.8	9.0
July 15	9.9	8.1	9.8	81.8	82.7	1.0
July 16	9.8	8.1	8.9	82.7	91.0	0.5
July 17	8.9	7.3	9.4	82.0	77.7	12.0
July 25	21.0	14.3	17.0	68.1	84.1	6.0
July 26	17.0	14.3	17.0	84.1	84.1	4.5
July 27	17.0	14.3	17.0	84.1	84.1	3.5
July 28	17.0	14.3	17.0	84.1	84.1	3.5

* on July 9

expected. Values of EDD ranged from 55.1% to 96.7% of RD.

The lag time from the EDD to the RD ranged from 0.5 and 48.0 *hrs*, but generally remained on the diurnal cycle, between 0.5 and 12.0 *hrs* (Table 5.21). The unusual occurrence of a 48 hour lag time resulted from a subjective interpretation of the hydrograph for event 6 (Figure 5.10). It is hypothesized that in response to relatively low intensity precipitation during event 6, the hydrograph was attenuated by an evapotranspiration-induced depression. The normal diurnal fluctuation was extended for two days as a result of overnight continuation of high temperature and lower than normal relative humidity.

The magnitude of these evapotranspiration-induced depressions is indicative of the importance of the hydrologically-active layer. During dry periods, streamflow is effectively controlled by the evaporative demand for water in the hydrologically-active layer. Given that EDD was observed to be as low as 55.1% of RD (Table 5.21), it is apparent that a substantial proportion of streamflow is generated directly from the hydrologically-active layer in the peatland of the Old Sams River catchment.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 SEASONAL HYDROCLIMATOLOGICAL REPRESENTATIVENESS

Analysis of the seasonal hydroclimatological representativeness of conditions preceeding and during the study period (Section 5.1) indicates that all three catchments underwent a transitiion from hydrometeorological conditions warmer (except Northeast Pond River which was slightly cooler than normal) and wetter than normal in winter and spring, to conditions much drier than normal in July and August. As such, the study period satisfied the study objective (Section 2.2) to monitor a number of hydrometeorological parameters through a range of very wet to relatively dry conditions.

6.2 DAILY HYDROMETEOROLOGICAL CHARACTERISTICS OF THE OLD SAMS RIVER CATCHMENT

6.2.1 Temperatures

Mean daily air temperature was slightly cooler at Old Sams River than at St. Shotts (Section 5.2.1). However, both of these southern Avalon Peninsula stations experienced much cooler temperatures than St. John's, where in the extreme case, mean daily temperature was 2.8 C° warmer in the month of July. Similarly, the mean daily range of temperatures was much greater at St. John's than it was at St. Shotts and Old Sams River.

6.2.2 Precipitation

At Old Sams River, measurable precipitation was recorded on 64% of the days in the study period, while on only 43% of the days at St. Shotts (Section 5.2.2). In the month of June, Old Sams River received 56.6 *mm* of precipitation more than St. Shotts. This difference arose as a result of several discrete events when the Old Sams River received substantially more precipitation. Banfield and Barnes (in preparation) suggest that these disparities arose under synoptic conditions which were conducive to the orographic enhancement of precipitation. It is suggested and supported by this thesis that the excess of runoff over precipitation noted for several Avalon Peninsula drainage basins (Section 3.5.2.1) can probably be attrituted, at least in part, to widespread orographic influence in the region.

In comparison with St. John's, it was observed that precipitation there was not always coincident with that recorded at Old Sams River. St. John's appears to be in the rainshadow of the southern Avalon Peninsula under conditions of southwesterly airflow which are common in spring and summer (Banfield and Barnes, in preparation). For example, during the month of June, St. John's received only 47% of the amount of precipitation which fell at Old Sams River.

6.2.3 Relative Humidity

Relative humidity at Old Sams River was frequently high (above 90%) during the study period (Section 5.2.3). On fine days, however, it followed the diurnal pattern typical for Newfoundland (Banfield 1981; 1983), falling from an overnight high at or near 100%, to values as low as 50% to 70% by mid-afternoon.

6.2.4 Evaporation

Pan evaporation recorded at Old Sams River between July 3 and August 3 was 81.46 *mm*, exceeding precipitation for the same period by 20% (Section 5.2.4). This amount is comparable to that recorded at St. John's, despite the cooler temperature and higher relative humidity observed at Old Sams River. It is postulated that mid-day onshore wind resulting from a diurnal land-sea breeze phemonenon is responsible for the enhancement of evaporation.

6.2.5 Bog Water Table

The mean depth of the water table for all wells during the study period was 9.2 *cm* (Section 5.2.5). Similarly, for all wells combined, the range of depth through the study period was 11.2 *cm*, and the maximum and minimum depth was 16.2 and 5.6 *cm*, respectively. These data indicate that shallow water table conditions prevailed despite the warmer and drier than normal conditions which were experienced in July and August.

The bivariate linear regression model derived to estimate mean daily water table depth for all wells combined from daily stream discharge (Section 4.1.4) is capable of estimating missing data to within ± 3.84 *cm* (± 2 *SEE y*) at the 95.5% level of confidence. However, the model is restricted to use with daily discharge values less than 137 $\ell\ sec^{-1} km^{-2}$. Using the range of daily discharge values observed during the study period, it is suggested that for all wells combined, mean water table depth ranged from 0.0 *cm* to 16.2 *cm*, 5.0 *cm* greater than the range in mean values actually observed.

During the 34-day period of decline from highest to lowest water table depth observed during the study period, the net rate of mean water table decline was 4.9 *mm day*$^{-1}$. During the dry five-day period preceeding July 17, the mean water table depth declined at a net rate of 15.4 *mm day*$^{-1}$.

6.3 RUNOFF CHARACTERISTICS OF THE OLD SAMS RIVER CATCHMENT

Daily runoff from the Old Sams River and Northwest Brook catchments was 2.7 and 3.4 times greater, respectively, than noted for the Northeast Pond River catchment (Section 5.3). At Old Sams River and Northwest Brook, daily runoff was less than 1.00 *mm day*$^{-1}$ on only 6 and 5 days of the 76-day study period, respectively. By marked contrast, daily runoff was less than 1.00 *mm day*$^{-1}$ at Northeast Pond River on 53 days. Despite seasonally drier and warmer than normal conditions in the southern Avalon Peninsula region, runoff exceeded 2.00 *mm day*$^{-1}$ on 31 and 44 days at Old Sams River and Northwest Brook, respectively. In contrast, runoff exceeded 2.00 *mm day*$^{-1}$ on 11 days only at Northeast Pond River.

Runoff during the study period was 27% greater at Northwest Brook than at Old Sams River (Section 5.3.1). A large proportion of this difference, 56%, was attributed to probable errors in the estimation of missing data at Old Sams River between June 10 and June 18. The remainder of this difference may be attributed to the much greater temporal base of the hydrograph at Northwest Brook, resulting in a more delayed runoff and base flow response to the much wetter and cooler than normal conditions which prevailed in May and June.

At odds with the above, daily runoff at the Old Sams River did exceed that of Northwest Brook for the last 12 days of the study period. This resilience in the recession curve is uncharacteristic for such a small catchment, especially during periods of below normal precipitation and stream discharge, and high rates of evapotranspiration. It was concluded in Section 5.3.1 that this phenomenon can be attributed to the influence of the more extensive tracts of peatland found in this catchment. This peatland-dominated catchment can sustain a much higher runoff yield than Northwest Brook catchment, a much larger nearby catchment which has substantially less peatland. It was concluded further that this observation supports the commonly held belief that peatlands gradually release their water through prolonged dry periods and is in disagreement with the literature (Romanov, 1961; Chapman, 1965; Baden&Eggelsmann, 1968; Robertson, et al., 1968; and Goode, et al., 1977) which suggests that runoff ceases under these dry conditions. It is postulated that owing to the hydroclimatology of the Old Sams River catchment and its peatlands, at no time, except perhaps during periods of drought of greater magnitude than that experienced during the study period, would runoff in fact cease. Thus, the peatland of the Old Sams River catcnment regulates runoff during dry periods, maintaining streamflow relatively higher than in adjacent catchments which have little or no peatland. It must be qualified, however, that the occurrence of dry periods in the southern Avalon Peninsula area is uncommon, and therefore, the regulation of streamflow by peatland in this manner is similarly an uncommon occurrence.

Comparative analysis of daily runoff data at Northeast Pond River supports the above conclusions. Between July 7 and July 17, the warmest and driest period of the study period, the runoff rate declined a total of 2.30 $mm\ day^{-1}$ at Northeast Pond River, while in comparison, the runoff rate declined only 0.30 $mm\ day^{-1}$ at Old Sams River.

6.4 STREAMFLOW RESPONSE TO PRECIPITATION FOR THE OLD SAMS RIVER CATCHMENT

Analyses of hourly data in Section 5.4 indicated that, regardless of, and through a range of antecedent moisture conditions, the peatland of the Old Sams River catchment did not, in comparison with Northwest Brook and Northeast Pond River, attenuate streamflow response to precipitation. It was observed that even under extremely dry conditions, low intensity precipitation resulted in much more rapid streamflow response than could be attributed solely to differences in the physical characteristics of the catchment relative to those of Northwest Brook and Northeast Pond River.

The fact that streamflow response to precipitation was relatively rapid through a range of hydrometeorological conditions (Section 5.4) suggests that at no time did the hydrologically-active layer become sufficiently dry to absorb precipitation and significantly delay streamflow response.

6.5 DIURNAL EVAPOTRANSPIRATION-INDUCED DEPRESSIONS IN THE HYDROGRAPH AT THE OLD SAMS RIVER CATCHMENT

At Old Sams River, evapotranspiration-induced depressions in the hydrograph were observed on 22 of the 76 days in the study period (Section 5.5). Following the diurnal pattern of the meteorological parameters responsible for evapotranspiration, these depressions were observed primarily during the recession phase of the hydrograph. However, they were occasionally noted on the rising limb, crest, and falling limb of the hydrograph. This phenomenon occurred when previous overnight recovery discharge (PORD) ranged between 8.9 $\ell\ sec^{-1} km^{-2}$ and 33.1 $\ell\ sec^{-1} km^{-2}$. The evaporation depressed discharge (EDD) was between 60.5% and 91.7% of the PORD, and 55.1% to 96.7% of the recovery discharge (RD). The lag time from the minimum EDD to the RD followed the diurnal pattern and typically ranged from 0.5 *hrs* to 12.0 *hrs*.

The magnitude of these evapotranspiration-induced depressions is indicative of the importance of the hydrologically-active layer. During dry periods, streamflow is effectively controlled by the evaporative demand for water in the hydrologically-active layer. Given that EDD was observed to be as low as 55.1% of RD, it is apparent that a substantial proportion of streamflow is generated directly from the hydrologically-active layer.

6.6 FUTURE RESEARCH

This thesis has perhaps raised more questions than it has answered. Pollett and Wells (1979) identified eight ecological peatland types in Newfoundland. In eastern Newfoundland alone, Wells (1981) has classified six morphological peatland types. Given the observed hydroclimatology of the blanket bog dominated Old Sams River catchment, which is presumably representative of the surrounding uplands of the southern region of the Avalon Peninsula, the extent to which the conclusions of this thesis are applicable to the hydroclimatology of other peatland types in Newfoundland remains unknown.

Although the study period allowed the assessment of a range of hydrometeorological conditions, this thesis did not investigate the winter period when the effects of frost may have a pronounced effect on the hydrologically-active layer.

This thesis has emphasized the critical role of the hydrometeorologic processes of the hydrologically-active layer. Detailed micrometeorological and water balance analyses of the relationships between precipitation, evapotranspiration, water table, and runoff are required to identify the physical processes within the hydrologically-active layer. These processes should be characterized for all peatland types in Newfoundland.

Increased interest in the development of peatland raises a major concern for the effects of development on not only the hydroclimatology of peatland, but also, the hydroclimatology of Newfoundland itself. This concern serves to amplify the need for additional research in this field so that the impact of future development can be assessed on a truly scientific basis.

6.7 DISCUSSION

From the analyses presented in this thesis, it is apparent that relative to the other catchments studied, the peatland-dominated Old Sams River catchment did, in the drier than normal conditions of the study period, gradually release moisture through prolonged dry periods. Conversely, under normal hydrometerological conditions, the peatland of the Old Sams River catchment did not regulate streamflow response to precipitation.

The results of this thesis suggest that the hydroclimatology of the Old Sams River catchment is such that its peatland seldom becomes sufficiently dry to enable it to effectively act as a regulator of streamflow. Normally, conditions of high water table persist year-round and cause the hydrologically-active layer to encourage rapid streamflow response to precipitation. In this way, the peatland of the Old Sams River catchment differs considerably from the hydroclimatology of peatlands reported in the literature (Romanov, 1961; Chapman, 1965; Baden and Eggelsmann, 1968; Bay, 1968; Robertson, et al., 1968; and Goode, et al., 1977). Typically, under wet conditions, runoff from peatland has been reported to behave in a manner similar to that observed for the Old Sams River catchment (Baden and Eggelsmann, 1968; Burke, 1972; and Goode, et al., 1977). Under dry conditions, however, peatlands initially act as regulators of streamflow, gradually releasing moisture through dry periods (Romanov, 1961; Chapman, 1965; Baden and Eggelsmann, 1968; Bay, 1968; Robertson, et al., 1977). Thereafter, under persistent or extremely dry conditions, runoff from peatland has been reported to cease altogether (Romanov, 1961; Chapman, 1965; and Robertson, et al., 1968).

The hydroclimatological resilience demonstrated by the Old Sams River catchment during the drier than normal conditions of the study period may explain why, as noted by Pollett and Wells (1979) and Wells

(1981), the proliferation of blanket bog, a bog type of climatic origin, is restricted to the uplands of the southernmost regions of the Avalon Peninsula. Similarly, the proliferation of the Moss Heath type in this region (Meades, 1983) may also be attributed to these same hydroclimatological conditions.

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APPENDIX A

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER

Time	May 18	May 19	May 20	May 21	May 22
00:30	M*	84.5	100	88.4	82.2
01:00	M	84.5	100	88.4	82.2
01:30	M	84.5	100	88.4	82.2
02:00	M	84.5	100	88.4	82.2
02:30	M	84.5	100	88.4	82.2
03:00	M	84.5	103	88.4	82.2
03:30	M	84.5	103	88.4	84.3
04:00	M	84.5	103	88.4	84.3
04:30	M	84.5	103	88.4	84.3
05:00	M	84.5	103	88.4	84.3
05:30	M	86.8	103	88.4	84.3
06:00	M	86.8	103	88.4	84.3
06:30	M	89.0	103	88.4	84.3
07:00	M	89.0	103	88.4	84.3
07:30	M	95.8	103	88.4	84.3
08:00	M	95.8	103	88.4	84.3
08:30	M	98.0	103	86.4	84.3
09:00	M	98.0	103	86.4	84.3
09:30	M	98.0	103	86.4	84.3
10:00	M	98.0	103	86.4	82.2
10:30	M	98.0	103	84.3	80.2
11:00	82.2	98.0	103	84.3	78.1
11:30	82.2	100	103	84.3	78.1
12:00	82.2	100	103	82.2	78.1
12:30	82.2	100	103	82.2	78.1
13:00	82.2	100	103	82.2	78.1
13:30	82.2	100	103	82.2	76.1
14:00	82.2	100	103	82.2	76.1
14:30	84.5	100	90.4	82.2	76.1
15:00	84.5	100	90.4	82.2	76.1
15:30	84.5	100	90.4	82.2	76.1
16:00	84.5	100	90.4	80.2	76.1
16:30	84.5	100	90.4	80.2	78.1
17:00	84.5	100	90.4	80.2	78.1
17:30	84.5	100	90.4	80.2	78.1
18:00	84.5	100	90.4	80.2	78.1
18:30	84.5	100	90.4	80.2	78.1
19:00	84.5	100	90.4	80.2	78.1
19:30	84.5	100	90.4	80.2	78.1
20:00	84.5	100	90.4	80.2	78.1
20:30	84.5	100	90.4	80.2	78.1
21:00	84.5	100	88.4	80.2	78.1
21:30	84.5	100	88.4	80.2	78.1
22:00	84.5	100	88.4	80.2	80.2
22:30	84.5	100	88.4	80.2	80.2
23:00	84.5	100	88.4	80.2	80.2
23:30	84.5	100	88.4	82.2	80.2
24:00	84.5	100	88.4	82.2	80.2

* M represents missing data

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	May 23	May 24	May 25	May 26	May 27
00:30	80.2	78.1	61.7	47.4	43.9
01:00	80.2	78.1	61.7	47.4	43.9
01:30	80.2	78.1	61.7	47.4	40.2
02:00	80.2	78.1	61.7	49.4	40.2
02:30	80.2	78.1	61.7	53.6	40.2
03:00	80.2	78.1	61.7	53.6	40.2
03:30	80.2	76.1	61.7	53.6	40.2
04:00	80.2	76.1	61.7	53.6	40.2
04:30	80.2	76.1	61.7	53.6	40.2
05:00	80.2	76.1	61.7	53.6	40.2
05:30	82.2	76.1	61.7	53.6	40.2
06:00	82.2	76.1	61.7	53.6	40.2
06:30	82.2	76.1	61.7	53.6	36.7
07:00	82.2	76.1	61.7	53.6	36.7
07:30	82.2	74.1	61.7	51.5	36.7
08:00	82.2	74.1	61.7	51.5	36.7
08:30	80.2	74.1	61.7	51.5	36.7
09:00	78.1	74.1	61.7	51.5	36.7
09:30	78.1	72.0	59.7	51.5	36.7
10:00	76.1	65.9	57.6	49.4	36.7
10:30	76.1	63.8	57.6	49.4	36.7
11:00	74.1	63.8	57.6	47.4	36.7
11:30	74.1	63.8	55.6	47.4	36.7
12:00	74.1	61.7	55.6	47.4	36.7
12:30	74.1	61.7	55.6	47.4	33.1
13:00	74.1	61.7	55.6	47.4	33.1
13:30	74.1	61.7	47.4	47.4	29.6
14:00	74.1	59.7	47.4	47.4	29.6
14:30	74.1	59.7	47.4	47.4	29.6
15:00	74.1	59.7	47.4	47.4	29.6
15:30	74.1	59.7	45.4	47.4	29.6
16:00	74.1	59.7	45.4	47.4	29.6
16:30	74.1	59.7	45.4	47.4	29.6
17:00	74.1	59.7	45.4	47.4	29.6
17:30	74.1	59.7	45.4	47.4	33.1
18:00	74.1	59.7	45.4	47.4	33.1
18:30	74.1	59.7	45.4	47.4	33.1
19:00	74.1	59.7	45.4	47.4	33.1
19:30	76.1	61.7	45.4	47.4	33.1
20:00	76.1	61.7	45.4	47.4	33.1
20:30	76.1	61.7	45.4	47.4	33.1
21:00	76.1	61.7	45.4	47.4	33.1
21:30	76.1	61.7	45.4	43.9	33.1
22:00	76.1	61.7	45.4	43.9	33.1
22:30	76.1	61.7	47.4	43.9	33.1
23:00	76.1	61.7	47.4	43.9	33.1
23:30	78.1	61.7	47.4	43.9	29.6
24:00	78.1	61.7	47.4	43.9	25.9

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	May 28	May 29	May 30	May 31	June 1
00:30	25.9	40.2	33.1	54.6	40.2
01:00	25.9	40.2	33.1	54.6	40.2
01:30	25.9	40.2	33.1	58.3	36.7
02:00	25.9	40.2	33.1	58.3	36.7
02:30	25.9	36.7	36.7	58.3	36.7
03:00	25.9	36.7	36.7	58.3	36.7
03:30	22.4	33.1	36.7	58.3	36.7
04:00	22.4	33.1	36.7	58.3	36.7
04:30	22.4	33.1	40.2	54.6	36.7
05:00	22.4	33.1	40.2	54.6	36.7
05:30	22.4	33.1	43.9	54.6	36.7
06:00	22.4	33.1	47.4	54.6	36.7
06:30	22.4	33.1	47.4	54.6	36.7
07:00	22.4	33.1	47.4	54.6	36.7
07:30	22.4	29.6	51.1	54.6	40.2
08:00	22.4	29.6	51.1	54.6	40.2
08:30	22.4	29.6	51.1	54.6	40.2
09:00	22.4	29.6	54.6	54.6	40.2
09:30	25.9	29.6	54.6	51.1	40.2
10:00	25.9	29.6	54.6	51.1	40.2
10:30	33.1	25.9	54.6	51.1	40.2
11:00	36.7	25.9	51.1	51.1	40.2
11:30	36.7	25.9	51.1	47.4	40.2
12:00	40.2	22.4	51.1	47.4	40.2
12:30	40.2	22.4	47.4	47.4	40.2
13:00	40.2	22.4	47.4	47.4	40.2
13:30	40.2	22.4	47.4	47.4	40.2
14:00	40.2	22.4	47.4	47.4	40.2
14:30	40.2	22.4	47.4	47.4	40.2
15:00	40.2	22.4	47.4	47.4	40.2
15:30	40.2	25.9	47.4	47.4	40.2
16:00	40.2	25.9	47.4	47.4	40.2
16:30	40.2	25.9	47.4	43.9	40.2
17:00	40.2	25.9	47.4	43.9	40.2
17:30	40.2	25.9	47.4	43.9	40.2
18:00	40.2	25.9	47.4	43.9	40.2
18:30	40.2	25.9	47.4	43.9	40.2
19:00	40.2	25.9	47.4	43.9	40.2
19:30	40.2	25.9	47.4	43.9	40.2
20:00	40.2	25.9	47.4	47.4	40.2
20:30	40.2	25.9	51.1	47.4	40.2
21:00	40.2	25.9	51.1	47.4	40.2
21:30	40.2	29.6	51.1	47.4	40.2
22:00	40.2	29.6	51.1	47.4	40.2
22:30	40.2	29.6	51.1	47.4	40.2
23:00	40.2	29.6	51.1	47.4	40.2
23:30	40.2	29.6	54.6	47.4	40.2
24:00	40.2	29.6	54.6	43.9	40.2

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	June 2	June 3	June 4	June 5	June 6
00:30	40.2	33.5	31.2	42.3	75.7
01:00	40.2	33.5	31.2	42.3	75.7
01:30	40.2	33.5	31.2	42.3	75.7
02:00	40.2	33.5	31.2	42.3	75.7
02:30	40.2	33.5	31.2	42.3	75.7
03:00	40.2	33.5	31.2	42.3	75.7
03:30	40.2	33.5	31.2	42.3	75.7
04:00	40.2	33.5	31.2	42.3	75.7
04:30	40.2	33.5	31.2	42.3	73.4
05:00	40.2	33.5	31.2	42.3	73.4
05:30	40.2	33.5	31.2	40.0	73.4
06:00	40.2	33.5	31.2	40.0	73.4
06:30	40.2	33.5	31.2	42.3	73.4
07:00	40.2	33.5	31.2	44.5	73.4
07:30	40.2	33.5	31.2	48.8	73.4
08:00	40.2	33.5	31.2	48.8	73.4
08:30	40.2	33.5	31.2	48.8	73.4
09:00	40.2	33.5	31.2	53.3	73.4
09:30	40.2	33.5	28.9	57.9	73.4
10:00	40.2	33.5	28.9	59.9	73.4
10:30	40.2	33.5	28.9	59.9	73.4
11:00	36.7	33.5	28.9	62.2	71.2
11:30	33.1	33.5	28.9	64.4	71.2
12:00	33.5	33.5	28.9	64.4	71.2
12:30	33.5	31.2	28.9	64.4	71.2
13:00	33.5	31.2	28.9	75.7	68.9
13:30	33.5	31.2	28.9	75.7	68.9
14:00	33.5	31.2	28.9	75.7	68.9
14:30	33.5	31.2	28.9	75.7	66.7
15:00	33.5	31.2	28.9	75.7	66.7
15:30	33.5	31.2	28.9	75.7	66.7
16:00	33.5	31.2	28.9	75.7	66.7
16:30	33.5	31.2	28.9	75.7	66.7
17:00	33.5	31.2	28.9	75.7	64.4
17:30	33.5	31.2	28.9	75.7	62.2
18:00	33.5	31.2	28.9	75.7	62.2
18:30	33.5	31.2	28.9	75.7	62.2
19:00	33.5	31.2	28.9	75.7	62.2
19:30	33.5	31.2	28.9	75.7	62.2
20:00	33.5	31.2	28.9	75.7	62.2
20:30	33.5	31.2	31.2	75.7	59.9
21:00	33.5	31.2	31.2	75.7	59.9
21:30	33.5	31.2	33.5	75.7	55.6
22:00	33.5	31.2	35.5	75.7	55.6
22:30	33.5	31.2	37.8	75.7	55.6
23:00	33.5	31.2	40.0	75.7	55.6
23:30	33.5	31.2	42.3	75.7	53.3
24:00	33.5	31.2	42.3	75.7	53.3

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	June 7	June 8	June 9	June 10	June 15
00:30	53.3	46.6	45.4	633	M
01:00	53.3	46.6	45.4	621	M
01:30	53.3	46.6	45.4	608	M
02:00	53.3	46.6	45.4	594	M
02:30	53.3	46.6	43.1	576	M
03:00	53.3	46.6	43.1	549	M
03:30	53.3	46.6	43.1	506	M
04:00	53.3	46.4	43.1	477	M
04:30	53.3	45.6	43.1	454	M
05:00	53.3	45.6	43.1	434	M
05:30	53.3	45.6	43.1	427	M
06:00	55.6	45.6	43.1	425	M
06:30	55.6	45.6	43.1	432	M
07:00	55.6	45.6	43.1	443	M
07:30	55.6	45.6	43.1	461	M
08:00	53.3	45.6	43.1	477	M
08:30	53.3	45.6	43.1	504	M
09:00	53.3	45.6	43.1	511	M
09:30	51.1	45.6	43.1	531	M
10:00	51.1	45.6	43.1	540	141
10:30	51.1	45.6	40.8	591	139
11:00	51.1	45.6	40.8	540	148
11:30	51.1	45.4	40.8	538	150
12:00	51.1	45.4	40.8	538	152
12:30	51.1	45.4	40.8	536	152
13:00	51.1	45.4	40.8	523	152
13:30	51.1	45.4	40.8	524	152
14:00	51.1	45.4	54.4	506	152
14:30	51.1	45.4	63.6	486	150
15:00	51.1	45.4	79.4	468	148
15:30	51.1	45.4	90.7	443	148
16:00	51.1	45.4	102	421	148
16:30	51.1	45.4	145	396	148
17:00	51.1	45.4	168	375	146
17:30	51.1	45.4	202	355	146
18:00	53.3	45.4	236	335	146
18:30	53.3	45.4	292	315	146
19:00	53.3	45.4	360	306	143
19:30	51.1	45.4	428	297	143
20:00	51.1	45.4	519	294	143
20:30	51.1	45.4	587	292	141
21:00	51.1	45.4	621	290	141
21:30	51.1	45.4	655	285	137
22:00	51.1	45.4	666	283	M
22:30	51.1	45.4	667	278	M
23:00	48.8	45.4	667	272	M
23:30	46.6	45.4	657	M	M
24:00	46.6	45.4	644	M	M

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	June 17	June 18	June 19	June 20	June 21
00:30	M	M	88.2	76.1	73.6
01:00	M	M	88.2	76.1	73.6
01:30	M	M	88.2	76.1	73.6
02:00	M	M	88.2	76.1	73.6
02:30	M	M	88.2	76.1	76.1
03:00	M	M	85.7	76.1	76.1
03:30	M	M	85.7	76.1	76.1
04:00	M	M	85.7	76.1	76.1
04:30	M	M	85.7	76.1	76.1
05:00	M	M	83.3	76.1	76.1
05:30	M	M	83.3	73.6	76.1
06:00	103	M	83.3	73.6	76.1
06:30	103	M	83.3	73.6	76.1
07:00	103	M	83.3	73.6	76.1
07:30	103	M	83.3	73.6	76.1
08:00	M	M	83.3	73.6	76.1
08:30	M	M	83.3	71.2	78.6
09:00	M	M	83.3	71.2	78.6
09:30	M	M	83.3	71.2	78.6
10:00	M	M	83.3	71.2	78.6
10:30	M	M	83.3	71.2	78.6
11:00	M	M	83.3	71.2	78.6
11:30	M	M	83.3	71.2	81.0
12:00	M	103	83.3	71.2	81.0
12:30	M	100	81.0	71.2	81.0
13:00	M	100	78.6	71.2	81.0
13:30	M	97.8	76.1	71.2	81.0
14:00	M	97.8	76.1	71.2	81.0
14:30	M	95.6	73.6	71.2	81.0
15:00	M	95.6	73.6	71.2	81.0
15:30	M	95.6	71.2	71.2	81.0
16:00	M	95.6	71.2	71.2	81.0
16:30	M	95.6	71.2	71.2	78.6
17:00	M	95.6	71.2	71.2	78.6
17:30	M	95.6	71.2	71.2	78.6
18:00	M	93.1	71.2	71.2	78.6
18:30	M	93.1	71.2	71.2	78.6
19:00	M	93.1	71.2	71.2	78.6
19:30	M	93.1	71.2	71.2	78.6
20:00	M	93.1	71.2	71.2	78.6
20:30	M	93.1	71.2	71.2	78.6
21:00	M	90.7	71.2	71.2	78.6
21:30	M	90.7	71.2	71.2	78.6
22:00	M	90.7	71.2	71.2	78.6
22:30	M	90.7	73.6	71.2	78.6
23:00	M	88.2	73.6	71.2	78.6
23:30	M	88.2	73.6	71.2	78.6
24:00	M	88.2	73.6	71.2	78.6

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	June 7	June 8	June 9	June 10	June 15
00:30	53.3	46.6	45.4	633	M
01:00	53.3	46.6	45.4	621	M
01:30	53.3	46.6	45.4	608	M
02:00	53.3	46.6	45.4	594	M
02:30	53.3	46.6	43.1	576	M
03:00	53.3	46.6	43.1	549	M
03:30	53.3	46.6	43.1	506	M
04:00	53.3	46.4	43.1	477	M
04:30	53.3	45.6	43.1	454	M
05:00	53.3	45.6	43.1	434	M
05:30	53.3	45.6	43.1	427	M
06:00	55.6	45.6	43.1	425	M
06:30	55.6	45.6	43.1	432	M
07:00	55.6	45.6	43.1	443	M
07:30	55.6	45.6	43.1	461	M
08:00	53.3	45.6	43.1	477	M
08:30	53.3	45.6	43.1	504	M
09:00	53.3	45.6	43.1	511	M
09:30	51.1	45.6	43.1	531	M
10:00	51.1	45.6	43.1	540	141
10:30	51.1	45.6	40.8	591	139
11:00	51.1	45.6	40.8	540	148
11:30	51.1	45.4	40.8	538	150
12:00	51.1	45.4	40.8	538	152
12:30	51.1	45.4	40.8	536	152
13:00	51.1	45.4	40.8	523	152
13:30	51.1	45.4	40.8	524	152
14:00	51.1	45.4	54.4	506	152
14:30	51.1	45.4	63.6	486	150
15:00	51.1	45.4	79.4	468	148
15:30	51.1	45.4	90.7	443	148
16:00	51.1	45.4	102	421	148
16:30	51.1	45.4	145	396	148
17:00	51.1	45.4	168	375	146
17:30	51.1	45.4	202	355	146
18:00	53.3	45.4	236	335	146
18:30	53.3	45.4	292	315	146
19:00	53.3	45.4	360	306	143
19:30	51.1	45.4	428	297	143
20:00	51.1	45.4	519	294	143
20:30	51.1	45.4	587	292	141
21:00	51.1	45.4	621	290	141
21:30	51.1	45.4	655	285	137
22:00	51.1	45.4	666	283	M
22:30	51.1	45.4	667	278	M
23:00	48.8	45.4	667	272	M
23:30	46.6	45.4	657	M	M
24:00	46.6	45.4	644	M	M

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	June 17	June 18	June 19	June 20	June 21
00:30	M	M	88.2	76.1	73.6
01:00	M	M	88.2	76.1	73.6
01:30	M	M	88.2	76.1	73.6
02:00	M	M	88.2	76.1	73.6
02:30	M	M	88.2	76.1	76.1
03:00	M	M	85.7	76.1	76.1
03:30	M	M	85.7	76.1	76.1
04:00	M	M	85.7	76.1	76.1
04:30	M	M	85.7	76.1	76.1
05:00	M	M	83.3	76.1	76.1
05:30	M	M	83.3	73.6	76.1
06:00	103	M	83.3	73.6	76.1
06:30	103	M	83.3	73.6	76.1
07:00	103	M	83.3	73.6	76.1
07:30	103	M	83.3	73.6	76.1
08:00	M	M	83.3	73.6	76.1
08:30	M	M	83.3	71.2	78.6
09:00	M	M	83.3	71.2	78.6
09:30	M	M	83.3	71.2	78.6
10:00	M	M	83.3	71.2	78.6
10:30	M	M	83.3	71.2	78.6
11:00	M	M	83.3	71.2	78.6
11:30	M	M	83.3	71.2	81.0
12:00	M	103	83.3	71.2	81.0
12:30	M	100	81.0	71.2	81.0
13:00	M	100	78.6	71.2	81.0
13:30	M	97.8	76.1	71.2	81.0
14:00	M	97.8	76.1	71.2	81.0
14:30	M	95.6	73.6	71.2	81.0
15:00	M	95.6	73.6	71.2	81.0
15:30	M	95.6	71.2	71.2	81.0
16:00	M	95.6	71.2	71.2	81.0
16:30	M	95.6	71.2	71.2	78.6
17:00	M	95.6	71.2	71.2	78.6
17:30	M	95.6	71.2	71.2	78.6
18:00	M	93.1	71.2	71.2	78.6
18:30	M	93.1	71.2	71.2	78.6
19:00	M	93.1	71.2	71.2	78.6
19:30	M	93.1	71.2	71.2	78.6
20:00	M	93.1	71.2	71.2	78.6
20:30	M	93.1	71.2	71.2	78.6
21:00	M	90.7	71.2	71.2	78.6
21:30	M	90.7	71.2	71.2	78.6
22:00	M	90.7	71.2	71.2	78.6
22:30	M	90.7	73.6	71.2	78.6
23:00	M	88.2	73.6	71.2	78.6
23:30	M	88.2	73.6	71.2	78.6
24:00	M	88.2	73.6	71.2	78.6

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	June 22	June 23	June 24	June 25	June 26
00:30	76.1	78.6	74.3	95.4	81.8
01:00	76.1	78.6	74.3	93.5	80.0
01:30	76.1	78.6	72.2	91.5	77.9
02:00	76.1	78.6	72.2	89.6	77.9
02:30	76.1	78.6	72.2	91.5	77.9
03:00	76.1	78.6	72.2	95.4	77.9
03:30	76.1	78.6	72.2	97.4	77.9
04:00	76.1	78.6	72.2	103	70.4
04:30	76.1	78.6	72.2	105	68.3
05:00	76.1	78.6	72.2	105	68.3
05:30	76.1	78.6	72.2	105	68.3
06:00	76.1	78.6	74.3	105	68.3
06:30	76.1	78.6	74.3	105	68.3
07:00	76.1	78.6	74.3	105	68.3
07:30	76.1	81.0	74.3	105	68.3
08:00	76.1	81.0	76.1	105	68.3
08:30	78.6	81.0	77.9	107	66.5
09:00	78.6	81.0	80.0	107	66.5
09:30	78.6	81.0	83.9	107	66.5
10:00	78.6	81.0	85.7	107	66.5
10:30	78.6	81.0	85.7	107	64.6
11:00	78.6	81.0	87.6	107	64.6
11:30	81.0	81.0	87.6	107	64.6
12:00	83.3	81.0	87.6	107	64.6
12:30	83.3	81.0	87.6	107	62.6
13:00	81.0	81.0	87.6	107	62.6
13:30	81.0	81.0	89.6	107	62.6
14:00	81.0	81.0	91.5	107	60.7
14:30	81.0	81.0	91.5	107	60.7
15:00	81.0	78.6	93.5	107	58.7
15:30	78.6	78.6	93.5	105	58.7
16:00	78.6	76.1	93.5	101	58.7
16:30	78.6	76.1	93.5	97.4	56.8
17:00	78.6	76.1	95.4	95.4	56.8
17:30	78.6	76.1	97.4	93.5	56.8
18:00	78.6	76.1	99.3	91.5	56.8
18:30	78.6	76.1	101	89.6	56.8
19:00	78.6	76.1	103	89.6	54.8
19:30	78.6	72.2	103	87.6	54.8
20:00	78.6	72.2	103	87.6	54.8
20:30	78.6	72.2	103	85.7	54.8
21:00	78.6	72.2	101	85.7	54.8
21:30	78.6	74.3	101	83.9	54.8
22:00	78.6	74.3	101	83.9	54.8
22:30	78.6	74.3	101	83.9	54.8
23:00	78.6	74.3	99.3	83.9	54.8
23:30	78.6	74.3	97.4	83.9	54.8
24:00	78.6	74.3	95.4	83.9	54.8

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	June 27	June 28	June 29	June 30	July 1
00:30	54.8	54.8	43.3	118	78.4
01:00	54.8	54.8	43.3	116	78.4
01:30	54.8	54.8	43.3	116	76.5
02:00	54.8	54.8	43.3	114	76.5
02:30	54.8	54.8	43.3	113	76.5
03:00	54.8	51.1	43.3	111	74.7
03:30	54.8	51.1	43.3	111	74.7
04:00	54.8	51.1	43.3	107	74.7
04:30	54.8	51.1	47.8	105	74.7
05:00	54.8	51.1	54.6	104	74.7
05:30	54.8	49.0	63.6	102	74.7
06:00	54.8	49.0	70.4	102	73.0
06:30	54.8	49.0	77.1	100	73.0
07:00	51.1	49.0	81.6	100	73.0
07:30	51.1	43.3	88.4	100	69.5
08:00	51.1	43.3	95.2	100	67.5
08:30	51.1	43.3	99.7	100	67.5
09:00	51.1	43.3	104	100	67.5
09:30	51.1	43.3	109	100	67.5
10:00	51.1	43.3	113	98.2	67.5
10:30	49.0	43.3	116	96.4	65.6
11:00	49.0	43.3	120	96.4	65.6
11:30	49.0	43.3	125	96.4	65.6
12:00	49.0	43.3	127	94.6	64.0
12:30	49.0	43.3	129	92.9	64.0
13:00	49.0	43.3	127	91.1	62.2
13:30	49.0	43.3	127	91.1	62.2
14:00	49.0	43.3	125	91.1	62.2
14:30	49.0	43.3	125	91.1	62.2
15:00	49.0	43.3	125	89.2	62.2
15:30	49.0	43.3	125	85.5	62.2
16:00	49.0	43.3	125	83.9	62.2
16:30	49.0	43.3	124	83.9	62.2
17:00	49.0	43.3	124	83.9	62.2
17:30	49.0	43.3	124	83.9	62.2
18:00	49.0	43.3	124	83.9	62.2
18:30	49.0	43.3	124	82.0	62.2
19:00	51.1	43.3	124	82.0	62.2
19:30	51.1	43.3	124	82.0	62.2
20:00	51.1	43.3	124	82.0	62.2
20:30	51.1	43.3	122	78.4	62.2
21:00	52.9	43.3	122	78.4	62.2
21:30	52.9	43.3	122	78.4	62.2
22:00	52.9	43.3	122	78.4	62.2
22:30	52.9	43.3	120	78.4	62.2
23:00	52.9	43.3	120	78.4	62.2
23:30	54.8	43.3	118	78.4	62.2
24:00	54.8	43.3	118	78.4	62.2

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	July 2	July 3	July 4	July 5	July 6
00:30	62.2	60.3	47.4	37.1	24.9
01:00	62.2	60.3	47.4	37.1	24.9
01:30	62.2	60.3	45.4	37.1	24.9
02:00	62.2	60.3	45.4	37.1	24.9
02:30	62.2	60.3	45.4	35.1	24.9
03:00	62.2	60.3	45.4	35.1	24.9
03:30	62.2	60.3	45.4	35.1	24.9
04:00	62.2	60.3	45.4	35.1	26.9
04:30	62.2	60.3	45.4	35.1	28.9
05:00	62.2	60.3	45.4	35.1	31.0
05:30	62.2	60.3	45.4	33.1	33.1
06:00	62.2	60.3	45.4	33.1	33.1
06:30	62.2	62.2	45.4	33.1	33.1
07:00	62.2	58.5	45.4	33.1	35.1
07:30	62.2	58.5	45.4	33.1	35.1
08:00	62.2	58.5	45.4	33.1	35.1
08:30	62.2	58.5	43.3	31.0	35.1
09:00	62.2	58.5	43.3	31.0	35.1
09:30	62.2	56.6	41.2	31.0	35.1
10:00	62.2	54.8	39.2	28.9	35.1
10:30	62.2	53.1	37.1	26.9	37.1
11:00	62.2	51.3	37.1	24.9	37.1
11:30	62.2	49.4	37.1	24.9	37.1
12:00	62.2	49.4	37.1	24.9	37.1
12:30	60.3	49.4	37.1	24.9	37.1
13:00	60.3	49.4	37.1	24.9	37.1
13:30	56.5	49.4	37.1	24.9	37.1
14:00	53.1	49.4	37.1	24.9	39.2
14:30	51.3	49.4	37.1	24.9	39.2
15:00	51.3	49.4	37.1	24.9	39.2
15:30	51.3	49.4	37.1	24.9	39.2
16:00	51.3	49.4	37.1	24.9	39.2
16:30	51.3	49.4	37.1	24.9	39.2
17:00	51.3	49.4	37.1	24.9	39.2
17:30	52.9	49.4	37.1	24.9	39.2
18:00	52.9	49.4	37.1	24.9	39.2
18:30	52.9	49.4	37.1	28.9	39.2
19:00	52.9	49.4	37.1	28.9	39.2
19:30	54.8	49.4	37.1	28.9	39.2
20:00	54.8	49.4	37.1	28.9	39.2
20:30	56.6	47.4	37.1	28.9	41.2
21:00	56.6	47.4	37.1	28.9	41.2
21:30	56.6	47.4	37.1	26.9	41.2
22:00	58.5	47.4	37.1	26.9	41.2
22:30	58.5	47.4	37.1	26.9	41.2
23:00	60.3	47.4	37.1	26.9	41.2
23:30	60.3	47.4	37.1	24.9	41.2
24:00	60.3	47.4	37.1	24.9	41.2

TABLE A.1 STREAM DISCHARGE ($\ell \cdot sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	July 7	July 8	July 9	July 10	July 11
00:30	41.2	26.9	35.1	43.3	37.1
01:00	41.2	26.9	35.1	43.3	37.1
01:30	41.2	26.9	35.1	43.3	37.1
02:00	41.2	26.9	35.1	43.3	37.1
02:30	41.2	26.9	35.1	43.3	37.1
03:00	41.2	26.9	35.1	43.3	37.1
03:30	41.2	28.9	35.1	43.3	37.1
04:00	41.2	28.9	35.1	43.3	37.1
04:30	41.2	28.9	35.1	43.3	37.1
05:00	41.2	28.9	35.1	43.3	37.1
05:30	41.2	28.9	37.1	43.3	37.1
06:00	39.2	28.9	37.1	43.3	37.1
06:30	39.2	28.9	37.1	43.3	35.1
07:00	39.2	28.9	37.1	43.3	35.1
07:30	39.2	28.9	37.1	43.3	35.1
08:00	39.2	28.9	35.1	43.3	35.1
08:30	39.2	28.9	35.1	43.3	35.1
09:00	39.2	28.9	35.1	43.3	35.1
09:30	37.1	28.9	35.1	43.3	37.1
10:00	35.1	28.9	35.1	43.3	38.2
10:30	33.1	28.9	35.1	43.3	39.2
11:00	26.9	28.9	35.1	43.3	39.2
11:30	24.9	28.9	35.1	43.3	39.2
12:00	24.9	28.9	35.1	43.3	39.2
12:30	24.9	31.0	37.1	41.2	39.2
13:00	24.9	31.0	37.1	41.2	39.2
13:30	24.9	31.0	37.1	41.2	39.2
14:00	24.9	31.0	37.1	41.2	39.2
14:30	24.9	31.0	37.1	41.2	39.2
15:00	24.9	31.0	37.1	41.2	39.2
15:30	24.9	31.0	37.1	41.2	39.2
16:00	24.9	31.0	35.1	41.2	39.2
16:30	24.9	31.0	35.1	39.2	39.2
17:00	24.9	31.0	35.1	39.2	39.2
17:30	24.9	31.0	35.1	39.2	39.2
18:00	24.9	31.0	35.1	39.2	39.2
18:30	24.9	31.0	35.1	39.2	39.2
19:00	24.9	31.0	37.1	39.2	39.2
19:30	24.9	31.0	39.2	39.2	39.2
20:00	24.9	31.0	39.2	39.2	39.2
20:30	24.9	33.1	41.2	39.2	39.2
21:00	24.9	33.1	41.2	39.2	39.2
21:30	24.9	33.1	43.3	39.2	39.2
22:00	24.9	33.1	45.4	39.2	39.2
22:30	26.9	33.1	45.4	37.1	39.2
23:00	26.9	33.1	45.4	37.1	39.2
23:30	26.9	33.1	45.4	37.1	39.2
24:00	26.9	35.1	45.4	37.1	39.2

TABLE A.1 STREAM DISCHARGE ($\ell \cdot sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	July 12	July 13	July 14	July 15	July 16
00:30	39.2	38.6	28.1	22.2	24.9
01:00	39.2	38.6	28.1	22.2	24.9
01:30	41.2	38.6	28.1	22.2	24.9
02:00	41.2	38.6	28.1	22.2	24.9
02:30	41.2	38.6	29.8	22.2	24.9
03:00	41.2	38.6	29.8	22.2	24.9
03:30	41.2	38.6	29.8	22.2	24.9
04:00	41.2	37.1	31.2	22.2	24.9
04:30	41.2	37.1	31.2	23.8	24.9
05:00	41.2	37.1	31.2	23.8	24.9
05:30	41.2	37.1	29.8	23.8	24.9
06:00	41.2	37.1	29.8	23.8	24.9
06:30	41.2	37.1	29.8	23.8	22.8
07:00	41.2	37.1	29.8	23.8	22.8
07:30	41.2	37.1	29.8	23.8	22.8
08:00	41.2	37.1	29.8	23.8	22.8
08:30	41.2	37.1	28.1	23.8	22.8
09:00	41.2	35.7	28.1	25.3	22.8
09:30	41.2	35.7	28.1	25.3	22.8
10:00	41.2	34.1	26.7	23.8	22.8
10:30	41.2	34.1	26.7	23.8	22.8
11:00	41.2	32.6	25.3	22.2	22.8
11:30	41.2	32.6	23.8	22.2	22.8
12:00	41.2	31.2	22.2	20.7	22.8
12:30	41.2	31.2	22.2	20.7	22.8
13:00	41.2	29.8	22.2	20.7	20.7
13:30	41.2	29.8	20.7	20.7	20.7
14:00	41.2	29.8	20.7	20.7	20.7
14:30	41.2	28.1	20.7	20.7	20.7
15:00	41.2	28.1	20.7	20.7	20.7
15:30	39.2	28.1	20.7	20.7	20.7
16:00	39.2	28.1	20.7	20.7	20.7
16:30	39.2	26.7	20.7	20.7	20.7
17:00	39.2	26.7	20.7	20.7	20.7
17:30	39.2	26.7	20.7	20.7	20.7
18:00	39.2	26.7	20.7	20.7	20.7
18:30	39.2	26.7	20.7	20.7	22.8
19:00	37.1	25.3	20.7	22.8	22.8
19:30	37.1	25.3	20.7	24.9	22.8
20:00	37.1	25.3	20.7	24.9	22.8
20:30	37.1	25.3	20.7	24.9	22.8
21:00	37.1	25.3	20.7	24.9	22.8
21:30	37.1	26.7	20.7	24.9	22.8
22:00	37.1	28.1	20.7	24.9	22.8
22:30	38.6	28.1	20.7	24.9	22.8
23:00	38.6	28.1	20.7	24.9	22.8
23:30	38.6	28.1	20.7	24.9	22.8
24:00	38.6	28.1	20.7	24.9	22.8

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	July 17	July 18	July 19	July 20	July 21
00:30	22.8	24.0	113	52.3	38.6
01:00	22.8	24.0	113	52.3	38.6
01:30	22.8	24.0	113	52.3	38.6
02:00	22.8	24.0	113	50.1	38.6
02:30	22.8	24.0	113	50.1	38.6
03:00	22.8	24.0	113	47.8	38.6
03:30	22.8	24.0	111	47.8	38.6
04:00	22.8	24.0	109	47.8	38.6
04:30	22.8	24.0	106	47.8	38.6
05:00	22.8	24.0	104	47.8	38.6
05:30	22.8	24.0	102	47.8	38.6
06:00	22.8	24.0	99.7	47.8	38.6
06:30	20.7	24.0	97.4	47.8	38.6
07:00	20.7	24.0	97.4	47.8	38.6
07:30	20.7	24.0	97.4	47.8	37.1
08:00	20.7	39.4	97.4	47.8	37.1
08:30	20.7	48.6	95.2	43.3	35.7
09:00	20.7	71.6	93.5	43.3	34.5
09:30	18.7	90.0	92.9	43.3	34.5
10:00	18.7	94.6	92.9	43.3	34.5
10:30	18.7	96.8	92.9	43.3	34.5
11:00	18.7	96.8	90.7	43.3	33.1
11:30	18.7	99.3	90.7	41.2	33.1
12:00	18.7	99.3	88.4	41.2	33.1
12:30	21.0	104	86.1	41.2	33.1
13:00	21.0	106	83.9	41.2	33.1
13:30	21.0	108	79.4	41.2	33.1
14:00	21.0	108	79.4	41.2	33.1
14:30	21.0	111	94.9	41.2	33.1
15:00	21.0	113	72.6	41.2	33.1
15:30	21.0	115	70.4	41.2	33.1
16:00	21.0	118	70.4	41.2	33.1
16:30	21.0	120	68.1	39.8	33.1
17:00	21.0	122	68.1	39.8	33.1
17:30	21.0	125	68.1	39.8	33.1
18:00	21.0	125	63.6	39.8	33.1
18:30	21.0	125	59.1	38.6	33.1
19:00	21.0	125	56.8	38.6	33.1
19:30	22.5	122	54.6	38.6	33.1
20:00	22.5	122	54.4	38.6	33.1
20:30	22.5	122	54.4	38.6	33.1
21:00	22.5	122	54.4	38.6	33.1
21:30	22.5	122	54.4	38.6	34.5
22:00	22.5	120	54.4	38.6	34.5
22:30	22.5	120	54.4	38.6	34.5
23:00	22.5	120	54.4	38.6	34.5
23:30	22.5	117	54.4	38.6	34.5
24:00	22.5	113	54.4	38.6	34.5

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	July 22	July 23	July 24	July 25	July 26
00:30	34.5	33.1	M	53.6	43.3
01:00	34.5	33.1	M	53.6	43.3
01:30	34.5	33.1	M	53.6	43.3
02:00	34.5	33.1	M	53.6	43.3
02:30	34.5	33.1	M	53.6	43.3
03:00	34.5	33.1	M	53.6	43.3
03:30	34.5	33.1	M	53.6	43.3
04:00	34.5	33.1	M	53.6	43.3
04:30	34.5	33.1	M	53.6	43.3
05:00	34.5	33.1	M	53.6	43.3
05:30	34.5	33.1	M	53.6	43.3
06:00	34.5	33.1	M	53.6	43.3
06:30	34.5	33.1	M	48.4	43.3
07:00	34.5	33.1	M	48.4	43.3
07:30	34.5	33.1	M	48.4	43.3
08:00	34.5	33.1	M	48.4	43.3
08:30	34.5	33.1	M	43.3	43.3
09:00	34.5	33.1	M	43.3	43.3
09:30	34.5	33.1	M	41.0	41.0
10:00	34.5	33.1	M	38.8	38.8
10:30	34.5	33.1	M	38.8	38.8
11:00	34.5	33.1	M	38.8	38.8
11:30	34.5	33.1	53.6	38.8	38.8
12:00	34.5	33.1	53.6	38.8	38.8
12:30	34.5	30.8	53.6	36.5	36.5
13:00	33.1	30.8	53.6	36.5	36.5
13:30	33.1	28.5	53.6	36.5	36.5
14:00	33.1	28.5	53.6	36.5	36.5
14:30	33.1	28.5	53.6	36.5	36.5
15:00	33.1	28.5	53.6	36.5	36.5
15:30	33.1	28.5	53.6	36.5	36.5
16:00	33.1	28.5	53.6	36.5	36.5
16:30	31.6	28.5	53.6	36.5	38.8
17:00	31.6	26.3	53.6	36.5	38.8
17:30	31.6	26.3	53.6	38.8	38.8
18:00	31.6	26.3	53.6	38.8	38.8
18:30	31.6	26.3	53.6	38.8	38.8
19:00	31.6	26.3	53.6	38.8	38.8
19:30	30.4	26.3	48.4	38.8	38.8
20:00	30.4	26.3	48.4	38.8	38.8
20:30	30.4	26.3	48.4	41.0	43.3
21:00	30.4	26.3	48.4	41.0	43.3
21:30	31.6	26.3	48.4	41.0	43.3
22:00	31.6	M	48.4	41.0	43.3
22:30	33.1	M	48.4	41.0	43.3
23:00	33.1	M	48.4	43.3	43.3
23:30	33.1	M	48.4	43.3	43.3
24:00	33.1	M	53.6	43.3	43.3

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	July 27	July 28	July 29	July 30	July 31
00:30	43.3	41.0	43.3	30.2	59.1
01:00	43.3	41.0	43.3	30.2	59.1
01:30	43.3	41.0	43.3	30.2	59.1
02:00	43.3	41.0	43.3	30.2	59.1
02:30	43.3	43.3	43.3	27.9	61.3
03:00	43.3	43.3	43.3	27.9	61.3
03:30	43.3	43.3	43.3	27.9	61.3
04:00	43.3	43.3	43.3	27.9	61.3
04:30	43.3	43.3	43.3	27.9	61.3
05:00	43.3	43.3	43.3	27.9	61.3
05:30	43.3	43.3	43.3	27.9	61.3
06:00	43.3	43.3	43.3	27.9	61.3
06:30	43.3	43.3	43.3	27.9	61.3
07:00	43.3	43.3	43.3	27.9	61.3
07:30	43.3	43.3	43.3	27.9	61.3
08:00	43.3	43.3	43.3	27.9	61.3
08:30	43.3	43.3	43.3	27.9	61.3
09:00	43.3	43.3	43.3	27.9	61.3
09:30	43.3	43.3	43.3	27.9	61.3
10:00	43.3	43.3	43.3	27.9	61.3
10:30	43.3	43.3	41.0	27.9	63.6
11:00	40.6	43.3	41.0	27.9	63.6
11:30	38.8	43.3	38.8	27.9	63.6
12:00	38.8	43.3	38.8	27.9	63.6
12:30	36.5	43.3	38.8	27.9	61.3
13:00	36.5	41.0	38.8	27.9	61.3
13:30	36.5	41.0	38.8	27.9	61.3
14:00	36.5	38.8	38.8	27.9	61.3
14:30	36.5	38.8	36.5	25.7	61.3
15:00	36.5	38.8	36.5	25.7	61.3
15:30	36.5	38.8	36.5	25.7	61.3
16:00	36.5	38.8	36.5	25.7	59.1
16:30	36.5	38.8	36.5	25.7	54.6
17:00	36.5	36.5	36.5	27.9	52.3
17:30	36.5	36.5	36.5	38.8	50.1
18:00	36.5	36.5	36.5	45.6	50.1
18:30	36.5	36.5	36.5	45.6	50.1
19:00	36.5	36.5	36.5	45.6	50.1
19:30	36.5	36.5	36.5	45.6	50.1
20:00	36.5	36.5	34.3	52.3	50.1
20:30	36.5	38.8	34.3	54.6	52.3
21:00	36.5	38.8	34.3	54.6	52.3
21:30	36.5	38.8	34.3	54.6	52.3
22:00	36.5	38.8	32.0	54.6	52.3
22:30	36.5	41.0	32.0	56.8	52.3
23:00	36.5	41.0	32.0	59.1	52.3
23:30	38.8	43.3	32.0	59.1	52.3
24:00	38.8	43.3	30.2	59.1	52.3

TABLE A.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) OLD SAMS RIVER (cont'd)

Time	August 1	August 2	August 3
00:30	52.3	43.3	M
01:00	52.3	43.3	M
01:30	52.3	43.3	M
02:00	52.3	43.3	M
02:30	52.3	43.3	M
03:00	52.3	43.3	M
03:30	52.3	M	M
04:00	52.3	M	M
04:30	52.3	M	M
05:00	52.3	M	M
05:30	52.3	M	M
06:00	52.3	M	M
06:30	52.3	M	M
07:00	52.3	M	M
07:30	52.3	M	M
08:00	52.3	M	M
08:30	52.3	M	M
09:00	52.3	M	35.1
09:30	50.1	M	M
10:00	50.1	M	M
10:30	47.8	M	M
11:00	45.6	M	M
11:30	43.3	M	M
12:00	43.3	M	M
12:30	41.0	M	M
13:00	41.0	M	M
13:30	41.0	M	M
14:00	41.0	M	M
14:30	41.0	M	M
15:00	41.0	M	M
15:30	41.0	M	M
16:00	41.0	24.9	M
16:30	41.0	M	M
17:00	41.0	M	M
17:30	41.0	M	M
18:00	41.0	M	M
18:30	41.0	M	M
19:00	41.0	M	M
19:30	41.0	M	M
20:00	41.0	M	M
20:30	41.0	M	M
21:00	41.0	M	M
21:30	41.0	M	M
22:00	41.0	M	M
22:30	43.3	M	M
23:00	43.3	M	M
23:30	43.3	M	M
24:00	43.3	M	M

APPENDIX B

TABLE B.1 PRECIPITATION (*mm*) OLD SAMS RIVER

Date	Time*	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
May 20	14:30	0.2	15:30	0.2						
May 21										
May 22	07:30	2.0								
May 23										
May 24										
May 26	01:00	0.6	01:30	1.6	02:00	1.2	09:00	0.2		
May 27										
May 28	07:00	0.2	07:30	0.6	08:00	0.6	08:30	1.6	09:00	0.8
May 28	09:30	0.8	10:00	0.2	10:30	0.2	11:00	0.4	11:30	0.6
May 28	12:00	0.8	12:30	0.6	13:30	0.2				
May 29	12:30	0.2	19:00	0.4	19:30	0.4	20:00	0.4	20:30	0.6
May 29	21:00	1.2	21:30	1.0	22:00	0.6	23:30	0.2		
May 30	00:30	0.2	01:30	0.4	03:00	0.2	11:00	0.2		
May 31										
June 1										
June 2										
June 3										
June 4	05:30	0.2	06:30	0.2	12:30	0.2	14:30	0.4	15:00	1.6
June 4	15:30	0.2	20:30	0.8	21:30	1.2	22:00	1.8	22:30	0.2
June 4	24:00	1.8								
June 5	01:00	0.2	06:30	0.2	07:00	0.2	08:00	0.8	08:30	0.2
June 5	09:00	0.2	09:30	0.2	10:00	1.0	10:30	1.0	11:00	0.4
June 5	11:30	0.6	12:00	0.4	12:30	2.0	13:00	0.8	13:30	0.8
June 5	14:00	0.2	14:30	0.2						
June 6										
June 7										
June 8										

* For the previous half hour

(cont'd)

TABLE B.1 PRECIPITATION (*mm*) OLD SAMS RIVER (cont'd)

Date	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
June 9	11:00	0.2	12:00	0.4	12:30	1.2	13:00	2.8	13:30	3.0
June 9	14:00	2.4	14:30	2.6	15:00	2.6	15:30	2.8	16:00	3.4
June 9	16:30	4.2	17:00	5.0	17:30	5.0	18:00	4.8	18:30	4.2
June 9	19:00	4.6	19:30	2.8	20:00	4.2	20:30	4.4	21:00	2.2
June 9	21:30	2.2	22:00	1.2	22:30	1.0	23:00	1.4	23:30	2.2
June 9	24:00	0.6								
June 10	00:30	1.6	01:00	0.6	01:30	1.0	02:00	0.2	02:30	0.2
June 10	03:00	0.2	03:30	0.2	04:00	0.2	04:30	0.8	05:00	1.2
June 10	05:30	2.0	06:00	2.8	06:30	3.6	07:00	1.8	07:30	2.2
June 10	08:00	1.4	08:30	2.8	09:00	1.8	09:30	0.8	10:00	1.8
June 10	10:30	0.4	11:00	1.0	11:30	1.6	12:00	1.0	12:30	1.6
June 10	13:00	0.2								
June 11										
June 12										
June 13										
June 14	01:30	0.2								
June 15	03:30	0.8	04:00	0.6	04:30	1.0	05:00	3.6	05:30	3.4
June 15	06:00	0.6	06:30	0.4	07:00	1.0	07:30	1.2	08:00	0.8
June 15	08:30	1.4	09:00	0.2	09:30	0.2	10:00	1.0		
June 16										
June 17										
June 18										
June 19	08:30	0.2								
June 20	13:30	0.2	14:00	0.4	16:00	0.2	22:30	0.2		
June 21	03:00	0.4	07:30	0.2	22:30	0.2				
June 22	04:00	0.2	21:00	0.4	21:30	1.0	22:00	0.2	23:30	0.2
June 23	00:30	0.6	01:00	0.6	02:30	0.2	03:00	0.6	03:30	0.4
June 23	04:00	0.6	04:30	0.4	05:00	0.6	05:30	0.6	09:00	0.2
June 23	09:30	0.6								

(cont'd)

TABLE B.1 PRECIPITATION (*mm*) OLD SAMS RIVER (cont'd)

Date	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
June 24	01:30	0.2	02:30	4.0	03:30	0.2	05:00	0.2	05:30	0.2
June 24	06:00	0.2	06:30	0.2	07:00	1.2	07:30	0.4	10:00	0.2
June 24	10:30	0.6	12:00	0.2	18:00	0.2	19:00	0.4	21:30	0.2
June 24	22:30	0.2	23:00	0.8	23:30	0.2	24:00	0.2		
June 25	00:30	0.4	01:00	0.2	01:30	0.4	02:00	1.0	02:30	0.6
June 25	03:00	0.2	03:30	0.2	05:00	0.2				
June 26										
June 27										
June 28	11:00	0.4	13:00	0.2	17:00	0.2	18:30	0.2	24:00	0.2
June 29	01:30	0.6	03:30	0.2	04:00	0.4	04:30	2.2	05:00	2.6
June 29	05:30	1.4	06:00	2.4	06:30	1.4	07:00	0.8	07:30	0.2
June 29	08:00	0.2	09:00	0.2	09:30	0.2	11:00	0.6	12:00	0.4
June 30	02:30	0.2	12:30	0.2						
July 1	15:30	0.2								
July 2	02:30	0.2								
July 3	03:00	0.2	07:00	0.2	08:00	0.2				
July 4	16:00	0.2								
July 5	18:00	0.2	18:30	0.4	19:30	0.2	20:00	0.2	20:30	0.2
July 5	21:00	0.2	21:30	0.4	22:00	0.4	22:30	0.2	23:00	0.2
July 5	23:30	0.2	24:00	0.2						
July 6	00:30	0.2	01:00	0.4	01:30	0.4	02:00	0.4	02:30	0.4
July 6	03:00	0.8	03:30	0.8	04:00	0.6	04:30	0.2	05:00	0.2
July 6	05:30	0.2	07:00	0.2	07:30	0.2	08:00	0.2	09:00	0.4
July 6	10:00	0.2	12:30	0.2	13:00	0.6	13:30	0.2	14:00	0.2
July 6	14:30	0.4	15:00	0.2						
July 7	23:00	0.2								
July 8										
July 9	04:30	0.2								
July 10	05:00	0.2								
July 11	01:30	0.2	09:00	0.2	09:30	0.4	10:00	0.2	21:30	0.2

(cont'd)

TABLE B.1 PRECIPITATION (mm) OLD SAMS RIVER (cont'd)

Date	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
July 11	23:00	0.6								
July 12	00:30	0.2	03:30	0.2	05:30	1.2	06:00	0.4	08:30	0.2
July 13	01:00	0.2								
July 14										
July 15	00:30	0.2								
July 16										
July 17										
July 18	02:00	0.2	04:00	0.2	04:30	0.2	05:00	0.4	05:30	0.4
July 18	06:00	0.8	06:30	1.4	07:00	1.4	07:30	3.4	08:00	4.2
July 18	08:30	6.4	09:00	0.8	10:30	0.2	12:30	0.2	13:00	0.6
July 18	14:00	1.0	16:00	0.2						
July 19										
July 20										
July 21	18:00	0.2	18:30	0.2	19:00	0.2	19:30	1.0	20:00	0.2
July 21	20:30	0.6	21:00	0.2	24:00	0.2				
July 22	02:30	0.2	03:00	0.2	03:30	0.2	04:00	0.2	05:30	0.2
July 23	04:30	0.2								
July 24	02:00	0.2	03:30	0.4	04:00	0.2	04:30	0.2	05:00	0.6
July 24	05:30	0.8	06:30	1.4	07:00	1.0	07:30	1.0	09:00	0.2
July 24	09:30	0.2	11:30	0.2	12:00	0.2	13:00	0.2	15:00	0.2
July 24	16:00	0.2	20:00	0.2	22:00	0.2				
July 25										
July 26										
July 27										
July 28	07:30	0.2	21:00	0.2						
July 29	01:30	0.2	05:00	0.2						
July 30	03:00	0.2	15:00	0.4						
July 31										
August 1										
August 2										

(cont'd)

TABLE B.1 PRECIPITATION (mm) OLD SAMS RIVER

Date	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
August 3	02:30	0.2	03:30	0.4	04:00	0.2	07:30	0.2		
August 4	05:00	0.2	15:00	0.4	15:30	0.6	16:00	0.6	16:30	0.6
August 4	17:00	0.6	19:00	0.2	20:00	0.2	20:30	0.2	22:00	0.2
August 5	01:30	0.2	05:30	0.2	10:00	0.2				
August 6										
August 7	03:30	0.2								
August 8										
August 9										
August 10	04:00	0.6	05:00	0.2	06:30	0.2	07:30	0.2	08:00	0.6
August 11										

APPENDIX C

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER

Time	May 20	May 21	May 22	May 23	May 24	May 25	May 26	May 27	May 28
01:00	M *	-1.0	3.1	2.3	1.2	0.0	4.4	-1.1	4.0
02:00	M	-1.0	3.3	2.0	0.5	-0.3	4.6	-0.8	4.0
03:00	M	-1.1	4.0	1.5	-0.4	-1.0	4.4	-0.7	4.2
04:00	M	-1.1	4.0	1.5	-0.8	-0.5	3.8	-0.7	4.1
05:00	M	-1.0	4.0	1.0	-0.2	-0.3	2.0	-0.4	4.0
06:00	M	-0.9	5.0	1.4	0.3	-0.1	0.8	-0.2	3.7
07:00	M	0.1	5.9	2.7	1.7	1.8	1.0	1.1	3.8
08:00	M	0.7	6.4	3.3	2.7	3.6	1.9	2.3	3.8
09:00	M	1.1	4.9	4.4	3.6	7.3	2.9	2.7	4.5
10:00	M	3.5	3.6	5.0	4.9	10.0	4.5	3.0	4.7
11:00	M	6.2	3.8	5.4	5.0	9.7	6.3	3.9	4.1
12:00	8.0	7.5	4.7	5.5	5.3	9.5	8.5	5.2	5.0
13:00	6.5	7.5	5.5	5.7	5.0	9.0	10.0	6.1	5.3
14:00	4.4	6.7	6.5	5.5	6.0	9.1	6.5	5.9	5.5
15:00	4.7	5.7	6.3	5.4	6.3	10.2	6.5	5.3	5.8
16:00	5.5	4.5	6.0	5.1	5.9	10.0	5.9	5.2	5.9
17:00	5.7	3.9	6.0	4.8	5.4	8.1	5.0	4.0	5.9
18:00	5.0	3.0	5.7	4.1	5.0	8.5	4.0	3.5	5.8
19:00	4.6	2.7	4.2	3.6	4.1	7.7	2.6	3.4	5.2
20:00	3.3	2.5	3.6	2.0	3.2	6.9	2.0	3.1	5.2
21:00	1.2	2.3	2.9	1.2	2.0	6.2	0.7	3.0	4.9
22:00	0.8	2.3	3.1	1.8	1.4	5.4	0.7	3.0	4.6
23:00	0.0	2.6	2.0	1.5	1.2	5.0	0.8	3.2	3.4
24:00	-0.8	2.8	2.5	0.8	0.6	4.5	-0.4	3.7	2.3

* M denotes missing data

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	May 29	May 30	May 31	June 1	June 2	June 3	June 4	June 5
01:00	2.0	2.0	1.4	2.4	5.1	-2.1	5.6	7.7
02:00	1.1	2.2	1.1	2.5	4.0	-1.4	5.5	7.0
03:00	0.5	2.4	1.5	2.5	2.4	-0.4	5.6	6.5
04:00	0.1	2.9	1.8	2.4	1.4	0.1	6.5	6.0
05:00	0.5	3.0	1.3	2.4	0.8	0.3	6.7	6.1
06:00	0.5	3.6	1.1	2.4	1.1	0.7	8.0	6.9
07:00	0.6	4.0	1.1	2.9	0.0	1.4	8.2	6.9
08:00	0.8	4.0	1.2	3.2	0.0	1.5	8.2	6.4
09:00	1.7	5.0	2.2	3.4	1.4	2.0	8.3	6.0
10:00	2.2	5.5	2.3	3.9	2.4	2.7	8.7	5.8
11:00	3.2	7.8	5.0	4.9	5.6	3.6	8.6	6.3
12:00	4.4	7.1	5.4	4.9	7.1	4.3	9.2	6.1
13:00	6.3	7.5	6.0	6.0	8.1	M	9.6	6.1
14:00	6.2	8.4	6.2	6.8	8.7	M	9.5	6.7
15:00	4.0	9.1	6.3	6.1	9.3	M	9.2	7.0
16:00	3.2	10.3	6.0	5.9	8.9	M	9.1	5.8
17:00	2.8	7.3	5.9	5.2	8.7	M	9.0	5.9
18:00	1.8	10.3	5.8	7.4	8.2	M	8.1	5.0
19:00	1.5	11.1	5.2	7.7	5.0	M	7.7	4.1
20:00	1.4	10.8	4.7	7.8	3.7	M	7.9	3.3
21:00	1.3	9.6	3.0	7.3	2.2	5.7	7.8	2.7
22:00	1.4	7.2	1.3	7.1	-0.7	5.7	7.6	2.3
23:00	1.7	4.2	1.7	6.9	-1.3	5.7	10.6	1.5
24:00	1.8	2.9	2.0	6.5	-1.0	5.6	9.4	0.9

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	June 6	June 7	June 8	June 9	June 10	June 13	June 14	June 15
01:00	0.9	M	M	M	9.1	M	M	M
02:00	0.9	M	M	M	9.1	M	M	11.5
03:00	0.8	M	-1.7	M	9.1	M	M	11.7
04:00	0.8	M	M	M	9.1	M	M	11.3
05:00	M	M	-1.9	M	9.3	M	M	10.3
06:00	M	M	-1.9	M	9.8	M	M	10.8
07:00	M	M	0.6	6.0	10.5	M	M	11.0
08:00	2.0	3.5	1.9	5.8	10.6	M	12.6	10.5
09:00	3.6	4.0	3.3	5.8	10.0	M	12.2	8.4
10:00	5.2	6.1	4.0	6.0	9.5	13.4	12.3	10.3
11:00	5.1	7.7	4.9	6.2	8.7	11.5	13.7	8.0
12:00	5.9	9.5	5.8	6.1	8.3	11.1	13.2	7.7
13:00	6.4	9.8	6.1	6.6	8.0	12.9	14.1	8.1
14:00	6.2	10.4	7.1	7.1	7.6	14.0	13.9	M
15:00	6.8	8.3	7.5	7.5	7.1	13.8	M	M
16:00	7.6	7.3	7.5	7.8	7.0	M	M	M
17:00	7.4	5.1	7.4	7.9	6.9	M	M	M
18:00	6.7	4.1	7.2	8.6	6.2	M	M	M
19:00	5.5	3.5	6.5	9.4	5.8	M	M	M
20:00	4.3	M	5.8	9.3	5.0	M	M	M
21:00	3.4	M	5.2	9.1	3.9	M	M	M
22:00	3.3	-0.1	M	9.7	3.4	M	M	M
23:00	3.2	-0.8	M	9.8	3.2	M	M	M
24:00	3.0	M	M	9.4	3.1	M	M	M

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	June 18	June 19	June 20	June 21	June 22	June 23	June 24	June 25
01:00	M	8.1	8.0	9.4	12.1	8.8	11.0	13.6
02:00	M	8.2	7.6	9.2	12.2	9.2	11.2	13.4
03:00	M	8.7	7.8	9.5	11.3	10.0	11.3	12.5
04:00	M	9.5	7.1	10.1	11.4	9.8	11.4	12.1
05:00	M	9.7	9.2	9.4	10.9	10.0	11.6	11.6
06:00	M	10.0	10.3	10.3	10.6	10.7	12.1	10.6
07:00	M	10.0	10.4	10.5	10.7	10.5	12.5	10.8
08:00	M	10.1	13.8	10.5	11.6	10.5	12.8	11.1
09:00	M	10.8	14.6	10.7	11.5	10.9	13.2	12.2
10:00	M	12.0	14.2	12.2	12.0	12.2	13.8	14.1
11:00	M	14.0	14.8	13.0	12.4	11.9	14.4	15.3
12:00	M	15.3	15.0	13.4	12.7	13.6	15.3	16.5
13:00	16.1	16.7	14.0	15.0	12.5	14.2	15.6	15.7
14:00	15.0	16.8	12.4	16.5	14.0	13.8	15.4	15.7
15:00	14.8	16.5	14.2	15.6	13.5	14.0	15.0	16.4
16:00	13.5	17.2	13.0	14.2	13.9	13.4	14.8	15.0
17:00	11.6	17.7	13.0	13.7	12.2	13.3	14.2	13.5
18:00	10.1	17.1	13.0	13.6	11.6	13.0	13.9	11.8
19:00	8.3	15.6	11.3	12.8	10.8	11.8	13.8	11.0
20:00	8.2	13.9	11.0	11.6	10.6	11.2	13.8	10.7
21:00	8.3	11.2	11.4	12.1	11.0	11.0	13.6	9.1
22:00	8.0	9.3	11.3	12.6	10.0	11.1	13.0	9.2
23:00	7.9	8.7	10.1	12.3	9.7	11.1	12.8	9.2
24:00	8.4	8.0	9.5	12.1	9.0	11.0	13.0	9.1

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	June 26	June 27	June 28	June 29	June 30	July 1	July 2	July 3
01:00	9.1	7.4	8.0	12.5	M	5.9	9.2	7.8
02:00	9.0	7.7	8.7	12.5	M	4.7	7.1	9.2
03:00	9.0	7.0	9.3	12.6	M	4.1	5.9	9.9
04:00	8.9	7.3	10.1	12.4	M	4.2	5.4	10.0
05:00	8.7	6.0	10.3	12.8	8.1	4.6	8.0	10.0
06:00	8.8	5.6	11.1	12.6	8.2	6.6	8.8	9.9
07:00	9.5	11.0	10.6	12.4	8.1	8.3	10.1	9.0
08:00	11.0	14.0	12.8	12.2	7.9	9.4	12.0	8.3
09:00	12.8	16.2	14.7	12.9	8.0	9.2	11.7	9.0
10:00	14.2	16.7	14.0	13.8	8.1	8.3	12.2	9.8
11:00	15.3	17.4	12.8	14.2	8.5	11.4	13.3	12.0
12:00	15.1	18.0	13.2	14.0	8.8	12.5	15.6	12.4
13:00	16.1	18.5	13.3	13.7	9.5	10.2	17.8	12.7
14:00	15.7	18.3	13.6	13.0	10.6	10.1	18.4	12.8
15:00	16.3	17.7	13.2	12.8	10.0	9.9	16.0	12.1
16:00	16.2	17.1	13.3	11.9	9.5	10.9	13.2	11.5
17:00	15.5	16.6	13.4	11.8	8.9	11.5	13.5	10.5
18:00	14.5	16.0	13.6	11.7	8.6	11.1	13.7	10.0
19:00	13.2	14.0	13.7	10.3	8.0	10.8	12.6	9.0
20:00	11.9	12.2	13.5	10.3	7.8	10.7	12.1	8.8
21:00	10.2	10.6	13.2	8.9	6.9	10.0	11.3	8.1
22:00	10.0	9.4	12.9	8.0	5.7	10.0	10.2	8.0
23:00	8.8	8.7	12.8	7.0	5.2	10.4	8.7	6.2
24:00	8.0	8.2	12.6	M	5.2	10.5	7.6	6.3

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	July 4	July 5	July 6	July 7	July 8	July 9	July 10	July 11
01:00	7.0	4.0	7.8	8.5	3.8	10.1	10.4	11.7
02:00	8.0	3.1	7.8	8.9	3.1	10.0	10.5	11.7
03:00	7.9	4.0	8.0	8.2	3.1	10.0	10.7	11.7
04:00	7.7	3.3	8.0	8.0	3.0	10.0	11.0	11.6
05:00	7.2	2.7	7.8	7.5	2.8	9.9	11.0	11.6
06:00	7.5	4.2	7.7	6.9	3.5	9.8	10.6	11.8
07:00	8.2	8.2	7.8	9.1	8.0	9.8	10.5	12.3
08:00	9.7	11.1	7.9	9.3	7.4	10.1	11.0	12.9
09:00	10.5	13.1	8.0	10.5	9.6	10.6	12.3	13.4
10:00	11.6	13.7	8.5	12.1	9.0	10.8	15.1	13.6
11:00	12.5	12.7	8.9	11.5	8.8	11.3	13.5	13.8
12:00	13.4	11.7	9.0	10.8	9.9	12.5	17.1	14.7
13:00	14.4	10.4	8.6	11.3	11.0	13.0	18.0	16.0
14:00	14.8	11.0	8.5	12.2	12.0	13.2	19.8	15.5
15:00	14.1	10.3	9.0	11.6	12.6	15.7	18.8	15.8
16:00	11.5	10.3	9.0	11.2	11.9	14.7	19.0	16.5
17:00	13.2	10.9	9.5	11.2	11.2	15.6	19.0	15.4
18:00	12.4	8.8	8.4	11.6	11.6	15.5	17.7	15.5
19:00	13.0	7.8	8.3	11.6	10.7	14.4	16.6	14.5
20:00	11.8	7.8	8.3	10.2	10.6	12.1	15.8	14.4
21:00	10.3	7.6	8.2	8.6	10.5	11.3	14.4	14.1
22:00	6.1	7.4	8.0	7.4	10.1	10.7	12.1	13.6
23:00	5.0	7.5	8.2	6.8	10.2	10.0	11.4	13.7
24:00	3.6	7.6	8.3	4.2	10.4	10.1	11.6	14.0

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	July 12	July 13	July 14	July 15	July 16	July 17	July 18	July 19
01:00	14.0	11.0	9.7	10.8	11.8	8.7	12.2	11.9
02:00	13.8	10.0	9.0	11.4	11.8	9.9	12.3	11.6
03:00	13.6	9.7	10.3	11.3	11.2	10.0	12.5	11.6
04:00	13.8	9.4	10.2	11.8	10.2	10.0	12.8	11.6
05:00	13.6	9.4	10.0	11.8	11.6	9.0	13.0	11.3
06:00	13.7	8.1	10.8	11.7	11.3	8.9	13.2	11.2
07:00	13.8	10.0	11.1	11.8	12.7	10.2	15.0	11.4
08:00	13.8	11.7	12.6	12.5	14.0	13.7	14.8	11.7
09:00	13.7	13.4	14.2	14.0	15.8	15.6	16.0	12.5
10:00	14.6	14.2	15.8	16.3	17.7	16.4	16.4	13.0
11:00	14.8	15.0	17.0	18.3	19.7	16.9	16.1	14.2
12:00	14.5	16.0	17.0	18.6	20.5	17.0	16.4	15.4
13:00	15.0	16.5	16.8	19.2	20.9	17.5	16.6	16.3
14:00	15.7	16.9	16.1	19.0	21.1	17.6	16.4	16.1
15:00	14.5	16.8	16.8	19.0	21.3	17.7	16.4	16.2
16:00	14.9	16.7	15.4	18.2	20.1	16.5	16.0	16.1
17:00	16.5	15.9	15.0	17.0	19.5	13.8	15.2	15.9
18:00	15.5	14.8	15.1	16.0	18.7	13.8	14.1	15.2
19:00	13.2	13.0	14.5	14.8	16.7	11.0	13.1	14.5
20:00	12.7	12.2	13.0	13.0	14.7	11.1	12.5	13.4
21:00	11.3	11.0	10.3	12.0	12.8	11.6	12.8	12.2
22:00	11.4	8.0	10.0	11.8	11.4	11.9	12.5	11.4
23:00	11.2	8.1	9.5	11.8	9.6	12.0	12.5	12.0
24:00	11.1	7.6	9.8	11.8	9.0	12.0	12.0	12.6

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	July 20	July 21	July 22	July 23	July 24	July 25	July 26	July 27
01:00	11.9	9.0	13.0	11.0	12.7	7.7	6.1	10.2
02:00	11.6	8.5	13.0	11.0	12.8	7.6	5.4	10.2
03:00	11.3	7.4	12.9	10.4	12.9	7.7	5.1	11.3
04:00	10.2	6.9	12.8	10.5	128	7.7	7.2	11.6
05:00	9.2	6.9	12.9	10.3	12.6	7.0	8.0	11.2
06:00	9.1	10.9	12.5	10.9	12.2	8.2	7.8	11.0
07:00	11.1	12.6	13.2	13.1	12.0	8.8	11.6	11.5
08:00	14.3	13.2	14.0	15.0	12.3	10.3	14.5	13.0
09:00	15.4	13.5	13.3	16.9	12.8	12.0	16.0	14.0
10:00	16.8	13.9	13.7	17.5	12.8	12.7	17.1	15.7
11:00	18.9	14.4	14.0	17.1	12.1	13.6	18.0	17.0
12:00	20.9	15.2	14.5	17.9	12.5	15.0	18.3	18.2
13:00	20.0	13.6	17.6	17.9	12.8	16.5	18.5	19.2
14:00	20.0	14.1	17.5	16.3	13.1	17.6	18.1	19.7
15:00	20.0	15.0	13.9	16.3	13.0	18.4	17.6	20.0
16:00	19.3	15.2	13.1	16.0	13.0	16.8	17.0	20.1
17:00	17.9	13.5	12.5	14.5	12.2	15.1	16.3	20.0
18:00	16.7	13.2	11.5	14.0	11.7	16.0	15.3	19.6
19:00	14.0	13.2	10.4	12.9	11.7	14.5	13.7	17.6
20:00	11.1	13.1	10.0	12.4	10.5	12.9	12.3	16.0
21:00	9.4	13.1	10.2	12.1	8.6	10.9	11.0	13.0
22:00	10.9	13.4	10.2	12.1	8.4	9.1	10.5	10.9
23:00	9.3	13.3	10.2	12.0	8.0	8.0	10.4	9.1
24:00	9.0	13.1	10.6	12.1	7.9	7.2	10.3	8.6

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	July 28	July 29	July 30	July 31	August 1	August 2	August 3	August 4
01:00	10.0	13.6	13.1	13.5	10.1	9.0	13.7	10.4
02:00	10.9	13.0	13.0	13.2	9.9	9.6	13.8	9.2
03:00	11.9	12.0	13.0	13.1	9.8	10.0	13.8	8.0
04:00	11.6	12.0	13.0	13.0	9.8	10.3	13.9	7.4
05:00	11.9	12.2	13.1	12.9	9.2	10.5	13.8	10.7
06:00	12.7	12.4	13.2	13.0	8.3	11.0	13.4	11.1
07:00	12.8	12.6	13.4	13.0	8.4	11.2	14.1	11.6
08:00	13.4	13.2	13.6	13.0	9.1	11.4	14.0	12.7
09:00	14.5	13.8	13.8	13.1	11.9	11.9	14.8	13.9
10:00	16.7	14.1	14.0	13.3	13.4	12.3	15.8	14.2
11:00	17.5	15.0	14.6	14.0	15.7	13.0	17.2	15.2
12:00	18.6	15.6	15.0	13.8	16.2	13.6	17.2	16.0
13:00	17.6	14.7	16.5	14.6	17.0	14.1	17.5	14.5
14:00	16.1	15.1	16.4	15.6	17.1	14.6	17.8	14.3
15:00	17.9	14.9	15.9	16.4	17.5	15.3	19.4	14.0
16:00	19.4	15.4	16.2	17.1	17.9	15.1	18.3	13.9
17:00	18.1	16.7	15.7	17.2	17.7	16.0	17.3	13.7
18:00	17.0	16.9	15.5	17.5	16.1	14.2	17.0	13.7
19:00	14.9	15.9	15.1	17.0	15.5	14.0	14.0	13.8
20:00	14.4	15.1	14.9	15.4	14.2	13.2	13.4	13.8
21:00	14.3	14.5	14.8	13.8	13.0	13.3	12.6	14.0
22:00	14.2	14.0	14.4	12.2	11.6	13.5	12.6	14.2
23:00	14.1	13.9	14.0	10.7	10.1	13.5	12.5	14.3
24:00	14.0	13.4	13.8	10.8	9.0	13.6	11.8	14.6

TABLE C.1 AIR TEMPERATURE (°C) OLD SAMS RIVER (cont'd)

Time	August 5	August 6	August 7	August 8	August 9	August 10
01:00	14.8	11.6	13.8	10.1	11.4	11.7
02:00	15.0	10.6	13.8	12.0	11.5	12.8
03:00	15.1	11.0	13.8	9.2	11.3	13.2
04:00	15.0	10.6	13.9	6.9	10.0	13.3
05:00	15.0	10.5	14.0	9.9	9.8	13.5
06:00	15.1	9.5	14.1	7.2	10.5	13.5
07:00	15.5	10.6	14.1	9.9	10.2	13.6
08:00	15.9	16.2	14.0	12.6	12.5	14.1
09:00	16.3	18.0	14.1	13.6	13.8	15.0
10:00	16.2	18.2	14.1	14.0	14.8	15.6
11:00	16.5	19.0	15.8	15.0	16.6	16.2
12:00	16.9	20.0	15.3	15.6	17.1	16.1
13:00	16.7	19.5	16.9	16.0	16.9	16.2
14:00	17.0	19.4	18.8	16.1	17.2	16.3
15:00	17.1	20.1	16.2	16.0	15.8	16.3
16:00	17.3	18.9	16.0	16.1	16.0	16.2
17:00	18.0	15.1	15.5	15.5	16.7	16.1
18:00	18.0	14.6	15.0	14.6	17.7	15.5
19:00	17.0	14.0	14.9	14.3	17.1	15.5
20:00	15.1	14.0	13.8	13.1	16.0	15.4
21:00	14.0	14.0	13.2	11.6	14.1	15.0
22:00	13.2	14.0	12.9	11.6	12.0	15.0
23:00	12.1	14.0	12.8	11.2	10.6	15.0
24:00	11.2	13.9	11.9	11.2	10.1	14.9

APPENDIX D

TABLE D.1 RELATIVE HUMIDITY (%) AT OLD SAMS RIVER, CORRECTED FOR TEMPERATURE

Time	May 20	May 21	May 22	May 26	May 27	May 28	May 29	May 30	May 31	June 1	June 2
01:00	M*	90	96	M	94	99	90	99	97	98	90
02:00	M	89	96	M	94	99	94	99	97	99	94
03:00	M	89	97	M	92	99	97	99	95	98	95
04:00	M	89	97	M	89	99	98	98	93	96	96
05:00	M	89	97	M	87	99	98	98	93	93	96
06:00	M	90	97	M	86	98	98	98	94	94	95
07:00	M	89	98	M	82	99	98	99	94	93	91
08:00	M	90	99	M	65	99	94	98	94	92	89
09:00	M	92	98	M	69	99	90	98	91	93	83
10:00	M	89	97	M	65	99	90	98	89	97	77
11:00	M	73	98	M	69	99	85	99	76	100	64
12:00	85	70	83	M	63	99	81	89	70	99	59
13:00	89	73	80	M	60	99	75	87	69	95	57
14:00	91	79	M	62	59	99	75	84	69	88	57
15:00	91	84	M	62	62	99	83	84	70	88	55
16:00	90	90	M	62	66	99	86	80	70	95	52
17:00	82	94	M	64	81	98	89	91	70	95	49
18:00	81	96	M	68	90	96	95	80	69	98	51
19:00	80	96	M	71	91	90	98	75	70	93	58
20:00	84	96	M	74	94	84	99	75	72	91	75
21:00	84	96	82	83	97	83	99	77	84	93	88
22:00	89	96	83	85	98	84	99	78	95	91	93
23:00	89	96	89	88	97	86	99	95	98	91	93
24:00	90	96	93	91	96	85	99	90	98	97	95

* M represents missing data

TABLE D.1 RELATIVE HUMIDITY (%) AT OLD SAMS RIVER, CORRECTED FOR TEMPERATURE (cont'd)

Time	June 3	June 4	June 5	June 6	June 7	June 8	June 9	June 18	June 19	June 20
01:00	94	98	99	95	M	M	M	M	95	97
02:00	95	98	99	96	M	M	M	M	95	97
03:00	96	98	99	95	M	94	M	M	95	97
04:00	97	99	98	95	M	M	M	M	96	97
05:00	96	99	98	M	M	94	M	M	96	98
06:00	96	99	99	M	M	94	M	M	96	97
07:00	97	99	99	M	M	M	96	M	96	97
08:00	96	100	99	93	93	96	96	M	96	98
09:00	96	100	98	87	87	97	96	M	96	98
10:00	97	100	98	85	76	97	96	M	97	94
11:00	96	100	99	81	73	97	96	M	98	94
12:00	86	101	98	80	66	90	92	M	86	93
13:00	M	101	98	77	68	90	91	53	76	96
14:00	M	101	99	77	58	83	91	60	74	96
15:00	M	101	99	75	59	83	91	68	83	98
16:00	M	101	98	73	78	83	M	74	71	97
17:00	M	101	98	73	87	83	M	82	74	97
18:00	M	100	94	75	90	94	M	86	78	97
19:00	M	100	94	78	93	95	M	90	83	98
20:00	M	100	95	79	M	94	M	92	89	97
21:00	99	100	95	83	M	94	M	93	94	98
22:00	99	100	96	86	95	94	M	93	96	98
23:00	99	101	96	87	95	94	M	94	96	97
24:00	98	101	95	89	M	94	M	94	97	97

TABLE D.1 RELATIVE HUMIDITY (%) AT OLD SAMS RIVER, CORRECTED FOR TEMPERATURE (cont'd)

Time	June 21	June 22	June 23	June 24	June 25	June 26	June 27	June 28	June 29	June 30
01:00	97	97	96	98	101	98	96	95	100	M
02:00	97	97	96	98	101	98	96	94	100	M
03:00	97	97	96	99	101	98	95	95	100	M
04:00	97	97	96	99	101	98	96	96	100	M
05:00	97	96	96	99	101	97	96	96	100	100
06:00	97	96	96	99	100	98	97	98	100	100
07:00	97	96	96	99	100	97	92	98	100	100
08:00	97	97	96	99	100	91	80	99	100	100
09:00	97	97	96	99	101	87	64	88	M	100
10:00	98	97	97	101	72	82	65	89	M	100
11:00	97	97	97	101	79	81	M	98	102	93
12:00	97	97	97	102	M	76	M	100	102	92
13:00	98	97	98	102	74	72	M	100	101	88
14:00	92	94	98	102	76	74	M	100	101	84
15:00	90	92	98	103	75	71	65	100	101	85
16:00	94	94	97	103	75	68	65	100	102	87
17:00	96	94	99	103	87	70	65	100	102	93
18:00	95	94	100	103	95	78	65	100	102	93
19:00	97	95	100	103	95	83	78	100	101	93
20:00	97	95	99	103	95	92	90	100	101	93
21:00	97	95	99	102	97	92	94	100	101	95
22:00	97	96	98	102	98	92	95	100	100	96
23:00	97	96	98	101	98	95	94	100	100	96
24:00	97	96	98	101	98	96	95	100	100	97

TABLE D.1 RELATIVE HUMIDITY (%) AT OLD SAMS RIVER, CORRECTED FOR TEMPERATURE (cont'd)

Time	July 1	July 2	July 3	July 4	July 5	July 6	July 7	July 8	July 9	July 10	July 11
01:00	98	98	97	97	96	95	92	97	100	98	101
02:00	98	97	98	96	95	95	92	96	100	98	101
03:00	98	96	98	96	96	95	91	96	100	98	101
04:00	98	96	98	96	95	96	92	96	100	98	101
05:00	98	97	98	97	95	97	94	96	100	98	101
06:00	99	98	98	98	96	98	94	96	100	99	101
07:00	99	98	98	95	96	99	91	98	100	99	101
08:00	97	98	97	85	85	99	91	98	100	99	101
09:00	97	98	98	81	67	99	88	99	100	100	101
10:00	98	99	79	76	59	99	85	99	100	101	101
11:00	81	94	66	75	75	96	89	99	101	97	102
12:00	77	84	73	69	79	83	82	99	101	86	102
13:00	94	74	71	67	82	93	92	99	101	79	102
14:00	95	72	73	66	84	95	93	99	89	94	102
15:00	98	89	77	67	84	97	92	94	88	90	102
16:00	98	96	83	83	79	94	92	97	88	87	103
17:00	99	95	89	79	78	96	92	97	87	85	102
18:00	98	96	91	63	92	91	89	99	87	97	102
19:00	98	97	91	70	93	88	90	98	86	98	102
20:00	98	99	93	82	95	89	98	99	89	98	102
21:00	98	99	93	82	95	89	98	99	89	98	102
22:00	98	98	95	94	95	89	97	100	97	101	101
23:00	98	97	95	95	95	90	97	100	98	101	101
24:00	98	97	97	94	95	89	97	100	98	101	102

TABLE D. 1 RELATIVE HUMIDITY (%) AT OLD SAMS RIVER, CORRECTED FOR TEMPERATURE (cont'd)

Time	July 12	July 13	July 14	July 15	July 16	July 17	July 18	July 19	July 20	July 21
01:00	102	98	97	98	93	92	95	102	93	94
02:00	102	98	98	99	93	93	95	102	94	94
03:00	101	98	98	99	93	93	95	102	92	93
04:00	102	98	98	99	92	94	95	102	93	93
05:00	101	98	98	99	93	94	95	102	92	93
06:00	101	96	98	99	93	94	95	100	93	94
07:00	102	92	98	99	93	94	97	101	90	95
08:00	102	81	93	99	92	87	97	101	84	95
09:00	101	71	78	90	80	78	98	101	75	96
10:00	102	66	M	76	73	76	100	92	73	97
11:00	102	65	M	71	64	76	100	88	60	93
12:00	102	M	M	69	60	74	101	82	60	90
13:00	102	M	M	67	70	74	102	79	60	94
14:00	102	M	80	65	66	73	102	80	60	96
15:00	102	M	80	64	67	67	103	79	65	97
16:00	95	M	85	70	67	73	102	77	71	92
17:00	97	M	86	74	70	85	102	78	74	96
18:00	94	67	80	82	72	74	102	81	79	96
19:00	96	77	82	87	75	91	101	86	87	96
20:00	98	90	97	90	83	92	101	93	93	97
21:00	99	94	99	92	85	93	101	96	94	97
22:00	99	95	99	92	91	94	101	97	94	97
23:00	98	95	99	93	91	95	101	97	94	97
24:00	98	96	99	93	92	95	102	94	94	97

TABLE D.1 RELATIVE HUMIDITY (%) AT OLD SAMS RIVER, CORRECTED FOR TEMPERATURE (cont'd)

Time	July 22	July 23	July 24	July 25	July 26	July 27	July 28	July 29	July 30	July 31
01:00	97	91	93	91	91	93	95	95	95	95
02:00	97	91	93	90	92	94	95	95	95	95
03:00	97	91	93	90	93	96	96	95	95	95
04:00	97	91	93	89	94	96	96	95	95	95
05:00	97	91	93	89	94	96	96	95	95	95
06:00	97	91	93	89	91	96	96	95	95	95
07:00	97	92	92	90	88	96	96	95	95	95
08:00	98	81	93	88	64	93	96	95	95	96
09:00	97	69	93	81	60	74	90	96	96	96
10:00	97	65	92	77	61	62	85	96	96	96
11:00	98	71	93	71	55	56	83	96	96	97
12:00	92	74	93	72	57	56	76	96	96	97
13:00	77	76	93	57	63	58	82	96	97	96
14:00	78	85	93	49	62	59	91	96	97	78
15:00	86	85	93	49	67	60	83	96	96	66
16:00	84	84	93	65	66	61	69	96	96	57
17:00	82	87	93	74	63	64	73	97	96	57
18:00	83	88	93	72	66	67	91	97	95	57
19:00	82	89	93	80	71	68	92	96	96	58
20:00	86	91	92	84	83	80	94	96	96	65
21:00	90	91	91	90	87	91	95	96	96	68
22:00	90	92	91	91	91	93	95	96	96	90
23:00	91	92	91	91	92	94	96	96	96	90
24:00	91	93	91	92	92	94	96	95	96	89

TABLE D.1 RELATIVE HUMIDITY (%) AT OLD SAMS RIVER, CORRECTED FOR TEMPERATURE (cont'd)

Time	August 1	August 2	August 3	August 4	August 5	August 6	August 7	August 8	August 9
01:00	89	92	99	97	99	93	100	96	97
02:00	88	94	100	97	99	84	100	95	96
03:00	84	94	100	96	99	87	100	93	97
04:00	83	95	100	96	99	92	100	95	98
05:00	84	95	100	97	99	95	100	98	98
06:00	86	95	100	97	99	95	100	97	99
07:00	83	95	102	98	99	88	100	95	97
08:00	86	96	102	98	99	72	100	81	90
09:00	75	96	102	98	100	73	100	73	95
10:00	69	96	102	91	99	83	100	M	89
11:00	69	98	99	86	100	76	100	M	81
12:00	69	99	83	82	100	M	98	M	79
13:00	71	99	86	83	100	M	93	M	83
14:00	67	97	80	93	100	M	88	M	77
15:00	66	94	74	98	100	M	96	74	89
16:00	61	94	83	98	85	77	98	74	83
17:00	59	90	87	98	85	98	100	77	79
18:00	59	96	89	98	88	100	100	80	99
19:00	59	98	97	99	89	100	97	81	100
20:00	59	98	97	99	95	100	96	86	101
21:00	64	98	98	99	97	100	96	95	101
22:00	75	98	98	99	97	100	98	96	99
23:00	81	99	98	99	97	100	97	95	98
24:00	86	99	98	99	96	100	95	96	96

TABLE D.1 RELATIVE HUMIDITY (%) AT OLD SAMS RIVER, CORRECTED FOR TEMPERATURE

Time	August 10	August 11
01:00	99	101
02:00	100	101
03:00	100	101
04:00	100	101
05:00	100	101
06:00	100	101
07:00	100	101
08:00	101	101
09:00	101	101
10:00	101	70
11:00	101	66
12:00	101	61
13:00	101	64
14:00	102	M
15:00	102	M
16:00	101	M
17:00	101	M
18:00	101	M
19:00	101	M
20:00	101	M
21:00	101	M
22:00	101	M
23:00	101	M
24:00	101	M

APPENDIX E

TABLE E.1 DEPTH OF BOG WATER TABLE BELOW SURFACE AT OLD SAMS RIVER (*cm*)

Date	Well Numbers								
	1	2	3	4	5	6	7	8	9
May 26	8.7	5.4	5.6	8.5	8.6	6.1	10.7	6.8	15.4
June 2	11.6	4.5	5.5	9.7	10.4	6.0	12.0	7.5	17.9
June 8	6.4	2.2	2.9	7.5	6.5	3.6	8.9	4.5	16.2
June 18	6.5	3.6	3.3	6.5	6.2	4.3	8.9	4.1	14.5
June 20	8.6	2.3	5.2	8.7	7.9	6.3	10.3	6.2	17.0
June 23	5.1	1.7	1.5	4.1	4.7	2.3	6.9	2.9	13.0
June 28	7.7	4.4	4.7	9.1	8.1	5.3	9.9	M*	17.2
July 3	6.8	3.3	2.6	7.6	5.8	4.0	9.0	4.1	16.2
July 4	8.3	4.5	4.4	10.0	7.6	5.7	10.4	5.7	18.4
July 10	9.6	4.2	4.1	8.1	7.2	5.3	10.9	5.4	19.5
July 11	M	M	M	8.7	M	5.8	M	M	M
July 15	14.3	7.4	8.5	14.3	13.6	10.6	16.4	12.0	23.9
July 17	16.9	9.3	11.1	16.8	15.5	13.6	18.1	15.4	27.9
July 20	9.5	3.1	3.3	7.8	7.7	4.1	8.5	9.2	17.8
July 23	11.1	4.5	5.1	9.5	9.7	5.5	10.0	6.6	19.0
August 2	M	M	M	9.7	M	5.9	M	M	M
August 3	8.1	2.3	2.3	6.7	7.3	8.7	9.3	4.8	18.3
August 4	M	M	M	9.8	M	5.8	M	7.5	21.6
Mean	9.3	4.2	4.7	9.0	8.5	6.1	10.7	6.8	18.4
$\hat{\sigma}$**	3.2	2.0	2.5	2.8	2.9	2.6	2.9	3.3	3.6
n**	15	15	15	18	15	18	15	15	16

* M denotes missing data

** $\hat{\sigma}$ is the best estimate of the standard deviation; and n is the number of observations

(cont'd)

TABLE E.1 DEPTH OF BOG WATER BELOW SURFACE AT OLD SAMS RIVER (*cm*) (cont'd)

Date	Well Numbers									
	10	11	12	12A	12B	12C	12D	13	14	15
May 26	6.3	9.5	11.4	M	M	M	M	8.2	14.3	10.3
June 2	7.0	10.5	14.2	M	M	M	M	8.6	16.2	12.0
June 8	4.8	8.9	9.3	6.4	5.8	13.3	4.1	5.3	11.8	10.0
June 18	4.8	6.5	6.4	5.1	4.6	11.9	3.2	5.6	12.3	10.0
June 20	5.6	9.1	9.2	6.3	5.3	12.0	4.0	7.0	13.1	9.9
June 23	4.5	5.0	5.6	4.3	3.5	11.7	3.1	5.0	11.6	9.1
June 28	M	9.2	10.8	6.7	M	M	M	M	M	M
July 3	5.1	8.7	8.1	5.5	4.6	11.9	4.1	5.5	11.6	10.0
July 4	5.8	10.7	10.9	6.9	6.1	13.8	4.5	6.6	13.2	11.7
July 10	5.8	10.5	11.9	7.6	7.1	14.5	4.7	7.2	14.6	11.9
July 11	M	M	M	M	M	M	M	M	M	M
July 15	10.9	15.6	17.5	12.6	12.1	19.5	9.4	12.9	20.8	16.9
July 17	13.4	16.9	20.3	16.0	14.3	22.4	12.7	14.6	23.3	19.7
July 20	5.4	9.6	9.7	6.9	5.9	14.7	5.1	6.3	12.6	11.1
July 23	6.5	11.2	13.8	9.2	8.1	15.3	7.2	8.3	15.5	12.2
August 2	M	M	M	M	M	M	M	M	M	M
August 3	5.1	8.2	12.3	7.9	6.6	14.7	6.2	5.6	13.3	9.9
August 4	7.1	11.2	15.4	10.0	9.2	15.3	8.5	8.1	16.1	11.9
Mean	6.5	10.1	11.7	8.0	6.9	14.7	5.9	7.7	14.7	11.8
$\hat{\sigma}$	2.5	2.9	3.9	3.1	3.1	3.1	2.8	2.8	3.4	2.9
n	15	16	16	14	13	13	13	15	15	15

TABLE E.2 REGRESSION EQUATIONS* FOR MISSING BOG WATER TABLE DATA**

Well Nos. (x)	Well No. (y)	Sample Size (n)	Slope (b)	Intercept (a)	Standard Error of the Estimate of y (SEE y)	Pearson Product moment Correlation Coefficient (r)
4	6	18	0.81	-1.3	1.3	0.86
$\bar{x}_{4,6}$†	1	15	1.0	1.4	1.2	0.92
$\bar{x}_{4,6}$	2	15	0.63	-0.59	0.89	0.90
$\bar{x}_{4,6}$	3	15	0.80	-1.4	0.84	0.94
$\bar{x}_{4,6}$	5	15	0.95	1.3	0.85	0.96
$\bar{x}_{4,6}$	7	15	0.99	3.2	0.73	0.97
$\bar{x}_{4,6}$	8	15	1.0	-1.0	1.4	0.91
$\bar{x}_{4,6}$	9	16	1.2	9.2	1.4	0.93
$\bar{x}_{4,6}$	10	15	0.81	0.37	0.70	0.96
$\bar{x}_{4,6}$	11	16	0.98	2.6	1.0	0.94
$\bar{x}_{4,6}$	12	16	1.3	2.1	1.7	0.91
$\bar{x}_{4,6}$	12A	14	1.0	0.42	0.99	0.95

* All significant at the 0.1% level of confidence

** Format: $y = a + bx$

† $\bar{x}_{4,6}$ is the mean of wells 4 and 6

(cont'd)

TABLE E.2 REGRESSION EQUATIONS FOR MISSING BOG WATER TABLE DATA (cont'd)

Well Nos. (x)	Well No. (y)	Sample Size (n)	Slope (b)	Intercept (a)	Standard Error of the Estimate of y (SEE y)	Pearson Product moment correlation coefficient (r)
$\bar{x}_{4,6}$	12B	13	0.94	0.026	1.0	0.95
$\bar{x}_{4,6}$	12C	13	0.94	7.6	1.1	0.94
$\bar{x}_{4,6}$	12D	13	0.83	-0.37	1.2	0.91
$\bar{x}_{4,6}$	13	15	0.90	0.79	0.90	0.95
$\bar{x}_{4,6}$	14	15	1.1	6.3	1.1	0.94
$\bar{x}_{4,6}$	15	15	0.93	4.7	0.97	0.94

TABLE E.3 DEPTH OF WATER TABLE BELOW SURFACE (*cm*) INCLUDING ESTIMATED VALUES

Date	Well Numbers								
	1	2	3	4	5	6	7	8	9
May 26	8.7	5.4	5.6	8.5	8.6	6.1	10.7	6.8	17.9
June 2	11.6	4.5	5.5	9.7	10.4	6.0	12.0	7.5	17.9
June 8	6.4	2.2	2.9	7.5	6.5	3.6	8.9	4.5	16.2
June 18	6.5	3.6	3.3	6.5	6.2	4.3	8.9	4.1	14.5
June 20	8.6	2.3	5.2	8.7	7.9	6.3	10.3	6.2	17.0
June 23	5.1	1.7	1.5	4.1	4.7	2.3	6.9	2.9	13.0
June 28	7.7	4.4	4.7	9.1	8.1	5.3	9.9	6.4*	17.2
July 3	6.8	3.3	2.6	7.6	5.8	4.0	9.0	4.1	16.2
July 4	8.3	4.5	4.4	10.0	7.6	5.7	10.4	5.7	18.4
July 10	9.6	4.2	4.1	8.1	7.2	5.3	10.9	5.4	19.5
July 11	8.6*	4.0*	4.5*	8.7	8.2*	5.8	10.4*	6.5*	18.0*
July 15	14.3	7.4	8.5	14.3	13.6	10.6	16.4	12.0	23.9
July 17	16.9	9.3	11.1	16.8	15.5	13.6	18.1	15.4	27.9
July 20	9.5	3.1	3.3	7.8	7.7	4.1	8.5	9.2	17.8
July 23	11.1	4.5	5.1	9.5	9.7	5.5	10.0	6.6	19.0
August 2	9.1*	4.3*	4.9*	9.7	8.7*	5.9	10.9*	7.5	21.6
August 3	8.1	2.3	2.3	6.7	7.3	8.7	9.3	4.8	18.3
August 4	9.1*	4.3*	4.9*	9.8	8.7*	5.8	10.9*	7.5	21.6
Mean	9.2	4.2	4.7	9.1	8.5	6.1	10.7	6.8	18.4
$\hat{\sigma}$**	2.85	1.85	2.24	2.81	2.61	2.63	2.67	2.97	3.43
Range	11.8	7.6	9.6	12.7	10.8	11.3	11.2	12.5	14.9

* Predicted values using regression equations in Table E.2
** $\hat{\sigma}$ is the best estimate of the standard deviation

(cont'd)

TABLE E.3 DEPTH OF WATER TABLE BELOW SURFACE (*cm*) INCLUDING ESTIMATED VALUES (cont'd)

Date	Well Numbers									
	10	11	12	12A	12B	12C	12D	13	14	15
May 2	6.3	9.5	11.4	7.7*	6.9*	14.4*	5.7*	8.2	14.3	10.3
June 2	7.0	10.5	14.2	8.3*	7.5*	15.0*	6.2*	8.6	16.2	12.0
June 8	4.8	8.9	9.3	6.4	5.8	13.3	4.1	5.3	11.8	10.0
June 18	4.8	6.5	6.4	5.1	4.6	11.9	3.2	5.6	12.3	10.0
June 20	5.6	9.1	9.2	6.3	5.3	12.0	4.0	7.0	13.1	9.9
June 23	4.5	5.0	5.6	4.3	3.5	11.7	3.1	5.0	11.6	9.1
June 28	6.2*	9.2	10.8	6.7	6.8*	14.3*	5.6*	7.3*	14.2*	11.4*
July 3	5.1	8.7	8.1	5.5	4.6	11.9	4.1	5.5	11.6	10.0
July 4	5.8	10.7	10.9	6.9	6.1	13.8	4.5	6.6	13.2	11.7
July 10	5.8	10.5	11.9	7.6	7.1	14.5	4.7	7.2	14.6	11.9
July 11	6.3*	9.8*	11.3*	7.7*	6.9*	14.4*	5.7*	7.4*	14.4*	11.5*
July 15	10.9	15.6	17.5	12.6	12.1	19.5	9.4	12.9	20.8	16.9
July 17	13.4	16.9	20.3	16.0	14.3	22.4	12.7	14.6	23.3	19.7
July 20	5.4	9.6	9.7	6.9	5.9	14.7	5.1	6.3	12.6	11.1
July 23	6.5	11.2	13.8	9.2	8.1	15.3	7.2	8.3	15.5	12.2
August 2	6.7*	10.3*	12.0*	8.2*	7.4*	14.9*	6.1*	7.8*	14.9*	12.0*
August 3	5.1	8.2	12.3	7.9	6.6	14.7	6.2	5.6	13.3	9.9
August 4	7.1	11.2	15.4	10.0	9.2	15.3	8.5	8.1	16.1	11.9
Mean	6.54	10.1	11.7	8.0	7.2	14.7	5.9	7.6	14.7	11.8
$\hat{\sigma}$**	2.23	2.75	3.67	2.75	2.61	2.63	2.38	2.51	3.08	2.61
Range	8.9	11.9	14.7	11.7	10.8	10.7	9.6	9.6	11.7	10.6

TABLE E.4 EXTENDED MEAN DAILY BOG WATER TABLE DEPTH RECORDED FOR OLD SAMS RIVER CATCHMENT*

Date	Estimated Bog Water Table Depth (*cm*)
May 19	4.3
May 20	4.2
May 21	5.5
May 22	6.0
May 23	6.2
May 24	7.2
May 25	8.7
May 26	(9.0)**
May 27	10.5
May 28	10.7
May 29	11.1
May 30	9.3
May 31	8.9
June 1	10.1
June 2	(10.0)
June 3	10.8
June 4	10.7
June 5	7.8
June 6	7.1
June 7	8.8
June 8	(7.3)
June 9	-5.2
June 10	-44.5
June 11	-46.3
June 12	-13.0
June 13	-1.7
June 14	2.6
June 15	3.1
June 16	0.8
June 17	1.7
June 18	(6.8)
June 19	6.0
June 20	(8.1)
June 21	6.1
June 22	6.1
June 23	(5.6)
June 24	5.2
June 25	3.7
June 26	7.6
June 27	8.8

* As estimated with regression model developed in Section 4.1.4
** Bracketed values are actual mean values from Table E.3.

TABLE E.4 EXTENDED MEAN DAILY BOG WATER TABLE DEPTH RECORDED FOR OLD SAMS RIVER CATCHMENT (cont'd)

Date	Estimated Bog Water Table Depth (*cm*)
June 28	(8.7)
June 29	3.9
June 30	4.3
July 1	7.4
July 2	8.1
July 3	(7.1)
July 4	(8.7)
July 5	11.1
July 6	10.5
July 7	10.9
July 8	11.0
July 9	10.3
July 10	(9.0)
July 11	(9.0)
July 12	10.0
July 13	10.8
July 14	11.6
July 15	(14.2)
July 16	11.7
July 17	(16.7)
July 18	5.8
July 19	5.6
July 20	(8.3)
July 21	10.5
July 22	10.7
July 23	(9.9)
July 24	10.2
July 25	9.6
July 26	10.2
July 27	10.0
July 28	9.9
July 29	10.1
July 30	10.5
July 31	8.2
August 1	9.4
August 2	(9.4)
August 3	(8.3)
August 4	(10.3)

APPENDIX F

TABLE F.1 PAN EVAPORATION AT OLD SAMS RIVER (*mm*)

From	To	Net Pan Evaporation (*mm*)
July 3, 15:28 *hrs*	July 4, 13:15 *hrs*	3.06
July 4, 13:15 *hrs*	July 10, 13:09 *hrs*	9.71
July 10, 13:09 *hrs*	July 11, 13:48 *hrs*	3.24
July 11, 13:48 *hrs*	July 15, 15:28 *hrs*	14.47
July 15, 15:28 *hrs*	July 17, 11:20 *hrs*	8.28
July 17, 11:20 *hrs*	July 20, 12:13 *hrs*	11.86
July 20, 12:13 *hrs*	July 23, 11:55 *hrs*	7.54
July 23, 11:55 *hrs*	July 25, 11:30 *hrs*	4.18
July 25, 11:30 *hrs*	August 2, 17:17 *hrs*	16.48*
August 2, 17:17 *hrs*	August 3, 09:49 *hrs*	0.02*
August 3, 09:49 *hrs*	Augsut 4, 11:40 *hrs*	2.61
Total		81.46

* Estimated precipitation used in computation of these values

APPENDIX G

TABLE G.1 STREAM DISCHARGE (m^3 sec^{-1}) NORTHWEST BROOK

Time	May 18	May 19	May 20	May 21	May 22	May 23	May 24	May 25	May 26
01:00	2.98	2.50	2.34	2.22	1.99	1.87	1.61	1.36	1.25
02:00	2.95	2.49	2.34	2.21	1.99	1.86	1.60	1.36	1.25
03:00	2.93	2.48	2.33	2.20	1.97	1.84	1.59	1.35	1.26
04:00	2.90	2.47	2.32	2.18	1.95	1.83	1.58	1.34	1.27
05:00	2.88	2.46	2.32	2.17	1.93	1.81	1.56	1.34	1.27
06:00	2.85	2.45	2.31	2.16	1.92	1.79	1.55	1.33	1.28
07:00	2.83	2.44	2.31	2.16	1.91	1.77	1.54	1.33	1.28
08:00	2.81	2.43	2.30	2.15	1.90	1.76	1.52	1.32	1.28
09:00	2.78	2.42	2.30	2.14	1.90	1.74	1.51	1.32	1.28
10:00	2.76	2.40	2.30	2.13	1.90	1.73	1.50	1.31	1.28
11:00	2.74	2.39	2.31	2.13	1.90	1.72	1.48	1.30	1.27
12:00	2.72	2.38	2.31	2.12	1.90	1.71	1.47	1.29	1.27
13:00	2.70	2.37	2.31	2.11	1.90	1.70	1.45	1.28	1.26
14:00	2.68	2.36	2.31	2.09	1.89	1.69	1.44	1.27	1.26
15:00	2.67	2.36	2.31	2.08	1.89	1.68	1.42	1.26	1.25
16:00	2.65	2.36	2.31	2.07	1.89	1.67	1.42	1.26	1.24
17:00	2.64	2.36	2.31	2.07	1.89	1.66	1.41	1.25	1.24
18:00	2.62	2.35	2.30	2.05	1.89	1.66	1.41	1.24	1.23
19:00	2.60	2.35	2.29	2.04	1.89	1.65	1.40	1.24	1.23
20:00	2.58	2.35	2.27	2.02	1.88	1.64	1.40	1.23	1.22
21:00	2.56	2.35	2.26	2.01	1.88	1.64	1.39	1.22	1.21
22:00	2.55	2.35	2.26	2.00	1.88	1.63	1.38	1.23	1.21
23:00	2.53	2.35	2.25	2.00	1.87	1.62	1.38	1.24	1.20
24:00	2.52	2.35	2.24	1.99	1.87	1.61	1.37	1.24	1.20

TABLE G.1 STREAM DISCHARGE ($m^3\ sec^{-1}$) NORTHWEST BROOK (cont'd)

Time	May 27	May 28	May 29	May 30	May 31	June 1	June 2	June 3	June 4
01:00	1.19	1.08	1.36	1.69	2.04	1.92	1.70	1.39	1.24
02:00	1.18	1.08	1.38	1.71	2.05	1.91	1.69	1.38	1.23
03:00	1.18	1.08	1.39	1.74	2.05	1.90	1.68	1.37	1.23
04:00	1.17	1.07	1.40	1.76	2.05	1.89	1.66	1.36	1.23
05:00	1.17	1.07	1.41	1.78	2.04	1.88	1.65	1.35	1.23
06:00	1.17	1.07	1.42	1.80	2.04	1.87	1.64	1.34	1.22
07:00	1.16	1.07	1.43	1.82	2.03	1.87	1.63	1.33	1.22
08:00	1.16	1.08	1.44	1.85	2.02	1.86	1.62	1.32	1.21
09:00	1.15	1.10	1.45	1.87	2.01	1.85	1.61	1.31	1.20
10:00	1.15	1.12	1.46	1.89	2.01	1.84	1.59	1.30	1.20
11:00	1.14	1.15	1.47	1.91	2.01	1.83	1.58	1.29	1.19
12:00	1.13	1.18	1.47	1.92	2.00	1.82	1.56	1.28	1.19
13:00	1.13	1.20	1.48	1.94	2.00	1.81	1.54	1.27	1.19
14:00	1.12	1.22	1.49	1.95	2.00	1.80	1.53	1.27	1.18
15:00	1.12	1.24	1.50	1.96	2.00	1.79	1.52	1.26	1.18
16:00	1.11	1.25	1.51	1.97	1.99	1.78	1.50	1.26	1.18
17:00	1.11	1.26	1.53	1.98	1.99	1.77	1.49	1.26	1.17
18:00	1.10	1.27	1.54	1.99	1.98	1.77	1.47	1.25	1.17
19:00	1.10	1.29	1.56	2.00	1.97	1.76	1.46	1.25	1.17
20:00	1.10	1.30	1.58	2.01	1.97	1.75	1.45	1.25	1.17
21:00	1.10	1.31	1.60	2.02	1.96	1.74	1.43	1.24	1.17
22:00	1.09	1.32	1.62	2.03	1.95	1.83	1.42	1.24	1.18
23:00	1.09	1.34	1.65	2.03	1.94	1.72	1.41	1.24	1.18
24:00	1.09	1.35	1.67	2.04	1.93	1.71	1.40	1.24	1.18

TABLE G.1 STREAM DISCHARGE ($m^3\ sec^{-1}$) NORTHWEST BROOK (cont'd)

Time	June 5	June 6	June 7	June 8	June 9	June 10	June 11	June 12	June 13
01:00	1.18	1.47	1.66	1.66	1.45	4.35	28.2	12.3	5.96
02:00	1.18	1.49	1.66	1.66	1.44	5.17	27.6	11.8	5.84
03:00	1.18	1.50	1.66	1.66	1.44	6.07	26.7	11.3	5.71
04:00	1.18	1.51	1.66	1.65	1.43	7.06	25.9	10.9	5.58
05:00	1.19	1.52	1.66	1.64	1.42	8.26	25.0	10.5	5.44
06:00	1.20	1.53	1.66	1.63	1.41	9.58	24.1	10.1	5.32
07:00	1.22	1.54	1.66	1.62	1.41	10.9	23.2	9.77	5.19
08:00	1.24	1.55	1.66	1.60	1.40	12.4	22.3	9.40	5.07
09:00	1.25	1.56	1.66	1.59	1.39	14.1	21.5	9.06	4.97
10:00	1.27	1.57	1.66	1.58	1.38	16.8	20.8	8.74	4.88
11:00	1.29	1.48	1.66	1.57	1.37	19.5	20.1	8.43	4.79
12:00	1.30	1.49	1.66	1.56	1.37	21.8	19.3	8.18	4.70
13:00	1.32	1.60	1.66	1.54	1.37	23.9	18.6	7.96	4.62
14:00	1.33	1.61	1.66	1.53	1.37	25.4	18.0	7.73	4.53
15:00	1.35	1.61	1.66	1.53	1.39	26.9	17.3	7.53	4.44
16:00	1.36	1.62	1.66	1.52	1.46	28.1	16.7	7.36	4.36
17:00	1.38	1.63	1.66	1.52	1.56	28.9	16.2	7.20	4.28
18:00	1.39	1.63	1.67	1.51	1.70	29.5	15.7	7.04	4.20
19:00	1.40	1.64	1.67	1.51	1.86	30.0	15.2	6.87	4.14
20:00	1.41	1.64	1.67	1.50	2.09	30.2	14.6	6.71	4.08
21:00	1.42	1.65	1.67	1.49	2.42	30.2	14.0	6.54	4.02
22:00	1.43	1.65	1.67	1.48	2.79	29.9	13.7	6.38	3.96
23:00	1.44	1.65	1.67	1.47	3.20	29.4	13.2	6.22	3.91
24:00	1.46	1.66	1.67	1.46	3.71	28.9	12.8	6.09	3.85

TABLE G.1 STREAM DISCHARGE ($m^3\ sec^{-1}$) NORTHWEST BROOK (cont'd)

Time	June 14	June 15	June 16	June 17	June 18	June 19	June 20	June 21	June 22
01:00	3.80	2.80	3.37	3.91	3.09	2.31	1.96	1.72	1.56
02:00	3.74	2.77	3.76	3.89	3.06	2.30	1.94	1.71	1.55
03:00	3.69	2.74	3.78	3.86	3.03	2.27	1.93	1.70	1.55
04:00	3.63	2.76	3.81	3.84	2.99	2.25	1.92	1.69	1.54
05:00	3.58	2.81	3.84	3.83	2.96	2.24	1.90	1.68	1.54
06:00	3.53	2.87	3.86	3.81	2.92	2.22	1.89	1.68	1.53
07:00	3.49	2.92	3.88	3.79	2.88	2.21	1.88	1.67	1.52
08:00	3.45	2.97	3.90	3.77	2.84	2.20	1.87	1.66	1.51
09:00	3.41	3.02	3.91	3.74	2.80	2.19	1.85	1.65	1.50
10:00	3.37	3.07	3.93	3.70	2.77	2.17	1.84	1.64	1.49
11:00	3.33	3.11	3.95	3.67	2.73	2.16	1.83	1.63	1.49
12:00	3.29	3.17	3.96	3.63	2.69	2.15	1.82	1.62	1.48
13:00	3.25	3.22	3.97	3.60	2.66	2.14	1.81	1.61	1.47
14:00	3.20	3.28	3.98	3.56	2.63	2.12	1.80	1.60	1.47
15:00	3.16	3.33	3.99	3.51	2.60	2.11	1.79	1.60	1.46
16:00	3.12	3.38	3.99	3.47	2.58	2.10	1.78	1.59	1.46
17:00	3.08	3.43	4.00	3.43	2.55	2.08	1.77	1.59	1.45
18:00	3.04	3.48	4.00	3.39	2.52	2.06	1.77	1.59	1.45
19:00	3.01	3.53	4.00	3.35	2.49	2.05	1.76	1.58	1.44
20:00	2.97	3.58	4.00	3.30	2.47	2.03	1.75	1.58	1.43
21:00	2.94	3.61	3.99	3.26	2.44	2.01	1.75	1.57	1.43
22:00	2.91	3.64	3.98	3.21	2.41	2.00	1.74	1.57	1.42
23:00	2.88	3.67	3.95	3.17	2.39	1.98	1.73	1.56	1.41
24:00	2.84	3.70	3.93	3.13	2.35	1.97	1.73	1.56	1.40

TABLE G.1 STREAM DISCHARGE (m^3 sec^{-1}) NORTHWEST BROOK (cont'd)

Time	June 23	June 24	June 25	June 26	June 27	June 28	June 29	June 30	July 1
01:00	1.39	1.38	1.59	2.51	2.46	2.04	1.66	1.66	1.74
02:00	1.39	1.38	1.64	2.52	2.44	2.02	1.65	1.66	1.74
03:00	1.38	1.37	1.70	2.53	2.42	2.00	1.65	1.66	1.74
04:00	1.38	1.37	1.75	2.54	2.40	1.98	1.65	1.66	1.74
05:00	1.38	1.37	1.80	2.55	2.37	1.96	1.64	1.65	1.75
06:00	1.38	1.37	1.85	2.56	2.35	1.93	1.64	1.65	1.75
07:00	1.37	1.37	1.89	2.57	2.33	1.91	1.64	1.66	1.75
08:00	1.37	1.38	1.94	2.57	2.32	1.89	1.64	1.66	1.75
09:00	1.37	1.38	1.99	2.57	2.30	1.87	1.64	1.66	1.75
10:00	1.37	1.38	2.03	2.58	2.28	1.85	1.64	1.66	1.75
11:00	1.37	1.38	2.07	2.58	2.26	1.83	1.64	1.67	1.75
12:00	1.37	1.38	2.12	2.58	2.25	1.82	1.64	1.67	1.75
13:00	1.38	1.39	2.17	2.58	2.23	1.80	1.64	1.67	1.75
14:00	1.38	1.39	2.21	2.58	2.21	1.79	1.64	1.67	1.75
15:00	1.38	1.40	2.24	2.57	2.20	1.78	1.64	1.67	1.75
16:00	1.38	1.41	2.28	2.57	2.19	1.77	1.64	1.67	1.75
17:00	1.38	1.42	2.32	2.56	2.17	1.76	1.65	1.69	1.74
18:00	1.38	1.43	2.36	2.56	2.16	1.75	1.65	1.69	1.74
19:00	1.38	1.44	2.39	2.55	2.14	1.74	1.65	1.70	1.74
20:00	1.39	1.44	2.42	2.54	2.13	1.73	1.65	1.71	1.74
21:00	1.39	1.46	2.45	2.52	2.11	1.71	1.65	1.71	1.74
22:00	1.39	1.48	2.49	2.51	2.09	1.70	1.66	1.72	1.74
23:00	1.38	1.51	2.49	2.50	2.08	1.69	1.66	1.73	1.74
24:00	1.38	1.54	2.50	2.48	2.06	1.67	1.66	1.73	1.74

TABLE G.1 STREAM DISCHARGE ($m^3\ sec^{-1}$) NORTHWEST BROOK (cont'd)

Time	July 2	July 3	July 4	July 5	July 6	July 7	July 8	July 9	July 10
01:00	1.74	1.57	1.36	1.26	1.15	1.11	1.10	1.09	1.05
02:00	1.74	1.57	1.36	1.25	1.14	1.11	1.10	1.09	1.05
03:00	1.74	1.56	1.35	1.25	1.14	1.11	1.09	1.09	1.05
04:00	1.73	1.55	1.35	1.24	1.14	1.11	1.09	1.09	1.05
05:00	1.73	1.54	1.34	1.24	1.14	1.11	1.09	1.09	1.05
06:00	1.72	1.53	1.33	1.23	1.14	1.11	1.09	1.08	1.05
07:00	1.72	1.51	1.32	1.22	1.13	1.11	1.09	1.08	1.05
08:00	1.72	1.50	1.32	1.22	1.13	1.11	1.09	1.08	1.05
09:00	1.71	1.49	1.31	1.21	1.13	1.11	1.09	1.08	1.05
10:00	1.70	1.48	1.30	1.20	1.13	1.11	1.09	1.07	1.04
11:00	1.69	1.47	1.30	1.20	1.13	1.11	1.09	1.07	1.04
12:00	1.68	1.47	1.30	1.19	1.12	1.11	1.09	1.07	1.03
13:00	1.67	1.46	1.29	1.18	1.12	1.11	1.09	1.06	1.03
14:00	1.66	1.45	1.29	1.18	1.12	1.11	1.09	1.06	1.02
15:00	1.65	1.44	1.28	1.18	1.12	1.11	1.09	1.06	1.02
16:00	1.64	1.43	1.28	1.17	1.11	1.11	1.09	1.06	1.01
17:00	1.63	1.42	1.28	1.17	1.11	1.11	1.09	1.06	1.01
18:00	1.62	1.41	1.28	1.17	1.11	1.11	1.09	1.06	1.01
19:00	1.61	1.40	1.27	1.16	1.11	1.11	1.09	1.06	1.00
20:00	1.60	1.39	1.27	1.16	1.11	1.11	1.09	1.05	1.00
21:00	1.60	1.39	1.27	1.16	1.11	1.10	1.09	1.05	0.998
22:00	1.59	1.38	1.27	1.16	1.11	1.10	1.09	1.05	0.995
23:00	1.59	1.37	1.27	1.15	1.11	1.10	1.09	1.05	0.993
24:00	1.58	1.37	1.27	1.15	1.11	1.10	1.09	1.05	0.990

TABLE G.1 STREAM DISCHARGE ($m^3\ sec^{-1}$) NORTHWEST BROOK (cont'd)

Time	July 11	July 12	July 13	July 14	July 15	July 16	July 17	July 18	July 19
01:00	0.987	0.935	0.906	0.840	0.766	0.705	0.664	0.614	0.984
02:00	0.985	0.934	0.903	0.837	0.763	0.705	0.669	0.612	0.990
03:00	0.982	0.934	0.901	0.834	0.761	0.704	0.669	0.613	0.996
04:00	0.980	0.933	0.899	0.831	0.758	0.704	0.666	0.614	1.00
05:00	0.977	0.932	0.896	0.828	0.756	0.703	0.663	0.611	1.01
06:00	0.975	0.932	0.894	0.825	0.755	0.702	0.661	0.622	1.02
07:00	0.973	0.931	0.892	0.822	0.753	0.701	0.658	0.660	1.02
08:00	0.971	0.930	0.890	0.818	0.751	0.699	0.655	0.689	1.03
09:00	0.969	0.930	0.888	0.814	0.750	0.698	0.653	0.718	1.03
10:00	0.967	0.929	0.886	0.810	0.748	0.697	0.650	0.740	1.04
11:00	0.965	0.929	0.884	0.806	0.746	0.695	0.646	0.761	1.04
12:00	0.963	0.928	0.882	0.802	0.743	0.692	0.642	0.783	1.05
13:00	0.961	0.927	0.880	0.799	0.740	0.690	0.638	0.808	1.05
14:00	0.959	0.927	0.877	0.795	0.736	0.687	0.634	0.829	1.05
15:00	0.957	0.926	0.873	0.791	0.733	0.684	0.631	0.846	1.06
16:00	0.955	0.926	0.870	0.788	0.730	0.682	0.627	0.863	1.06
17:00	0.952	0.925	0.867	0.785	0.726	0.679	0.626	0.879	1.05
18:00	0.950	0.924	0.863	0.783	0.722	0.677	0.625	0.896	1.05
19:00	0.948	0.922	0.860	0.780	0.719	0.675	0.624	0.912	1.05
20:00	0.945	0.919	0.856	0.777	0.715	0.672	0.623	0.923	1.04
21:00	0.943	0.916	0.853	0.775	0.711	0.670	0.622	0.934	1.04
22:00	0.940	0.914	0.849	0.773	0.708	0.668	0.620	0.947	1.03
23:00	0.938	0.911	0.846	0.770	0.706	0.667	0.618	0.960	1.03
24:00	0.936	0.909	0.843	0.768	0.705	0.666	0.616	0.972	1.03

TABLE G.1 STREAM DISCHARGE ($m^3\ sec^{-1}$) NORTHWEST BROOK (cont'd)

Time	July 20	July 21	July 22	July 23	July 24	July 25	July 26	July 27	July 28
01:00	1.03	0.986	0.884	0.816	0.728	0.725	0.643	0.567	0.541
02:00	1.03	0.980	0.884	0.812	0.724	0.719	0.642	0.566	0.540
03:00	1.03	0.973	0.884	0.809	0.723	0.713	0.640	0.565	0.539
04:00	1.03	0.967	0.884	0.805	0.725	0.709	0.638	0.565	0.538
05:00	1.03	0.960	0.883	0.802	0.727	0.706	0.637	0.563	0.536
06:00	1.02	0.954	0.882	0.798	0.728	0.702	0.634	0.561	0.534
07:00	1.02	0.947	0.881	0.795	0.730	0.699	0.631	0.559	0.531
08:00	1.02	0.941	0.880	0.791	0.731	0.695	0.627	0.557	0.529
09:00	1.02	0.934	0.879	0.787	0.732	0.692	0.624	0.554	0.527
10:00	1.02	0.929	0.878	0.782	0.733	0.687	0.621	0.552	0.525
11:00	1.02	0.923	0.877	0.777	0.733	0.681	0.617	0.550	0.523
12:00	1.02	0.918	0.872	0.773	0.733	0.676	0.612	0.548	0.522
13:00	1.01	0.912	0.866	0.769	0.733	0.671	0.606	0.547	0.521
14:00	1.01	0.906	0.860	0.765	0.735	0.665	0.601	0.547	0.520
15:00	1.01	0.901	0.855	0.762	0.737	0.660	0.595	0.547	0.518
16:00	1.01	0.898	0.849	0.759	0.739	0.655	0.590	0.547	0.517
17:00	1.01	0.895	0.843	0.755	0.741	0.654	0.586	0.547	0.516
18:00	1.00	0.893	0.837	0.752	0.743	0.653	0.582	0.547	0.515
19:00	1.00	0.891	0.833	0.750	0.743	0.652	0.579	0.547	0.514
20:00	1.00	0.889	0.830	0.748	0.741	0.650	0.576	0.547	0.513
21:00	0.998	0.886	0.827	0.745	0.740	0.649	0.572	0.546	0.513
22:00	0.996	0.884	0.824	0.742	0.739	0.648	0.569	0.545	0.512
23:00	0.994	0.884	0.821	0.738	0.737	0.464	0.568	0.544	0.511
24:00	0.992	0.884	0.818	0.738	0.731	0.645	0.568	0.542	0.510

TABLE G.1 STREAM DISCHARGE ($m^3\ sec^{-1}$) NORTHWEST BROOK

Time	July 29	July 30	July 31	August 1	August 2	August 3
01:00	0.509	0.494	0.614	0.697	0.656	0.639
02:00	0.509	0.493	0.611	0.699	0.653	0.638
03:00	0.508	0.492	0.618	0.701	0.650	0.637
04:00	0.507	0.490	0.620	0.703	0.647	0.635
05:00	0.507	0.489	0.627	0.704	0.644	0.634
06:00	0.506	0.488	0.635	0.706	0.641	0.633
07:00	0.505	0.487	0.643	0.704	0.637	0.631
08:00	0.505	0.487	0.650	0.703	0.636	0.630
09:00	0.504	0.487	0.656	0.701	0.635	0.629
10:00	0.504	0.487	0.663	0.699	0.634	0.627
11:00	0.503	0.485	0.669	0.698	0.633	0.627
12:00	0.502	0.484	0.675	0.696	0.633	0.626
13:00	0.502	0.483	0.679	0.694	0.632	0.625
14:00	0.501	0.486	0.680	0.693	0.631	0.625
15:00	0.501	0.529	0.682	0.689	0.630	0.624
16:00	0.500	0.541	0.683	0.686	0.629	0.623
17:00	0.500	0.552	0.685	0.683	0.630	0.622
18:00	0.500	0.563	0.686	0.679	0.631	0.622
19:00	0.500	0.573	0.688	0.676	0.633	0.621
20:00	0.499	0.584	0.689	0.673	0.634	0.620
21:00	0.499	0.591	0.691	0.669	0.635	0.619
22:00	0.497	0.595	0.692	0.666	0.636	0.618
23:00	0.496	0.600	0.694	0.663	0.637	0.617
24:00	0.495	0.607	0.695	0.660	0.638	0.616

APPENDIX H

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER

Time	May 18	May 19	May 20	May 21	May 22	May 23	May 24	May 25	May 26
01:00	177	161	152	144	96	64	49	40	34
02:00	177	161	152	143	94	64	49	40	34
03:00	177	160	151	143	93	63	48	40	34
04:00	177	160	150	142	92	62	48	39	34
05:00	177	160	150	141	91	61	47	39	34
06:00	176	159	149	140	89	59	46	39	34
07:00	175	159	149	139	87	58	46	38	34
08:00	174	159	148	137	85	56	46	38	34
09:00	174	159	148	136	83	56	46	38	33
10:00	173	158	149	134	81	55	45	38	33
11:00	172	157	149	131	80	55	45	37	33
12:00	171	157	149	128	79	54	44	37	33
13:00	170	156	150	125	78	54	43	37	33
14:00	169	155	150	122	77	53	43	37	33
15:00	168	155	150	119	74	53	42	36	33
16:00	168	155	150	116	72	52	41	36	33
17:00	167	155	150	113	70	52	41	36	33
18:00	166	155	150	110	68	51	40	36	33
19:00	166	155	149	107	67	51	40	35	33
20:00	165	154	148	105	66	51	40	35	33
21:00	164	154	147	103	65	51	39	35	33
22:00	163	154	146	101	65	50	39	35	33
23:00	163	153	145	99	64	50	40	35	33
24:00	162	153	145	97	64	50	40	35	33

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER (cont'd)

Time	May 27	May 28	May 29	May 30	May 31	June 1	June 2	June 3	June 4
01:00	33	29	125	112	108	75	52	39	33
02:00	32	29	128	113	106	74	51	39	33
03:00	32	29	129	113	103	73	50	38	33
04:00	32	29	129	114	101	71	50	38	32
05:00	32	30	130	114	100	70	49	38	32
06:00	32	31	130	115	98	69	48	38	32
07:00	32	33	130	115	96	68	48	38	32
08:00	31	36	129	115	95	67	47	38	32
09:00	31	36	129	115	94	66	47	37	32
10:00	31	39	129	116	92	65	46	37	32
11:00	31	43	128	116	91	64	46	37	33
12:00	31	47	127	116	89	63	45	36	33
13:00	30	51	125	117	87	62	45	36	33
14:00	30	57	123	118	86	61	44	36	33
15:00	30	63	121	118	84	60	44	35	33
16:00	30	69	120	118	83	59	43	35	34
17:00	29	76	119	119	82	58	43	35	34
18:00	29	84	117	119	81	57	42	34	34
19:00	29	90	116	118	79	55	42	34	34
20:00	29	97	115	116	78	55	41	34	34
21:00	29	105	114	115	77	54	41	34	36
22:00	29	113	113	114	77	54	40	33	37
23:00	29	118	112	114	76	53	40	33	39
24:00	29	122	111	110	76	53	39	33	42

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER (cont'd)

Time	June 5	June 6	June 7	June 8	June 9	June 10	June 11	June 12	June 13
01:00	45	116	77	57	40	44	145	86	51
02:00	48	114	76	56	40	46	144	83	50
03:00	51	113	74	56	39	49	143	80	49
04:00	56	111	73	55	39	52	142	78	49
05:00	61	109	71	53	38	56	142	75	48
06:00	66	108	70	52	38	61	140	73	48
07:00	71	106	69	51	38	65	138	71	47
08:00	77	105	69	50	37	70	136	69	46
09:00	83	103	68	49	37	76	134	67	46
10:00	88	102	68	48	37	83	131	66	45
11:00	94	100	67	48	36	89	128	64	44
12:00	100	99	66	47	36	97	125	63	44
13:00	106	97	66	46	36	105	122	61	43
14:00	109	95	65	46	35	113	120	61	42
15:00	113	93	65	45	35	119	117	60	42
16:00	115	91	64	44	35	125	113	59	41
17:00	116	89	63	44	36	130	110	58	41
18:00	117	87	63	43	36	135	107	57	41
19:00	118	85	62	43	37	137	104	55	41
20:00	117	84	61	42	37	140	101	54	41
21:00	117	82	61	42	38	142	98	54	40
22:00	116	81	60	42	39	144	95	53	40
23:00	116	80	59	41	41	144	92	52	40
24:00	116	79	58	41	42	144	89	51	39

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER (cont'd)

Time	June 14	June 15	June 16	June 17	June 18	June 19	June 20	June 21	June 22
01:00	39	31	50	45	35	29	26	23	21
02:00	38	31	40	45	35	29	26	23	21
03:00	38	31	50	44	34	29	25	23	21
04:00	38	32	40	44	34	28	25	23	21
05:00	38	33	50	43	33	28	25	23	21
06:00	37	34	40	43	33	28	25	22	21
07:00	37	35	50	42	33	28	25	22	21
08:00	37	36	40	42	32	28	25	22	21
09:00	36	37	50	41	32	28	25	22	21
10:00	36	37	40	41	32	28	25	21	20
11:00	36	38	49	40	31	27	25	21	20
12:00	35	39	49	40	31	27	24	21	20
13:00	35	40	49	40	30	27	24	21	20
14:00	34	41	48	39	30	27	24	21	20
15:00	34	42	48	39	30	27	23	21	19
16:00	33	43	48	39	30	26	23	21	19
17:00	33	44	48	38	30	26	23	21	19
18:00	33	45	47	38	30	26	23	21	19
19:00	33	46	47	38	29	26	23	21	19
20:00	33	47	47	37	29	26	23	21	19
21:00	33	48	47	37	29	25	23	21	19
22:00	32	49	46	36	29	25	23	21	19
23:00	32	49	46	36	29	25	22	21	19
24:00	32	50	45	36	29	26	22	21	19

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER (cont'd)

Time	June 23	June 24	June 25	June 26	June 27	June 28	June 29	June 30	July 1
01:00	19	18	18	17	16	14	15	17	17
02:00	19	18	18	17	15	14	15	17	17
03:00	19	18	18	17	15	14	15	17	17
04:00	19	17	18	17	15	14	15	17	17
05:00	19	17	18	17	15	14	16	17	17
06:00	19	17	18	17	15	14	16	17	17
07:00	19	18	18	17	15	14	16	17	17
08:00	19	18	18	17	16	14	16	17	17
09:00	19	18	18	17	16	13	16	17	17
10:00	18	18	18	17	16	13	16	17	17
11:00	18	18	18	16	16	13	16	17	17
12:00	18	18	18	16	15	13	16	17	17
13:00	18	18	18	16	15	13	16	17	17
14:00	18	18	18	16	15	14	16	17	17
15:00	18	18	18	16	15	13	16	17	17
16:00	18	18	17	16	15	14	16	16	17
17:00	18	18	17	16	15	14	16	16	17
18:00	18	18	17	16	15	14	16	16	17
19:00	18	18	17	16	14	14	17	16	17
20:00	18	18	17	16	14	14	17	17	17
21:00	18	18	17	16	14	14	17	17	16
22:00	18	18	17	16	14	14	17	17	16
23:00	18	18	17	16	14	14	17	17	16
24:00	18	18	17	16	14	15	17	17	16

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER (cont'd)

Time	July 2	July 3	July 4	July 5	July 6	July 7	July 8	July 9	July 10
01:00	16	15	14	13	12	59	108	56	37
02:00	16	15	14	13	12	67	104	54	36
03:00	16	15	14	13	13	76	101	53	36
04:00	16	16	14	13	13	84	97	51	35
05:00	16	16	14	13	13	91	95	50	35
06:00	16	16	14	13	13	98	93	49	35
07:00	16	16	14	13	14	105	90	48	34
08:00	16	16	14	13	14	111	88	48	34
09:00	16	16	14	13	15	115	86	47	34
10:00	16	16	14	13	15	118	84	46	33
11:00	16	15	14	13	15	121	82	45	33
12:00	16	15	14	13	16	123	79	44	33
13:00	16	15	14	13	17	125	77	44	32
14:00	16	15	14	13	18	126	74	43	32
15:00	16	15	14	13	18	127	72	42	31
16:00	16	14	14	13	21	126	70	42	31
17:00	16	14	14	12	23	126	68	41	31
18:00	16	14	14	12	25	126	66	41	30
19:00	15	14	14	12	27	126	65	40	30
20:00	15	14	14	12	31	122	63	39	30
21:00	15	14	13	12	35	120	62	39	29
22:00	15	14	13	12	39	118	60	38	29
23:00	15	14	13	12	45	114	59	38	29
24:00	15	14	13	12	51	111	57	37	29

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER (cont'd)

Time	July 11	July 12	July 13	July 14	July 15	July 16	July 17	July 18	July 19
01:00	28	24	22	18	16	14	13	12	14
02:00	28	24	22	17	16	14	12	12	14
03:00	28	24	21	17	16	14	13	12	14
04:00	27	24	21	17	16	14	12	12	14
05:00	27	24	21	17	16	14	13	12	14
06:00	27	24	21	17	16	14	12	12	14
07:00	27	24	21	17	16	14	13	12	14
08:00	27	24	21	17	16	14	12	13	14
09:00	27	24	21	17	16	14	12	14	14
10:00	27	24	21	17	16	14	12	15	14
11:00	26	25	20	17	15	14	12	15	14
12:00	26	24	20	17	15	14	12	14	14
13:00	26	24	20	17	15	14	12	15	14
14:00	26	24	20	17	15	14	13	14	15
15:00	25	24	20	17	15	13	13	14	15
16:00	25	23	19	17	15	13	13	14	15
17:00	25	23	19	17	15	13	13	14	15
18:00	25	23	19	17	15	13	13	14	15
19:00	25	23	19	16	15	13	13	14	15
20:00	25	23	18	16	15	13	13	14	15
21:00	25	22	18	16	15	13	13	14	15
22:00	25	22	18	16	14	13	13	14	14
23:00	25	22	18	16	14	13	12	14	14
24:00	24	22	18	16	14	13	12	14	14

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER (cont'd)

Time	July 20	July 21	July 22	July 23	July 24	July 25	July 26	July 27	July 28
01:00	15	14	14	12	11	13	12	12	11
02:00	15	14	14	12	11	13	12	12	11
03:00	15	14	14	12	11	13	12	12	11
04:00	15	14	14	12	11	13	12	12	11
05:00	15	14	14	12	11	13	12	12	11
06:00	15	14	14	12	12	13	12	12	11
07:00	15	14	14	12	12	13	12	12	11
08:00	15	14	14	12	12	13	13	12	11
09:00	15	14	13	12	12	13	13	12	11
10:00	15	14	13	12	12	13	12	12	11
11:00	15	14	13	12	13	13	12	12	11
12:00	15	14	13	12	13	13	12	12	11
13:00	15	14	13	12	13	13	12	12	11
14:00	15	14	13	12	13	13	12	12	11
15:00	15	14	13	12	13	13	12	12	11
16:00	14	14	13	12	13	13	12	12	11
17:00	15	14	13	11	13	13	12	12	10
18:00	14	14	12	11	13	13	12	12	10
19:00	14	14	12	11	13	13	12	11	10
20:00	14	14	12	11	13	13	12	11	10
21:00	14	14	12	11	13	13	12	11	10
22:00	14	14	12	11	14	13	12	11	10
23:00	14	14	12	11	14	13	12	11	10
24:00	14	14	12	11	14	13	12	11	10

TABLE H.1 STREAM DISCHARGE ($\ell\ sec^{-1}$) FROM NORTHEAST POND RIVER (cont'd)

Time	July 29	July 30	July 31	August 1	August 2	August 3
01:00	10	11	17	25	23	22
02:00	10	11	18	25	22	23
03:00	10	11	19	25	22	23
04:00	10	11	19	25	22	23
05:00	10	11	20	25	22	23
06:00	10	11	21	25	22	23
07:00	10	11	21	25	22	23
08:00	10	11	22	25	21	23
09:00	10	11	23	25	21	24
10:00	10	11	23	25	21	24
11:00	10	11	24	25	21	24
12:00	11	11	24	25	21	24
13:00	11	11	24	25	21	24
14:00	11	11	24	25	21	23
15:00	11	12	25	25	21	23
16:00	11	16	25	24	21	23
17:00	11	15	25	24	21	23
18:00	11	16	25	24	21	23
19:00	11	17	25	24	20	23
20:00	11	17	25	24	20	24
21:00	11	17	25	23	20	24
22:00	11	17	25	23	20	24
23:00	11	17	25	23	21	24
24:00	11	17	25	23	22	24

APPENDIX I

TABLE I.1 PRECIPITATION (*mm*) ST. JOHN'S A

Date	Time*	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
May 18										
May 19	04:00	0.8	05:00	0.5						
May 20	04:00	0.2	07:00	0.2	08:00	0.7	09:00	0.2	10:00	0.2
May 20	11:00	0.5	12:00	0.2						
May 21										
May 22	07:00	0.3								
May 23										
May 24										
May 25	11:00	1.0	12:00	0.8	13:00	0.2	20:00	0.2	21:00	0.3
May 25	22:00	0.3								
May 26										
May 27										
May 28	05:00	3.3	06:00	5.1	07:00	3.3	08:00	0.8	09:00	1.9
May 28	10:00	1.0	11:00	0.6						
May 29	02:00	0.4	17:00	0.4	18:00	0.4	19:00	0.2	20:00	1.5
May 29	21:00	0.4	22:00	0.6	23:00	1.1	24:00	0.2		
May 30	01:00	0.2	02:00	0.4	03:00	0.2	23:00	0.2		
May 31	01:00	0.2	05:00	0.4						
June 1										
June 2										
June 3										
June 4	03:00	M**	04:00	M	05:00	M	06:00	M	07:00	M
June 4	08:00	M	09:00	M	10:00	M	11:00	M	12:00	M
June 4	13:00	M	14:00	M	15:00	M	16:00	M	17:00	M
June 4	18:00	M	19:00	M	20:00	M	21:00	M	22:00	M
June 4	23:00	M	24:00	M						

* For the previous hour
** Missing data

TABLE I.1 PRECIPITATION (*mm*) ST. JOHN'S A (cont'd)

Date	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
June 5	01:00	M	02:00	M						
June 6										
June 7										
June 8										
June 9	14:00	0.4	15:00	0.6	16:00	0.6	17:00	0.2	18:00	1.3
June 9	19:00	3.2	20:00	1.9	21:00	2.6	22:00	0.6	23:00	0.4
June 9	24:00	1.7								
June 10	01:00	0.6	04:00	0.2	05:00	0.2	06:00	1.5	07:00	1.9
June 10	08:00	0.2	10:00	0.2						
June 11										
June 12										
June 13										
June 14										
June 15	04:00	1.0	05:00	4.2	06:00	1.3	07:00	1.9	09:00	0.2
June 15	10:00	0.2								
June 16										
June 17										
June 18										
June 19										
June 20										
June 21										
June 22	16:00	0.6								
June 23	03:00	0.2	04:00	0.2	05:00	0.5	06:00	0.5	08:00	0.2
June 24	07:00	0.4	08:00	1.1	18:00	0.2	23:00	2.6		
June 25	01:00	0.6	02:00	0.2						
June 26										
June 27										
June 28	14:00	0.2	15:00	2.2	16:00	2.4	17:00	0.2	24:00	4.0
June 29	01:00	0.9	04:00	2.5	05:00	0.4				
June 30										

TABLE I.1 PRECIPITATION (*mm*) ST. JOHN'S A (cont'd)

Date	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
July 1										
July 2										
July 3										
July 4										
July 5	20:00	0.2	21:00	0.2	22:00	0.5	23:00	0.2	24:00	0.5
July 6	01:00	0.8	02:00	0.8	03:00	1.3	04:00	2.2	05:00	2.4
July 6	06:00	3.4	07:00	2.8	08:00	1.4	09:00	2.4	10:00	1.2
July 6	12:00	0.3	13:00	1.8	14:00	1.8	15:00	1.8	16:00	0.8
July 6	17:00	0.6	18:00	1.8	19:00	0.2	20:00	0.2		
July 7										
July 8										
July 9										
July 10										
July 11										
July 12	05:00	0.7	06:00	1.1	07:00	0.2				
July 13										
July 14										
July 15										
July 16										
July 17										
July 18	04:00	0.4	05:00	1.4	06:00	0.2	07:00	2.8	08:00	4.6
July 18	09:00	3.6	13:00	0.2						
July 19										
July 20										
July 21	19:00	0.5								
July 22										
July 23										
July 24	01:00	0.6	02:00	0.4	03:00	0.4	04:00	2.5	05:00	1.2
July 24	06:00	0.9	07:00	0.2	08:00	0.2	09:00	0.2	10:00	2.0

TABLE I.1 PRECIPITATION (*mm*) ST. JOHN'S A (cont'd)

Date	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount
July 24	11:00	0.7	13:00	0.2	14:00	1.1	16:00	2.7	17:00	0.2
July 24	18:00	0.9	19:00	1.4	20:00	0.9	21:00	0.4	22:00	0.2
July 24	23:00	0.2								
July 25										
July 26										
July 27										
July 28										
July 29	10:00	1.5	11:00	0.5						
July 30	15:00	5.4	16:00	1.1	17:00	0.6	18:00	12.0	19:00	1.1
July 31										

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