EFFECTS OF BEAVER DAMS

ON

SUBARCTIC WETLAND RUNOFF

BY

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ABSTRACT

Beaver dams located on streams of a western James Bay marsh were studied to determine their effects on the runoff from subarctic wetlands. A survey of the location, type, class, and geometry of 50 dams on five different creeks were related to streamflow hydrographs from the 1987 field season. The hydrographs showed that although gapflow and overflow type dams stored more water upstream during low flow, little alteration to stormflow occurred except for the shedding of water to the surrounding wetland. Throughflow type dams altered streamflow only at the local scale, while underflow type beaver dams, despite having little affect at low flow, created a 12 hour time lag and a long hydrograph recession during high flows.

A water balance comparison was performed for the period June 18th to July 28th, 1988 between a basin without a beaver dam and one dammed by the beaver to determine the effects of the beaver dams at the basin scale. The amount of water stored in the beaver dam basin (18mm) was 53mm greater than that stored in the basin without a dam (-35mm) indicating

a distinct difference in the basins' abilities to store water. In both basins, net subsurface flow was negligible. Precipitation was similar in magnitude between the two basins. Net surfaceflow in the beaver dam basin was 43mm compared to -28mm in the beaver dam-less basin. The beaver dam was responsible for preventing a portion of inflow from leaving the basin, and consequently caused the increase in storage. Increased evaporation occurred because of the larger ponded area upstream from the beaver dam which in turn decreased the amount of water stored in the basin. Downstream streamflow ceased during dry periods because of the loss and storage of water from the system upstream.

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CHAPTER I

INTRODUCTION

1.1 General Introduction

Much of the Canadian subarctic is covered by wetlands (Zoltai and Pollet, 1983), yet until the mid 1980s little or no research in subarctic wetlands dealt with hydrology explicitly. Hydrologic research in the subarctic wetlands now includes the breakup of small rivers (Woo and Heron, 1987a), the effects of forests on spring wetland runoff (Woo and Heron, 1987b), a study of lake storage during snowmelt runoff (Fitzgibbon and Dunne, 1981), the characteristics of subarctic snowcover (Fitzgibbon and Dunne, 1979), the hydrology and salinity of coastal marshes (Price, 1988; Price and Woo, 1988), the characteristics and generation of snowmelt runoff (Price, 1975; Price et al., 1976;), and a study of hydrologic processes in tributary basins (diCenzo, 1987). The wetland drainage mechanisms were found to depend on the position of the water level (diCenzo, 1987), and the spatial and temporal changes in water supply tended to alter the direction and magnitude of subarctic wetland runoff (Woo and Heron, 1987b). These studies have yielded much information on the effects of snowmelt, vegetation, and rainfall on subarctic wetland runoff. However, no consideration was given to the hydrological effects of animal habitats. The beaver is one such animal.

Many streams in the Canadian subarctic wetlands are home to the beaver. Because of its dam construction habits, the beaver (Castor canadensis) can affect the environment extensively (Neff, 1957). Beaver dams are usually comprised of logs, twigs, mud, stones, and pebbles and are often constructed concave upstream (Ives, 1942). Studies in mid-latitude wetlands indicate that the construction of beaver dams increases the upstream storage and water supply, while decreasing stream velocity (Allred, 1980; Allred, 1981; Buech, 1985), causing the water table of the wetland to rise and runoff fluctuations to be damped (Duncan, 1984).

Given the flat topography of subarctic wetlands, the runoff pattern is highly susceptible to changes as the stream courses are modified. Considerable alterations to the subarctic wetland runoff is, therefore, expected to result from beaver dams.

1.2 Research Objectives

It is the purpose of this research project to study the effects of beaver dams on runoff in a subarctic wetland. More specifically, this study will:

1. examine and characterize many beaver dams and relate them to the wetland streamflow.

2. examine how the beaver dams will influence the water balance of a drainage basin through alterations of its runoff.

3. draw conclusions and gain an understanding of the alterations of the overall wetland runoff patterns due to beaver dams.

CHAPTER II

STUDY AREA AND METHODS

2.1 Study Area

The research site (53^{0} 18'N, 82^{0} 08'W) selected for this study is located on western James Bay, 3 km north of Ekwan Point. The study area is influenced by a subarctic continental climate. The topography of the region is extremely flat with an average gradient of 0.9m/km towards the coast and has a large number of beach ridges running parallel to the coast. The ridges are dominated by white spruce (Picea glauca), tamarack (Larix laricina), sphagnum moss, and lichen, whereas the wetlands, which develop in the inter-ridge depressions, are characterized by stands of willow (Salix spp.), aquatic moss, marsh marigold (Caltha paluostris), and sedge (Carex aquatilis). Soil profiles indicate that the ridges are composed of 1.25m of gravel overlying a silty marine clay with a thin organic layer. The wetlands, however, consist of a thicker 20cm organic layer and have at least 50cm of silt overlying the marine clay.

Drainage from the wetland follows several streams that cut perpendicularly across the raised beach ridges, and as overland flow in the inter-ridge wetlands. The streamflow is altered by numerous beaver dams of differing size, age, and stage of disrepair. Groundwater flow exists between the inter-ridge wetlands as well.

The stream-wetland complex studied in this report is illustrated in figure 2.1. The study site was chosen because of the numerous beaver dams located along the creeks. Six unofficially named creeks (Alder Stream, Beaver Stream, Crooked Creek, Middle Creek, Triples Creek, and Willow Stream) were chosen for the detailed study of the beaver dams. Two drainage basins were selected to carry out the water balance comparison. The inter-ridge wetland (I-RW) has no major stream drainage and is typical of the drainage basins in the region. The beaver dam basin (BDB), however, has a stream flowing through it and its outlet is blocked by a beaver dam. The areas of the inter-ridge wetland and the beaver dam basin are 18,625 m^2 and 8,843 m^2 respectively (and reside in the same area as the streams chosen for the study). A meteorological site (met site on figure 2.1) was set up to obtain the meteorological data for the study area.

2.2 Methods

Field data were collected between June 12 and August 5, 1988. Additional data from the summer of 1987 were used. The 1988 instrument locations for the inter-ridge wetland and beaver dam basin are shown in figures 2.2 and 2.3 respectively.

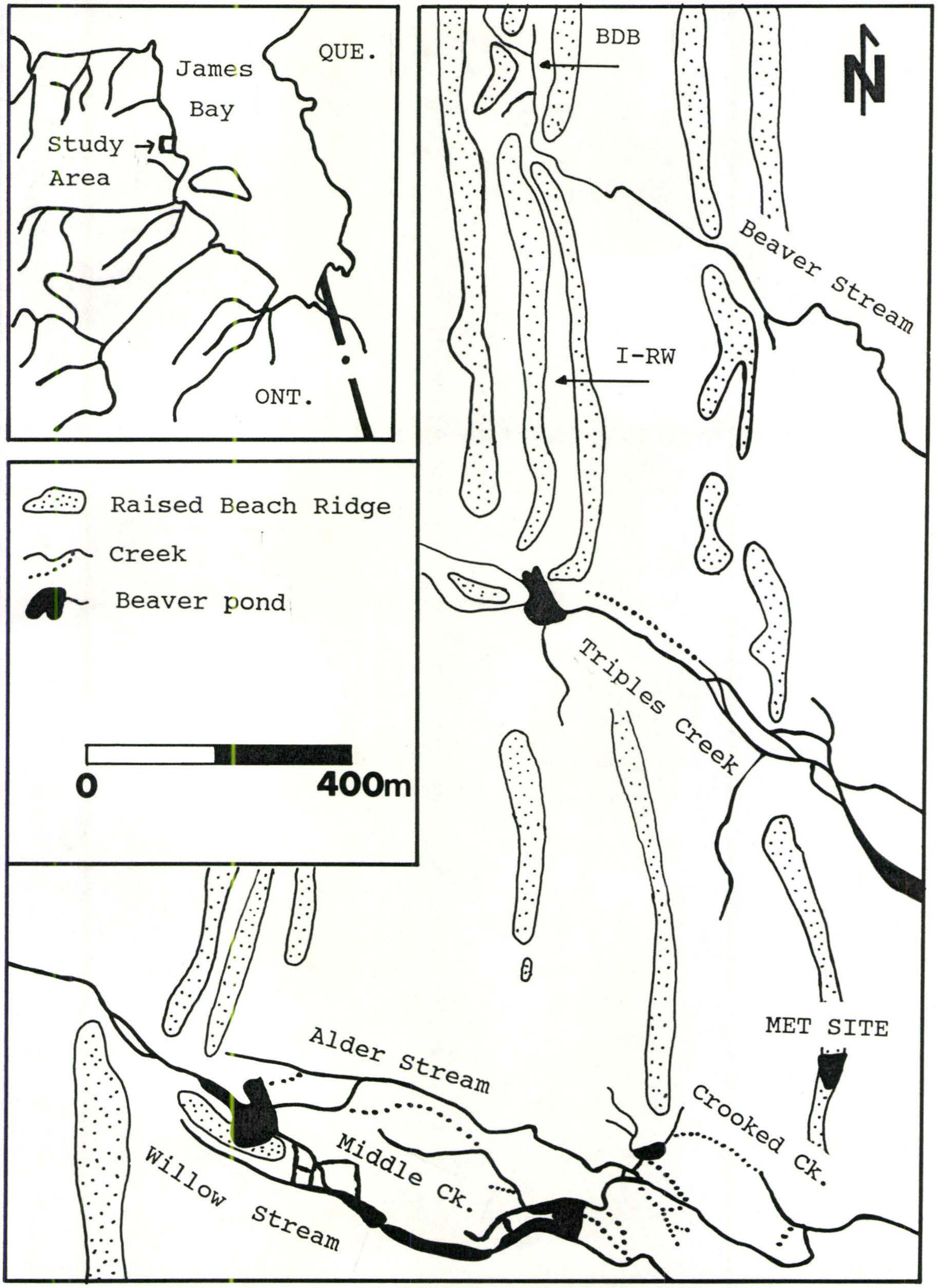

Figure 2.1 Location of the research site.

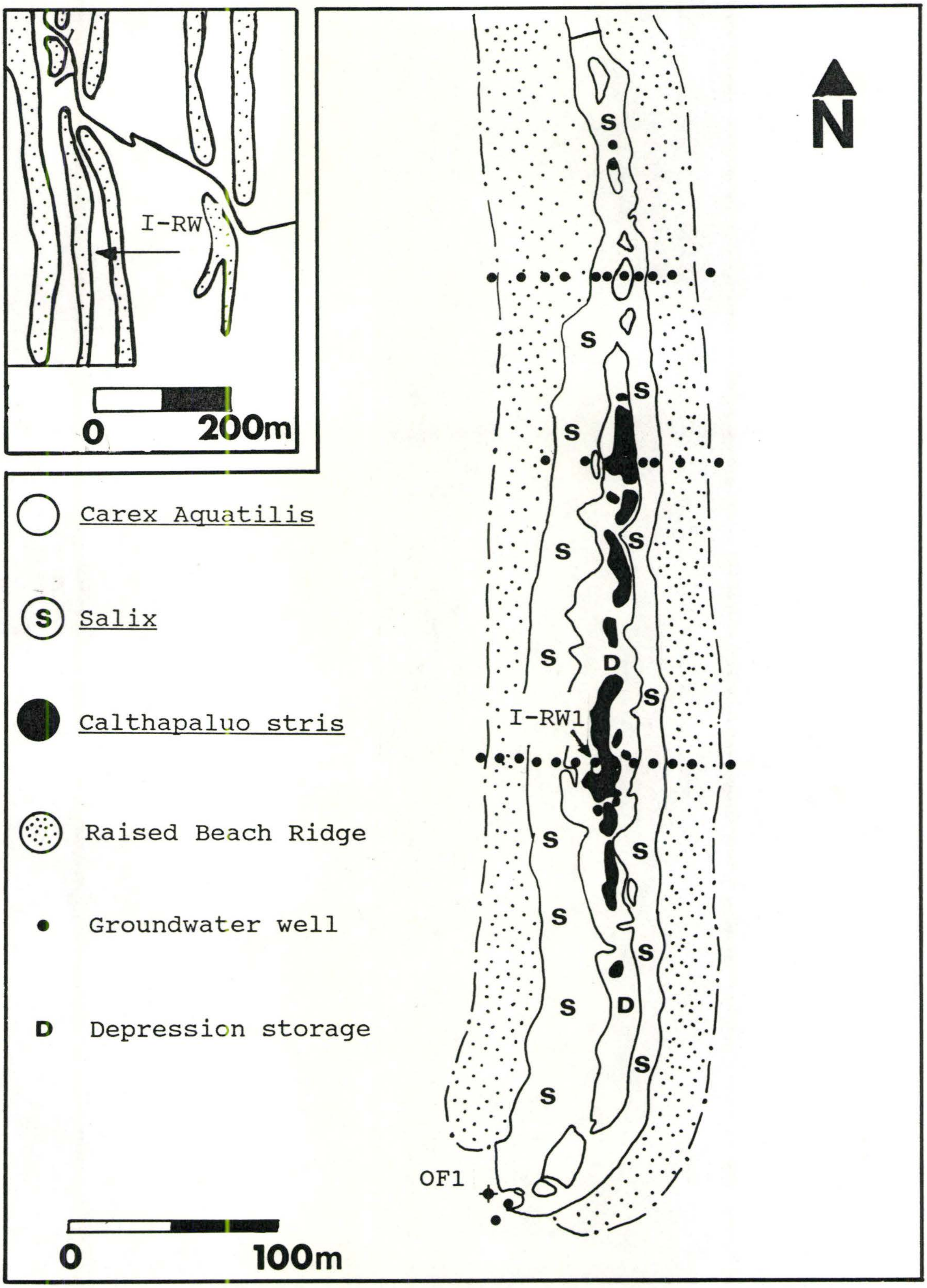

Figure 2.2 Inter-ridge wetland instrument locations.

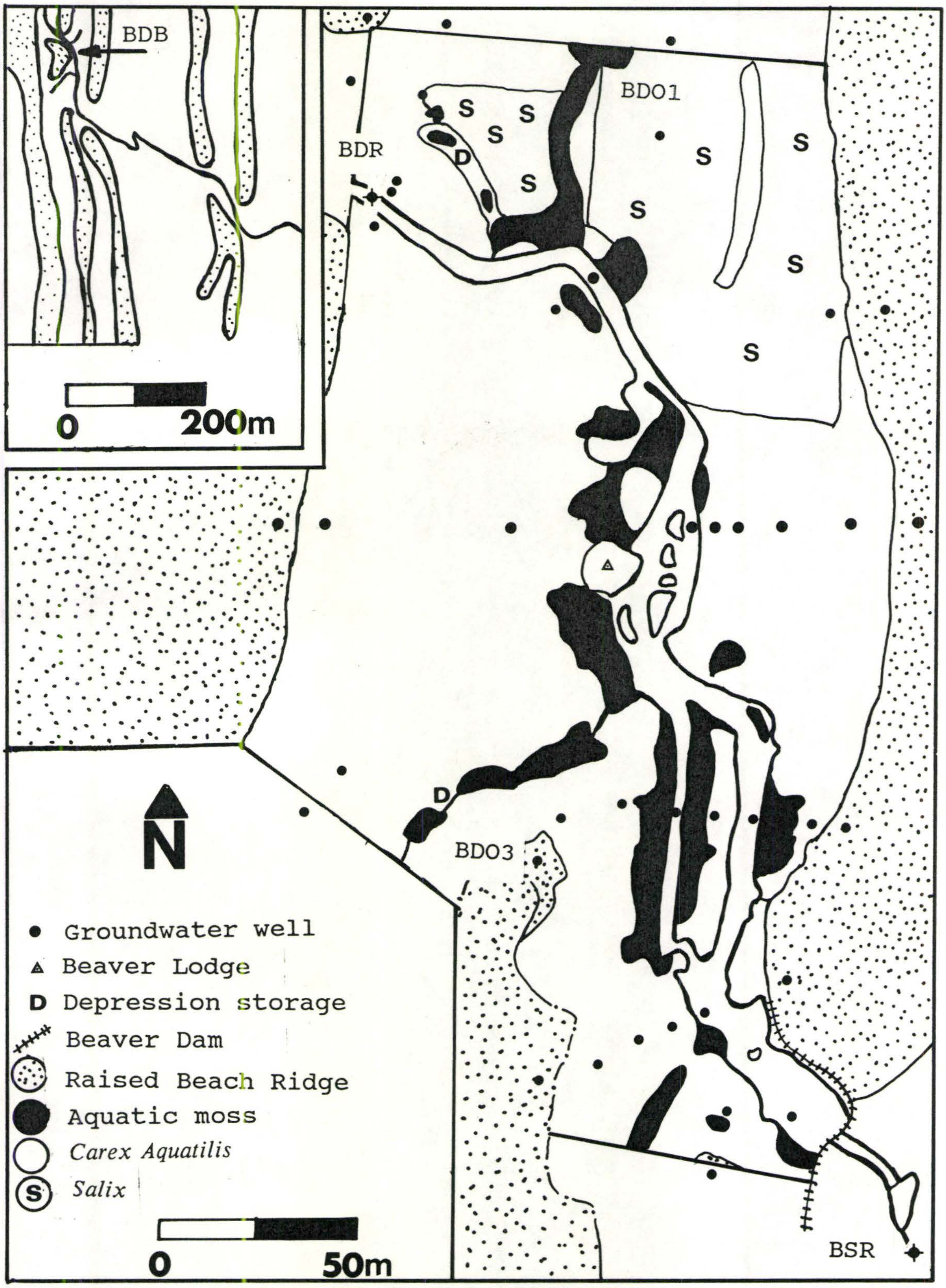

Figure 2.3 Beaver dam basin instrument locations.

2.2.1 Beaver Dam Data

Beaver Dam Classification System

According to Tanner (1977), the beaver creates a dam with wood from alder, willow, and aspen thickets, as well as from mud, leaves, and other debris. The dams are finally secured by rocks. This forms the basis of the beaver dam classification system, known as the "eight star system", which compares beaver dams in various stages of disrepair. The "eight star system" groups the beaver dams into eight classes and the criterion are summarized in table 2.1.

Table 2.1 The Eight Star Beaver Dam Classification System.

CLASS:		NAME:	CHARACTERISTICS:
*	(1)	Active	-Stones, new branches, fresh mud.
**	(2)	Active	-No stones, new branches, fresh mud.
***	(3)	Old	-Stones, old branches, mud, and debris.
****	(4)	Old	-No stones, old branches, mud, debris.
*****	(5)	Old	-No stones, old branches, half of mud and debris remains.
******	(6)	Old	-Only large branches and sticks remain.
*******	(7)	Relict	-Only small branches and twigs remain.
********	(8)	Relict	-Most branches are gone and only half of the original structure is intact.

The beaver dams were further classified according to the way they affect the flow of water. These types are: overflow, gapflow, throughflow, and underflow and are illustrated in figure 2.4. The geometry of the 50 dams was examined to further develop the beaver dam classification. For each beaver dam, the length (l), width (w), height (h), upstream (Ubar) and downstream water depth (Dbar), change in water level (dWL), were measured manually using a tape measure (table 2.2 and figure 2.4e). The class (C) was also assessed.

Table 2.2 Beaver Dam classification data. All data are expressed in m. Average values refer to the average value over both time and space for all dams sampled during periods of low flow.

		l	w	U	D	h	dWL	C
GAPFLOW:	Minimum	1.00	0.26	0.16	0.05	0.03	0.01	2
(15 dams)	Maximum	40.50	2.00	1.20	0.80	0.40	0.40	8
	Average	11.24	0.80	0.49	0.34	0.15	0.14	5
THROUGHFLOW:	Minimum	0.50	0.15	0.05	0.00	0.00	0.00	4
(15 dams)	Maximum	18.50	0.95	0.90	0.90	0.60	0.10	8
	Average	4.64	0.47	0.38	0.35	0.10	0.02	7
UNDERFLOW:	Minimum	2.50	0.40	0.15	0.05	0.02	0.02	2
(4 dams)	Maximum	35.80	1.55	0.25	0.35	1.15	0.40	8
	Average	11.52	0.79	0.19	0.17	0.51	0.15	6
OVERFLOW:	Minimum	2.40	0.20	0.00	0.00	0.00	0.00	1
(20 dams)	Maximum	67.70	1.70	5.00	0.50	0.75	0.77	7
	Average	15.54	0.63	0.67	0.24	0.15	0.30	2

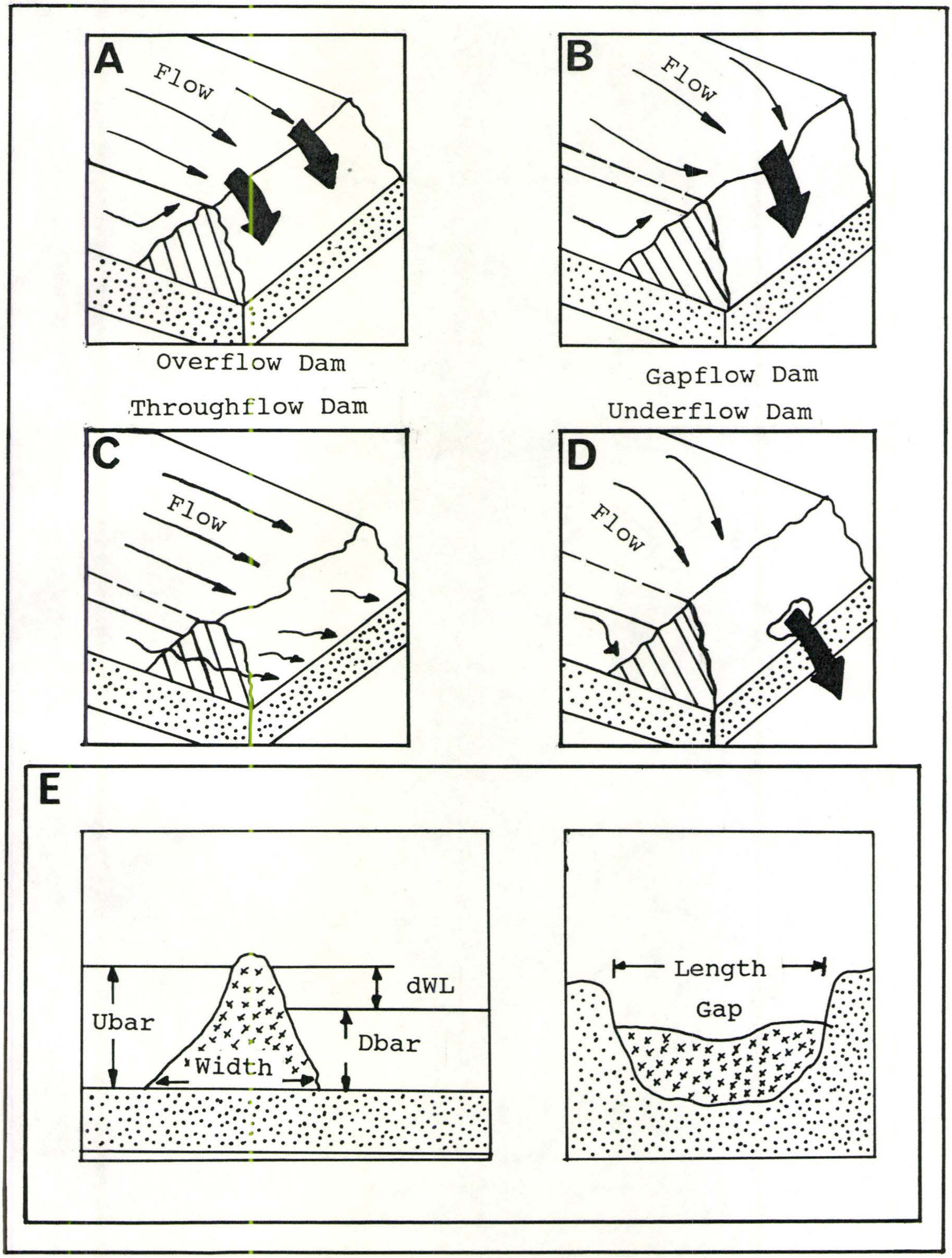

Figure 2.4 Beaver dam types: a) overflow, b) gapflow, c) throughflow, d) underflow, and e) schematic representation.

Streamflow Data

Water levels were recorded continuously on three of the streams during the 1987 field season using Leupold-Stevens Type F recorders. The recorders were located downstream of major dam complexes. The direction and velocity of flow near the beaver dams were determined by tracing the movement of dye injected into the stream. Because streams and their associated wetlands interact through the exchange of subsurface flow, overland flow and stream flow (Heron et al., 1989), a detailed survey of the stream-wetland complex was made. The descriptive map data were combined with the beaver dam classification system and the continuous water level records to draw qualitative conclusions on the alteration of the runoff patterns and subsequent interaction with the surrounding wetland.

2.2.2 Meteorological Data

Precipitation

A Weathertronics 6010 tipping-bucket rain gauge connected to a Campbell Scientific CR21 datalogger was used to record hourly rainfall totals for the entire study period. Three manual rain gauges were located over the study area to measure spatial variation of rainfall. These gauges were measured and emptied after each rainfall event. The data from a manual rain gauge located adjacent to the tipping-bucket rain gauge were regressed against the tipping bucket rain gauge data to calibrate the manual gauges located in the inter-ridge wetland and the beaver dam basin (equation 2.1).

$$\text{Manual (mm)} = (0.9464865*TP)-0.1270 \qquad [2.1]$$

$r^2 = 99.8$ n= 24   S= 0.0146

where TP is the tipping bucket reading in mm. The records for the manual rain gauges were then converted into a continuous rainfall record by regression analysis.

Air Temperature

Average hourly air temperatures were obtained with a Campbell 101 temperature probe. The probe, shielded from the sun, was at a height of one meter above the surface and connected to the Campbell Scientific CR21 datalogger.

Radiation

An Eppley Pyranometer hooked to the Campbell Scientific CR21 datalogger was used to measure mean hourly incoming solar radiation (Kdown). A roving Middleton Net Radiometer measured the total mean hourly net radiation (Q*) over various surfaces. Table 2.3a indicates the surface types measured and the period when the surface was studied. Mean hourly values were recorded by the datalogger and converted to daily averages. Regression analysis between Kdown and Q* was used to calculate continuous Q* values for the entire study period over all surfaces. Rating curve coefficients are listed in table 2.3b.

Table 2.3a Net Radiation (Q*) surface types measured.

June 17 to June 27	Carex aquatilis (long).
June 27 to July 5	Caltha paluostris.
July 5 to July 15	Salix spp.
July 15 to July 25	Aquatic moss.
July 25 to August 4	Carex aquatilis (short).

Table 2.3b Kdown vs. Q* Rating curve coefficients.

SURFACE	a	b	n	r^2	S
Carex aquatilis (l)	-27.3957	0.648608	240	92.4	0.0119
Caltha paluostris	-38.8826	0.776422	240	98.9	0.0053
Salix spp.	-12.5023	0.710409	240	98.8	0.0051
Aquatic moss	-18.0174	0.664838	240	99.1	0.0040
Carex aquatilis (s)	-26.27	0.613426	240	90.2	0.0198

Q* is calculated by the following equation: $Q^* = (b * Kdown) + a$

Evaporation

Evaporation was computed using the Priestley and Taylor (1972) method, where the evaporative heat flux (LE) can be calculated by:

$$LE = a'[S/(S + p)]\ (Q^* - Qg) \qquad [2.2]$$

where a' is an empirical coefficient, S is the slope of saturated vapour pressure-temperature curve, p is the psychrometric constant, Q* is net radiation, and Qg is ground heat flux. Many studies indicate that for wetland surfaces a mean a' value of 1.26 exists (Priestley and Taylor, 1972; Davies and Allen, 1973; Rouse et al, 1977; Marsh et al, 1981). This mean a' value was used in the calculation of the evaporative heat flux and Qg was assumed to be zero.

2.2.3 Hydrological Data

Streamflow

Discharge was recorded at four sites in the beaver dam basin (figure 2.3). Stream levels at the upper (BDR) and lower (BSR) Beaver Stream locations were measured with Leupold-Stevens Type F stage recorders. The stage was converted to discharge by establishing rating curves for each site by using the velocity-area method, with velocity obtained by a Price-type current meter. Only manual readings of a stake were made for the other two locations. A rating curve was constructed by the velocity-area method by injecting red dye into the stream at 0.6 of the stream depth. A continuous record was obtained by regressing the manual measurements at BDO1 and BDO3 against the stage of the BSR site. Rating curve coefficients are listed in table 2.4.

Table 2.4 Streamflow and Overland flow rating curve coefficients (for measurements in mm.).

LOCATION	ln(a)	b	n	r^2	S
BDR	17.083901	0.024579	9	97.8	0.0015
BDO1					
<289	29.675010	0.021323	3	95.8	0.3598
>289	3.132511	0.013143	3	99.5	0.0375
>325	0.000000	0.000000	3		
BDO3					
<374	9.382679	0.024189	4	94.5	0.1180
>374	0.000000	0.000000	5		
BSR	13.537186	0.018939	9	98.6	0.1815
OF1	36.721949	0.158966	11	95.5	0.0122

Discharge is calculated by the following equation:
Discharge = e^x, where x = ln(a) - b*(stage)

Overland Flow

The inter-ridge wetland lacks a stream and discharge from the basin flows in the form of unchannelized flow or overland flow. Overland flow was collected at OF1 (figure

2.2) by funnelling the water between plywood boards and spreading plastic sheeting between the boards to prevent water from seeping below the surface. The collected water then passed through a 3m pipe into a bucket. The level of the water in the bucket was recorded continuously using a Leupold-Stevens Type F recorder, located over the bucket, and was converted to discharge using manual measurements of the time required to fill a 500ml graduated cylinder (placed at the end of the pipe). Rating curve coefficients are also listed in table 2.4.

Water Level

Water levels were recorded continuously in the inter-ridge wetland at site I-RW1 (figure 2.2). Manual measurements of the water levels in the inter-ridge wetland and the beaver dam basin were made using a network of groundwater wells. The wells consisted of reinforced 19mm diameter PVC pipes with holes spaced every 40cm. Fine particles were prevented from entering the wells by covering the pipes with cloth. The water levels were read manually using an electronic sensor attached to a tape measure. The wells of both basins were surveyed using a Kern GKOA level to allow the water and well levels to be related to an arbitrary datum.

Depression Storage

The change in the storage of water located in depressions was calculated for the inter-ridge wetland and the beaver dam basin. The depth of water was measured in 20 positions along a 10m transect in several depressions located in each basin. The average depth was regressed against the continuous water level records of the groundwater well I-RW1 in the inter-ridge wetland. The regression equation for depression storage in the inter-ridge wetland was obtained from data collected in the summer of 1987. Table 2.5 indicates the regression equations used to calculate a daily change in depression storage.

Table 2.5 Depression storage regression equations.

SURFACE	a	b	n	R^2	S
Inter-ridge Wetland	351.19	-8.05246	11	89.0	0.943
Beaver Dam Basin	507.97	-0.87046	12	91.3	0.085

Depression storage is calculated by the following equation:

$$dSd=(b*S1)+a$$

where S1 is the elevation of the water table stake S1 in the inter-ridge wetland. The elevation must be expressed in mm.

Change in Storage

The change in storage of ground water was determined for the inter-ridge wetland and the beaver dam basin according to the method described by Bavina (1975) where:

$$S=WL(Sy) \quad [2.3]$$

where S is the change in storage measured in millimeters, WL is the change in water level also measured in millimeters, and Sy is the specific yield of the soil. When the water table is above the surface, the change in storage is equal to the change in the water level. Table 2.6 is a summary of average specific yield values found for various soil profiles. Soil samples were taken at a depth of 15 to 30cm and the specific yield was assumed to be constant for the entire soil profile.

Table 2.6 Average specific yield values for I-RW and BDB soil profiles.

Location	Specific Yield
BDB Peat wetland	0.26
BDB Sand ridge	0.23
BDB <u>Carex</u>	0.11
BDB aquatic moss	0.13
I-RW Gravel ridge	0.14
I-RW Peat wetland	0.19
I-RW Sphagnum moss	0.22

Groundwater Flux

The groundwater flux (Qg) into and out of the inter-ridge wetland and the beaver dam basin was determined through Darcy's law (Dunne and Leopold, 1978) where:

$$Qg = Ak[(h1-h2)/L] \qquad [2.4]$$

where A is the cross-sectional area of the aquifer, h1 is the elevation of the water table at point 1, h2 is the elevation of the water table at point 2, L is the distance of flow between points 1 and 2, and k is the hydraulic conductivity of the aquifer.

The net groundwater flux was obtained using the 84 groundwater wells located in the basins and the "slug test" described by Bouwer (1978) was used to determine the hydraulic conductivity for each well. The clay/ice layer was assumed to form the impermeable substrate beneath the peat and silt.

CHAPTER III

DIRECT EFFECTS OF BEAVER DAMS ON STREAMFLOW

Beaver dams are often found along the streams of the wetlands. This part of the study will characterize and classify beaver dams and relate them to the streamflow of the region.

Tanner (1977) stated that the beaver is not a precise surveyor. As a result, it may build a very wide dam when it could have chosen a location where the topography permits it to construct a shorter dam. Consequently, there should be no evident relationship between the dam length or width to the type of beaver dam. This is certainly the case for the 50 beaver dams surveyed in this study (table 2.2). The average lengths of the gapflow, throughflow, underflow, and overflow type beaver dams were 11.25, 4.64, 11.52, and 15.54m respectively. The standard deviations associated with these dam types were extremely high indicating that the beaver in this region behave similar to that described by Tanner (1977).

Although there is no relationship between the type of beaver dam and its size, there is a relationship between beaver dam size and its relative location on the stream. In general, the dams located the farthest downstream are not as broad as the upstream dams for two reasons. First, the downstream channels have higher banks because the streams are incised. The beaver dams then tend to be high rather than wide. Secondly, the downstream dams are smaller because they are usually subsidiary to the larger upstream dam complexes (Tanner, 1977).

These subsidiary dams are usually built by the beaver to raise the water level behind the large dam complexes. Not only does this provide the beaver access to the downstream portion of the large dam complexes, it also reduces the pressure exerted on the large dams. The beaver counteracts the large upstream water pressures by two other methods: 1) by shaping the dam concave upstream and 2) by creating a temporary spillway to 'sluice off' water during high stages.

The degree to which streamflow is altered by the presence of beaver dams not only depends on the location, class, and type of beaver dams but also the interaction of neighbouring dams. Figure 3.1 illustrates the complexity of the flow due to the presence of beaver dams. Some dams divert flow to the wetland, and this flow either returns directly below the dam, forms a pond and becomes overland flow in the wetland, or is transferred to an adjacent stream. In this section of the report the different dam types will be described and their effects upon hydrograph responses will be discussed.

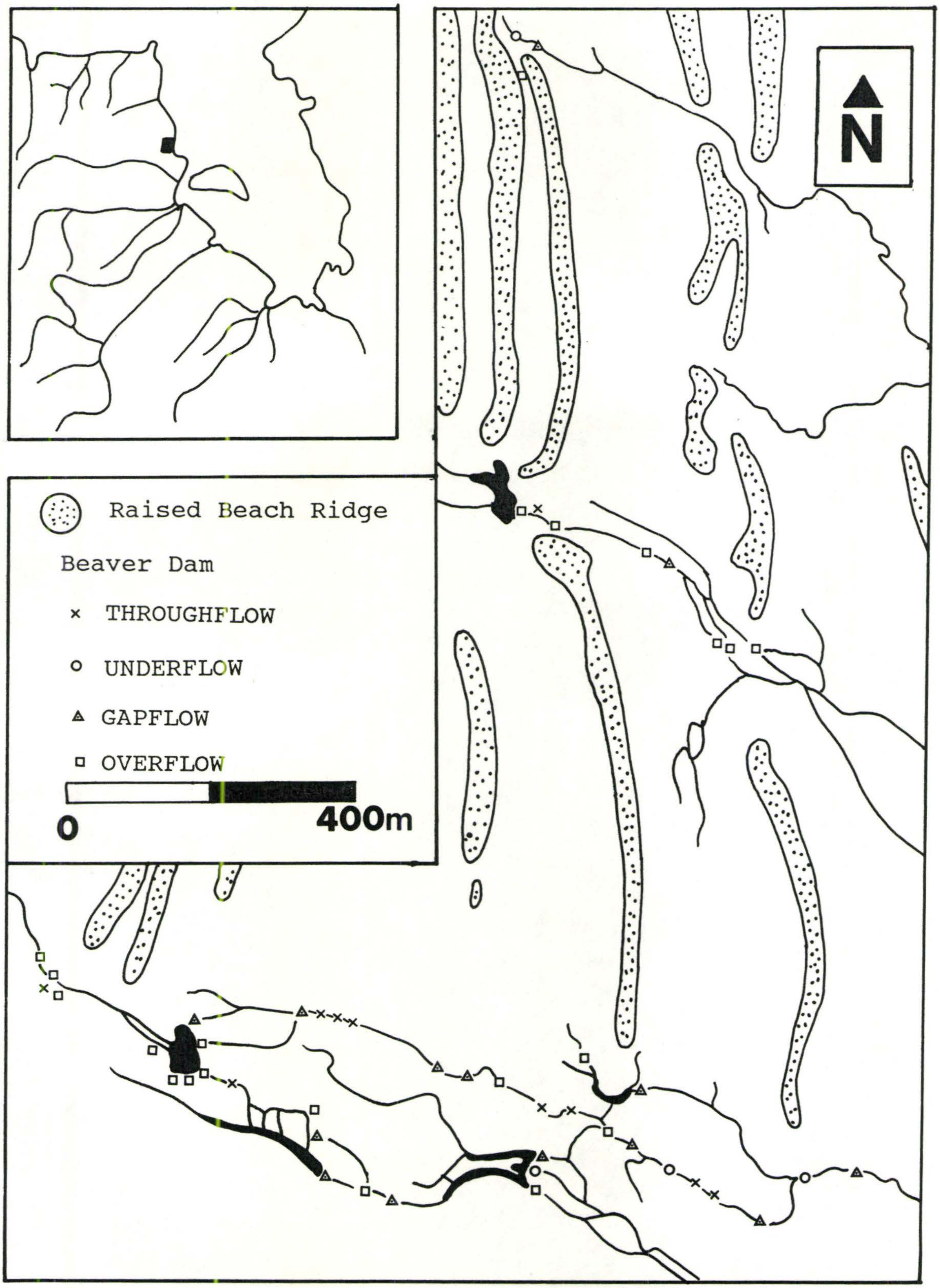

Figure 3.1 Influence of beaver dams on streamflow.

3.1 Overflow Type Beaver Dams

Figure 2.4a illustrates an ideal overflow type beaver dam in which water flows over the entire crest of the dam.

Of the 50 dams studied in the study region, 20 were of the overflow type, making this the largest sampled group of the study. Ten of these 20 dams were located on the Willow Stream, while the others were located on the other streams and creeks in the region. From Table 2.1, the average length and width of this type of dam was 15.54m and 0.63m respectively. The 20 dams however, ranged from 2.40m to 67.70m in length indicating that length and beaver dam type are not related. The change in water level from the upstream to downstream position of the dam averaged 0.30m +/- .20m (+/- 1 std). This change in water level was quite substantial for the region as the average gradient is merely 0.9m/km. This large change in water level can have a great effect on the groundwater flux of the wetland and will be discussed in section 3.6.

From table 2.1 it is evident that the average upstream and average downstream water depths differ greatly. In fact, the average depth difference for the overflow type of beaver dams is 0.19m. This datum supports the previous findings that beaver dams of this type have altered streamflow on a local scale. The average overflow type beaver dam is classified as 2 on the "eight star" system and it is able to pond large amounts of water and change the water level substantially.

From figure 2.4a, it is obvious that given a continuous supply of water upstream, the amount of water held in storage should not decrease below the height of the dam. Hence, this type of beaver dam continuously stores water upstream of the dam.

3.2 Gapflow Type Beaver Dams

The gapflow type beaver dam is the next most common type of dam surveyed. Of the 50 dams studied, 15 were of this type. The gapflow type beaver dam represents the beginning stages of an aging overflow type dam. A gap occurs where the stream thalweg intercepts the dam crest (figure 2.4b). This produces constricted flow over the crest at a lower height relative to the overflow type dam.

Hydrologically the gapflow type beaver dam does not store as much water upstream as the overflow type. The difference in water level between the upstream and downstream position of the dam averaged 0.14 +/- 0.11m. The depth of water upstream from the beaver dam is on the average 0.15m deeper than the depth of water downstream from the dam. Since the channel has a low gradient, the depth difference indicates an increase in storage upstream of the beaver dam.

The gapflow type beaver dam is, therefore, also effective in increasing channel storage of water. Given a continuous supply of water upstream, the water level behind the dam should not fall below the height of the gap. Hence, during storm events there should not be much change in the amount of water stored upstream.

3.3 Throughflow Type Beaver Dams

The throughflow type dam is the third most common category in the study area. A total of 11 dams were of this type, most of these are located in the downstream reaches of the Alder Stream. As the name suggests, this type of dam lets most of the water upstream to pass through the dam itself. These dams are not currently in use since much of the mud, leaves, debris, and larger sticks have been washed away leaving behind a rather porous structure. The average class of the throughflow type dam in this study was 7 on the "eight star" system.

As such dams are quite porous (figure 2.4C), the difference in water level between the upstream and the downstream side of the dams averages only 0.02 +/- 0.02m.

Although this dam type does not divert water to the surrounding wetland, dye traces indicate that the flow does slow down in the region of the dam. The water either flows through the dam at low stage or moves around the dam in abandoned spillways at higher stages.

3.4 Underflow Type Beaver Dams

The underflow type beaver dam was the least common category in the study area. The four dams of this type varied in their location as well as in their geometry. Figure 2.4d illustrates the general structure of an underflow type beaver dam. Unlike the gapflow and overflow types, water drains through the bottom of the dam, and the amount drained depends on the size of the hole in the dam and the upstream stage. If the upstream discharge exceeds the capacity of the hole, the upstream water level will rise, increasing the storage in the upstream zone. The average water level difference for the underflow type beaver dams was 0.16 +/- 0.15m. This value has a large variation but the measurements were made at only one point in time and did not consider the temporal variation of the water levels. These types of beaver dams have large effects on high flow but effects are minimal during low flow.

3.5 Dam effects on hydrograph responses

The degree to which storage and runoff is altered by beaver dams depends on the class and type of the dam. In general, the active dams (1 star and 2 star dams) increase water levels to the bankful stage and then divert the flow to the surrounding wetland whereas, the relict dams (6, 7 and 8 star dams) impound little water and do not divert flow to the wetland during storms. To fully understand the effects of the types of beaver dams, it is necessary to study the hydrographs in figure 3.2 which are located at overflow, throughflow, and underflow type beaver dams (gapflow type dams responded similarly to overflow type dams).

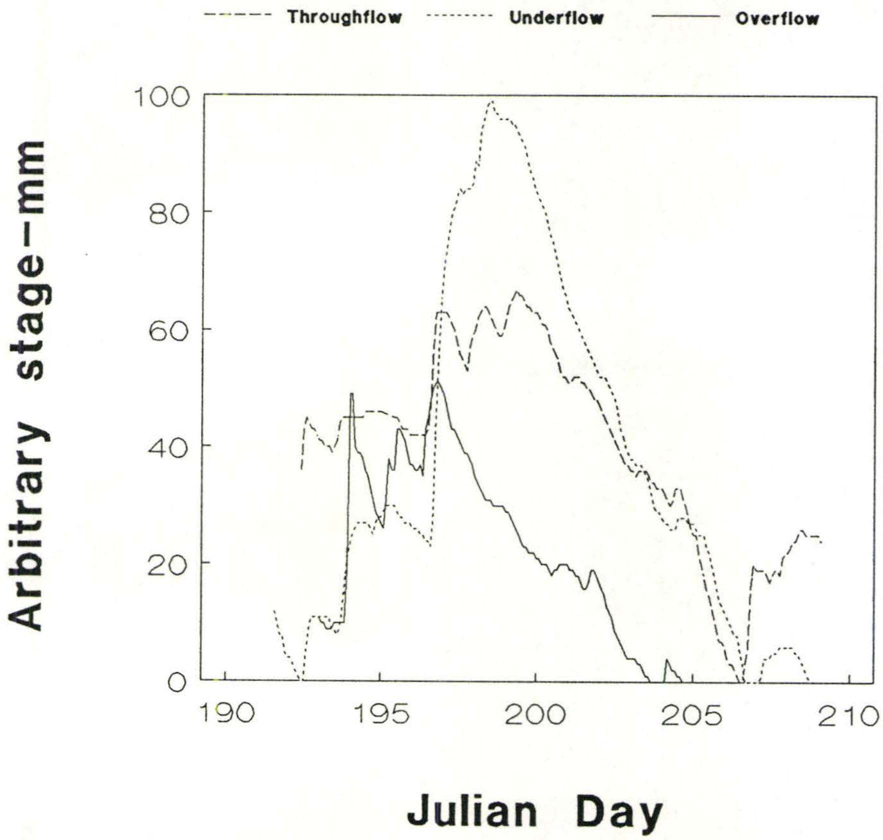

Figure 3.2 Typical hydrographs located downstream of overflow, throughflow, and underflow type beaver dams.

Precipitation Events:

Julian Day 197....... 9.6mm
Julian Day 198....... 2.4mm
Julian Day 199....... 7.4mm

The overflow hydrograph exhibits the quickest response to the rainfall (storm) event of any of the beaver dam types, while the underflow type exhibit the slowest response and the throughflow type shows little alteration relative to the other responses (a stage increase of merely 20mm).

The overflow type shows a quick response because the water level upstream from the dam is maintained close to the level of the dam crest. Hence, any increase in discharge upstream of the beaver dam will generate immediate response downstream from the dam. The dam in this case has little effect on modulating channel flow. Similarly, the gapflow type beaver dam does not alter stormflow greatly. There is however, a small lag associated with this type of dam as the upstream water level is below the top of the dam before the storm occurs. Hence, until the water reaches the crest, the dam will provide temporary storage to the water upstream. The hydrograph located at the throughflow type dam indicates that the dam caused very little alteration to the stormflow. The hydrograph of the typical underflow type beaver dam shows a larger time lag for peak flow than the other dam types (as a recession limb for the first two storms does not exist on the hydrograph). The hole that occurs at the bottom of the dam restricts the flow. As a result, once the maximum discharge permitted by the hole is met, the dam will continue to pond the water upstream. Peak flow will therefore be damped and occur later than other streams. At the conclusion of a rainfall event, discharge below this type of dam continues to rise as the temporarily ponded water drains from the upstream location. This contrasts with the other beaver dam types which all show steep (overflow) to moderate (gapflow) recession limbs. This occurs because during storm activity, the water that is stored upstream of the dam is slowly released as the stage decreases, causing the effect of the storm runoff response to be lengthened.

3.6 Beaver Dams and the Wetland

Beaver dams can create large water level changes between the upstream and the downstream parts of the beaver dam. The result is an elevated water table upstream of the beaver dam and a lowered water table downstream of the beaver dam (figure 4.4). This alters the groundwater exchange between the wetland and the stream. In the upstream regions, the hydraulic gradient between the wetland and the stream is greatly reduced, limiting the rate and amount of groundwater exchange. Conversely, in the downstream regions, the hydraulic gradient between the wetland and the stream is increased to enhance groundwater interaction between the stream and the wetland.

Groundwater interactions between the stream and wetland will modify the hydrological condition of their adjacent wetlands. It would be expected that areas surrounding the ponded up stream will remain extremely wet during much of the dry season, while the downstream regions will lose much of their water because of the enhanced groundwater flux. Previous studies indicate that soil within the beaver habitat has twice as much water content as soil outside the beaver habitat (Allred, 1980; Allred, 1981).

The active dams have the largest effect on the streamflow, while the relict dams are relatively ineffective in altering streamflow. Dye traces indicate that water that is ponded upstream of the beaver dams is often shed to the surrounding wetland or enters beaver made canals or spillways located in large dam complexes.

Figure 3.1 shows that with the creation of beaver ponds in the large upstream beaver complexes, water can flow into another channel and vacate its initial stream. This is hydrologically important because the dams are altering the overall runoff pattern of the wetland which may have an effect on the other components of the water balance at the basin scale.

CHAPTER IV

DIRECT EFFECTS OF BEAVER DAMS ON THE WETLAND WATER BALANCE

To evaluate the degree to which beaver dams affect the hydrology of the subarctic wetland on the basin scale, it is useful to compute the various components of the water balance. Two wetland basins, typical of the region, were used for this comparison. The inter-ridge wetland (I-RW) basin was used as a control basin as it did not contain a beaver dam, whereas the beaver dam basin (BDB) had its outflow dammed by a class three star, underflow type beaver dam. The water balance can be written as:

$$P - Qs - Qg - E = dS \qquad [4.1]$$

where P is an input to the wetland by precipitation, and Qs, Qg, and E are the net losses of water from the drainage basin by surface flow, groundwater flow, and evaporation respectively. The left side of equation 4.1 is equal to the change in basin storage (dS).

The water balances were computed for the two basins for the period lasting from June 18th to July 28th, a six week period. First, results from each component of the water balance will be discussed separately and lastly, the water balances as a whole will be discussed and compared.

4.1 Precipitation

Study period rainfall totals for the inter-ridge wetland and the beaver dam basin were 58mm and 60mm respectively. Variation in rainfall totals were attributable to several localized rainfall events occurring towards the end of the study period. Figure 4.1 illustrates the daily rainfall totals for both of the wetlands studied. The longest rain-free period lasted six days, from July 15 to July 20. The largest rainfall event during the study period occurred on July 24th when 19.6mm and 17.6mm of rainfall were recorded in the beaver dam basin and in the inter-ridge wetland respectively. Despite the large magnitude of this rainfall event, there were only two rainfall events throughout the study period which deposited greater than 10mm of rainfall. The other large rainfall event occurred on July 26th when 17.0 and 16.6mm of rainfall was deposited in the beaver dam basin and inter-ridge wetland respectively. These two large precipitation events accounted for more than half of the total study period rainfall.

4.2 Evaporation

Because of the different vegetation types and moisture conditions between the inter-ridge wetland and the beaver dam basin, it was necessary to construct a vegetation map of the two basins. The area covered by different vegetations were then used to calculate basin evaporation by summing up the products of the areas and evaporation rates for each vegetation type and dividing by the total area of the basin. Table 4.1 indicates the percentage of the different types of vegetation cover in the inter-ridge wetland (I-RW) and beaver dam basin (BDB). Hourly evaporation totals were calculated at the meteorological site for these five surface types (Table 2.4a) and converted to daytime totals for the entire study period. Figure 4.1 illustrates the daily evaporation totals for the inter-ridge wetland and the beaver dam basin and figure 4.2 shows the evaporation from the different surface types.

Table 4.1 I-RW and BDB vegetation types and percentage cover.

Vegetation type:	BDB	I-RW
Carex aquatilis (long)	64.5%	25.5%
Aquatic moss	8.0%	0.0%
Open Water	9.0%	0.0%
Salix spp.	18.5%	69.0%
Caltha paluostris	0.0%	5.5%

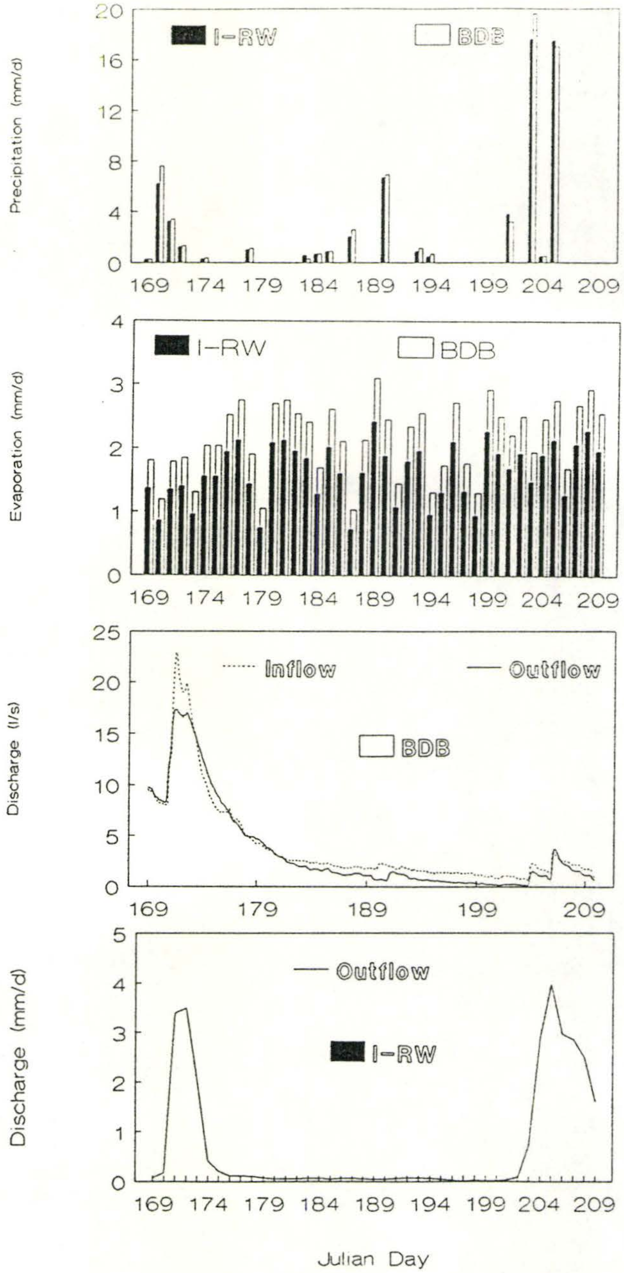

Figure 4.1 Precipitation, Evaporation, and Outflow for the I-RW and BDB.

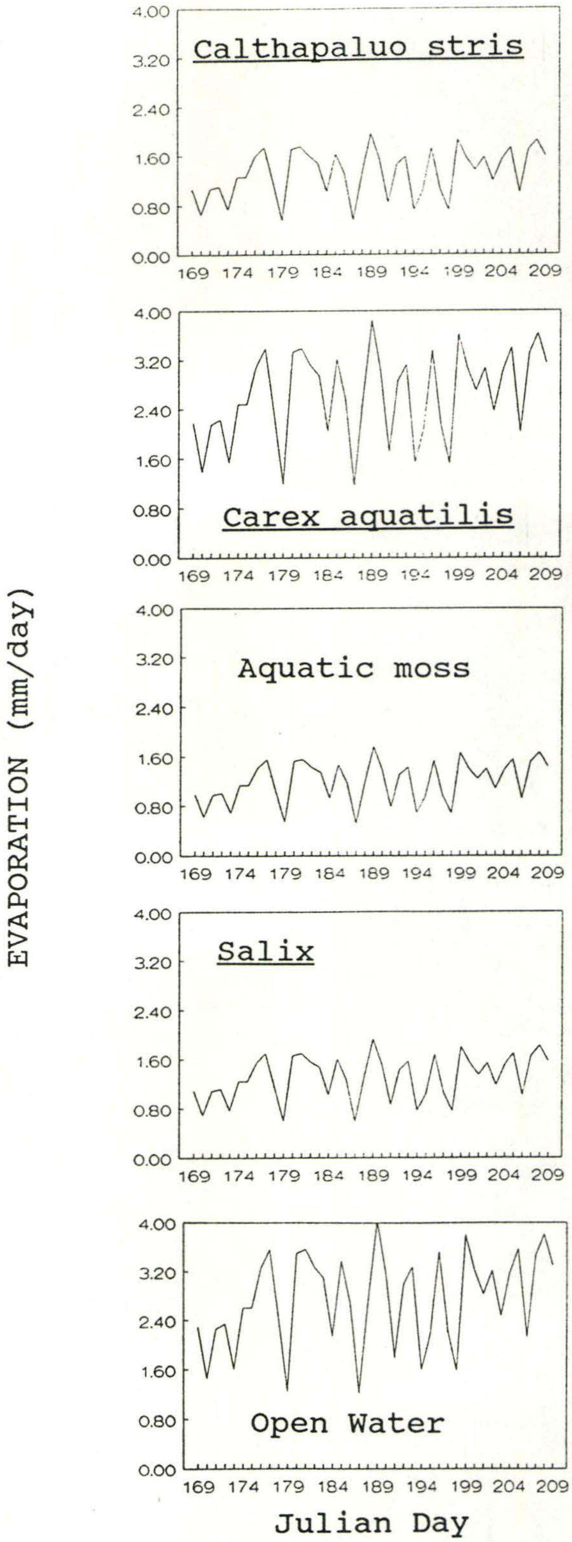

Figure 4.2 Evaporation from different surface types.

Total evaporation from the inter-ridge wetland during the study period was 65mm. The largest daily evaporation of 2.4mm occurred on July 8th. Average daily evaporation was 1.7mm with a standard deviation of 0.4mm.

Total evaporation from the beaver dam basin was 85mm for the entire study period. Average daily evaporation from this basin was 2.2mm with a standard deviation of 0.6mm. The maximum daily evaporation reached 3.1mm, also on July 8th. The beaver dam basin seasonal evaporation totals were 26 percent greater than those in the inter-ridge wetland, primarily as a result of the presence of the beaver-dammed stream. During periods of high flow, the surface area covered by water increased considerably, leading to an increased evaporation.

The evaporation values for the basins in this study are low compared with other studies in subarctic wetlands. Typical daily evaporation values computed by diCenzo (1987) in the southern James Bay region near Moosenee ranged between 1mm and 7mm, with a mean 3mm/day.

4.3 Groundwater Flux

The hydraulic conductivity for the inter-ridge wetland is in the order of 10^{-6} and 10^{-7} m/s for the depression and ridge locations respectively. Similarly, the depression and ridge hydraulic conductivities in the beaver dam basin are

10^{-6} to 10^{-7} and 10^{-8} m/s respectively. These results are in good agreement with the findings of Price and Woo (1988) and diCenzo (1987) where the hydraulic conductivity of silt in a southern James Bay location was in the order of 10^{-7} m/s.

The hydraulic gradient along the basin boundary is rather low. Mean daily hydraulic gradients along the west and east boundaries in the inter-ridge wetland are in the order of a couple of centimeters per meter.

Figures 4.3 and 4.4 illustrate the water table elevation for three selected periods for the inter-ridge wetland and beaver dam basin respectively. The three days chosen represent the initial conditions of the two basins (June 20), a period of low water table elevation (July 19), and a period when the water is being shed to the wetland (July 25).

Over the study period, the groundwater flux in the inter-ridge wetland and the beaver dam basin were 0.5 and 0.4mm respectively. The small groundwater flux values are a result of the low hydraulic conductivity of the silt underlying the surface peat and the gentle hydraulic gradients across the basin boundaries.

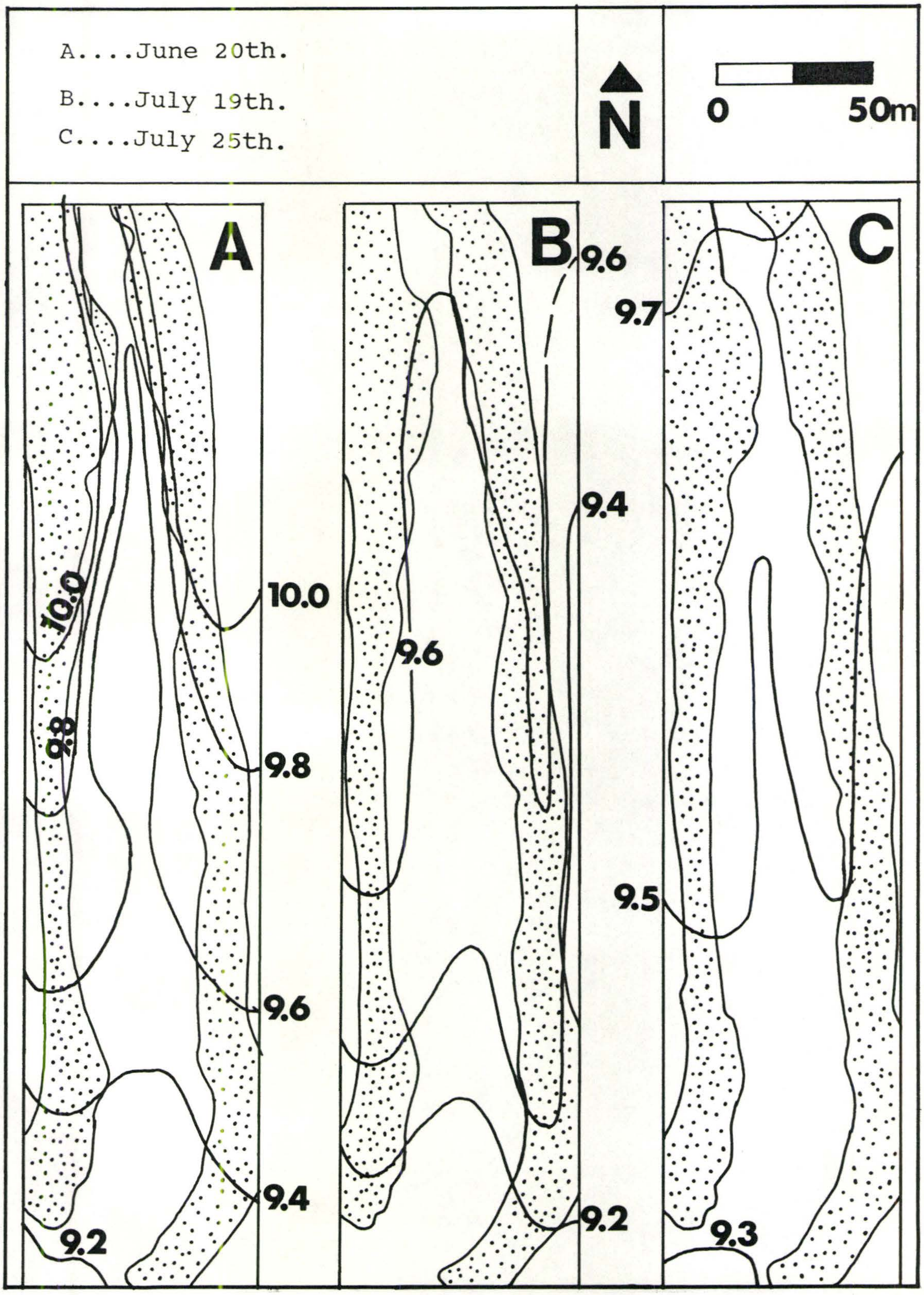

Figure 4.3 I-RW watertable elevation (m).

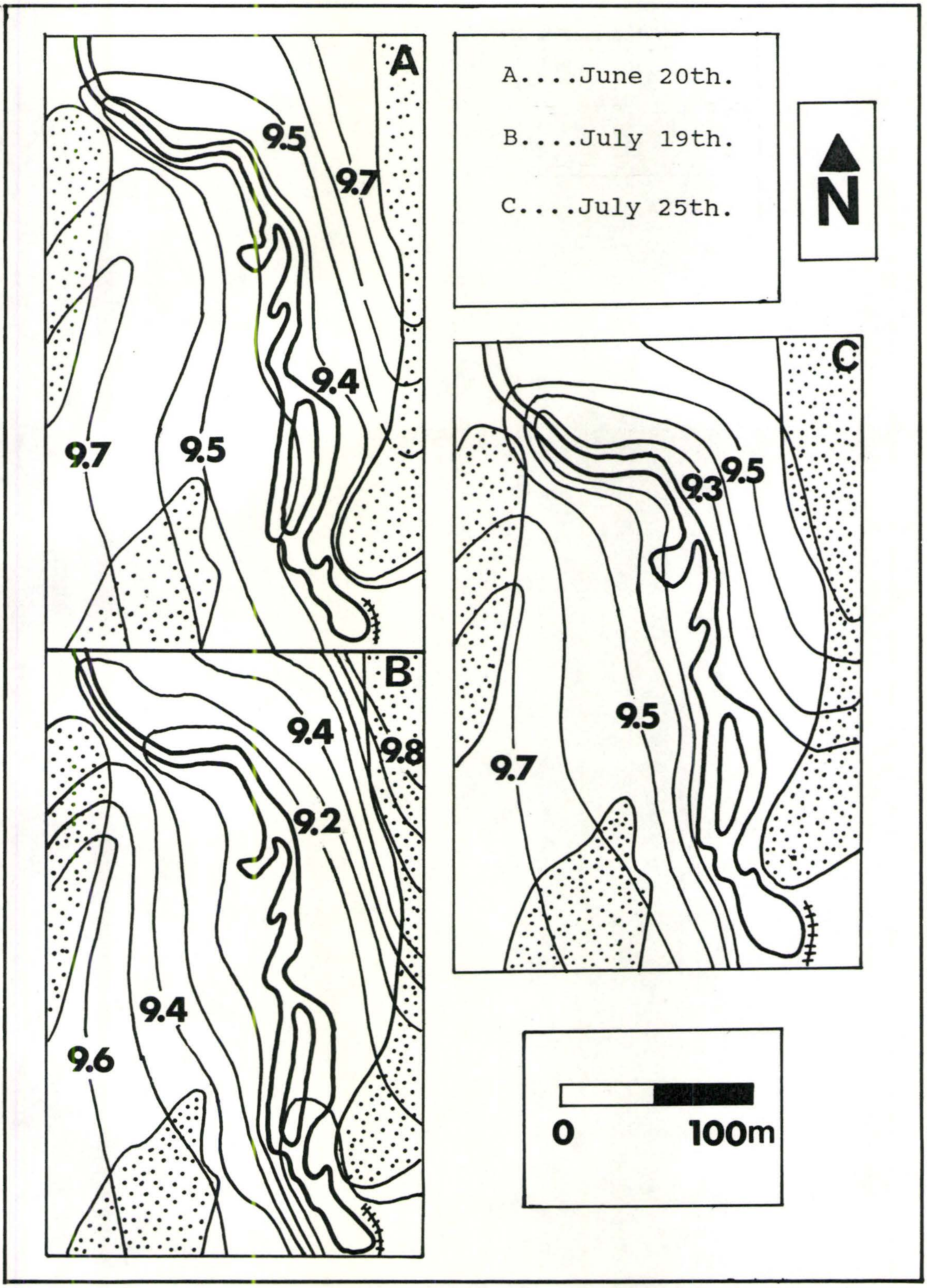

Figure 4.4 BDB watertable elevation (m).

The three days shown for the inter-ridge wetland indicate little variation in the direction of flow. Because of the presence of ice in the ridges, near the surface on June 20th, a larger hydraulic gradient exists between the ridges and the wetland. As the ice melted in the ridges the hydraulic gradient between the ridges and the inter-ridge wetland was reduced. At the beginning of the study water flowed into the basin from the ridges. However, by the end of the study period, when the wetland water table was higher, water flowed through the ridge to a depression bordering on the east.

Because of the presence of the stream and beaver dam in the beaver dam basin, the watertable elevation and flow directions often change. As is the case for the inter-ridge wetland, the hydraulic gradient between the ridges and the wetland decreases throughout the study period. The initial conditions of the study indicate water being shed to the wetland in the lower portions of the wetland. During the dry period, a falling water table greatly increased the hydraulic gradient between the wetland and the stream. However, after the rain event late in the study period, the hydraulic gradient decreased and water was again being shed to the wetland and ponding up near the beaver dam.

4.4 Runoff

Total runoff differs greatly between the inter-ridge wetland and the beaver dam basin. Figure 4.1 illustrates the daily outflow from the inter-ridge wetland. Outflow from the inter-ridge wetland was furnished entirely by overland flow and remained low through much of the study period. The maximum overland flow that occurred from the inter-ridge wetland was 1.3 l/s and the total runoff for the study period was 28mm. The high discharges occurred during periods of increased precipitation. This indicates that the inter-ridge wetland is able to react quickly to storm events with very little time lag.

Figure 4.1 illustrates the bi-hourly inflow and outflow for the beaver dam basin. The inflow occurs in three locations - at BD01 and BD03 which are minor seep lines and at BDR which is the beaver stream input. The BDR input is the major source of surface flow into the beaver dam basin. The maximum inflow occurred on June 20th when a peak discharge of 22.8 l/s was reached. The discharge out of the beaver dam basin occurs only at BSR on the beaver stream. Maximum outflow occurred on June 21st as a direct result of the rainstorm that occurred on June 17th to June 20th. The peak discharge recorded during the study period at BSR was 17.3 l/s, a full three hours after the peak inflow at BDR. A similar pattern occurs in two rainfall events that occurred on July 22nd to July 24th, however, the peak flow only reached a value of 3.3 l/s despite the 36.6mm of precipitation that fell on the basin. The large precipitation event produced a small response because the wetland storage had been depleted before the event occurred (see figure 4.6a). The precipitation initially recharges storage and then creates a small peak and gentle recession limb on the hydrograph (Bay, 1969; Balek and Perry, 1973; Bavina, 1975; Burke, 1975; diCenzo, 1987; Taylor, 1982) The beaver stream was able to maintain baseflow when streamflow ceased on other creeks adjacent to the study region. Because the beaver stream drains the inner wetland, streamflow was regulated by the inner wetland bogs and inland rain input recharges.

The presence of the beaver dam has caused the outflow (figure 4.1) to lag three hours behind the inflow of the beaver dam basin on June 21st. This beaver dam is of the underflow type and therefore permits a restricted amount of water to flow through the hole at the bottom of the dam. When the maximum inflow capacity is reached, excessive amounts of water added from upstream will be held in storage by the dam. At the conclusion of a rainfall event the inflow into the basin begins to decrease but outflow continues to rise as the temporarily ponded water drains. The effect of this peculiar runoff pattern is twofold. Not only is the timing of the storm response altered, but the change in storage of the beaver dam basin is also seriously altered. This will be discussed in section 4.6 to 4.8.

The cumulative inflow and outflow of the beaver dam basin were 1263 and 1220mm respectively for the entire study period. The result is a net outflow of -43mm. This contrasts with the outflow value of 28mm recorded in the inter-ridge wetland. Again, the presence of the beaver dam in the beaver dam basin has created this substantial difference in wetland runoff patterns.

4.5 Depression Storage

Average depression storage for the inter-ridge wetland and the beaver dam basin was -10 and -0.4mm respectively. Figure 4.5 illustrates the estimated depression storage changes during the study period. The inter-ridge wetland is not drained by any stream and excess water was collected in a large depression. The beaver dam basin, however, lacked large depressions and consequently has a lower magnitude of depression storage in the basin.

4.6 Beaver Dam Basin Water Balance

Table 4.2 and figure 4.6a summarize the water balance components for the beaver dam basin during the six week study period. The gains to the basin in decreasing order of magnitude were surface inflow (1263mm), precipitation (60mm) and subsurface flow (0.4mm). These gains were countered by the surface outflow (1220mm), and evaporation (85mm). From June 19th to July 28th, beaver dam basin gains totalled 1323mm and losses totalled 1305mm, such that the difference between gains and losses, 18mm, must have been stored in the basin as groundwater and depression storage. Depression storage change (dSd) (-0.4mm) accounted for 2.3% of the total water stored.

Table 4.2 BDB Water balance summary from June 19 to July 28 1988. All values in mm.

P	E	Qs	Qg	dS	(dSd)
60	85	-43	0	18	(-0.4)

4.7 Inter-ridge Wetland Water Balance

The water balance summary for the inter-ridge wetland is summarized in Table 4.3 and figure 4.6b. Total gains to the basin were precipitation (58mm) and subsurface flow (0.5mm) while losses from the basin were evaporation (65mm), and surface outflow (28mm). Inter-ridge wetland gains therefore totalled 58.5mm whereas basin losses totalled 93mm. The difference between gains and losses, which represents the amount of water stored, was -35mm. Depression storage change (-10mm) accounted for 29% of the change in storage.

The stored water measured using the approach described in section 2.2.3, equation 2.3, was -39mm. The small disagreement between these two values is quite reasonable considering the possible sources of error associated with both data collection techniques.

Table 4.3 I-RW Water balance summary from June 19 to July 28 1988. All values in mm.

P	E	Qs	Qg	dS	(dSd)
58	65	28	0	-35	(-10)

4.8 Water Balance Comparison

The amount of water stored in the beaver dam basin (18mm) is 53mm greater than that stored in the inter-ridge wetland (-35mm). These results indicate that there is a distinct difference in the basins' abilities to store water.

From equation 4.1 it is clear that water storage is dependent on the gains and losses for the basins discussed in sections 4.6 and 4.7. Figures 4.6a and 4.6b illustrate cumulative gains and losses for each water balance component in the inter-ridge wetland and beaver dam basin respectively. In both basins, net subsurface flow was negligible due to the dominance of the other components. As mentioned in section 4.5, the presence of the beaver dam decreases the amount of outflow from the beaver dam basin, but the dam increases the flooded area and enhances evaporation. Outflow and evaporation in the inter-ridge wetland were 71 and 20mm greater than outflow and evaporation in the beaver dam basin. Together these two components accounted for 96% of the difference in the basins' storage terms. Hence, evaporation and surface outflow are the most important components in determining the effects of beaver dams on the water balance of a subarctic wetland.

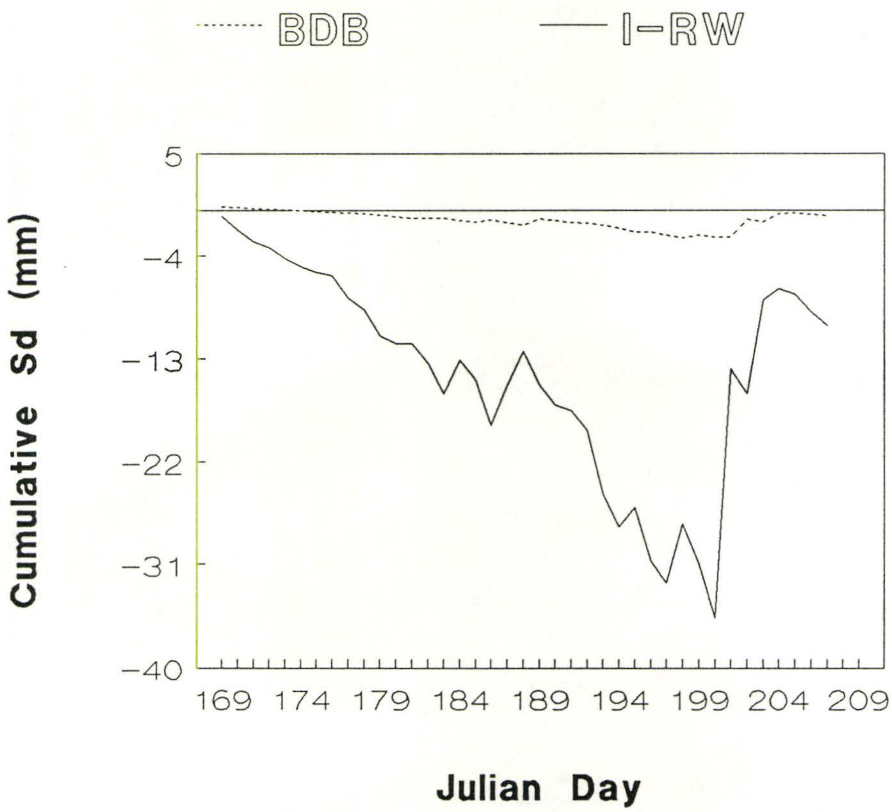

Figure 4.5 I-RW and BDB cumulative depression storage.

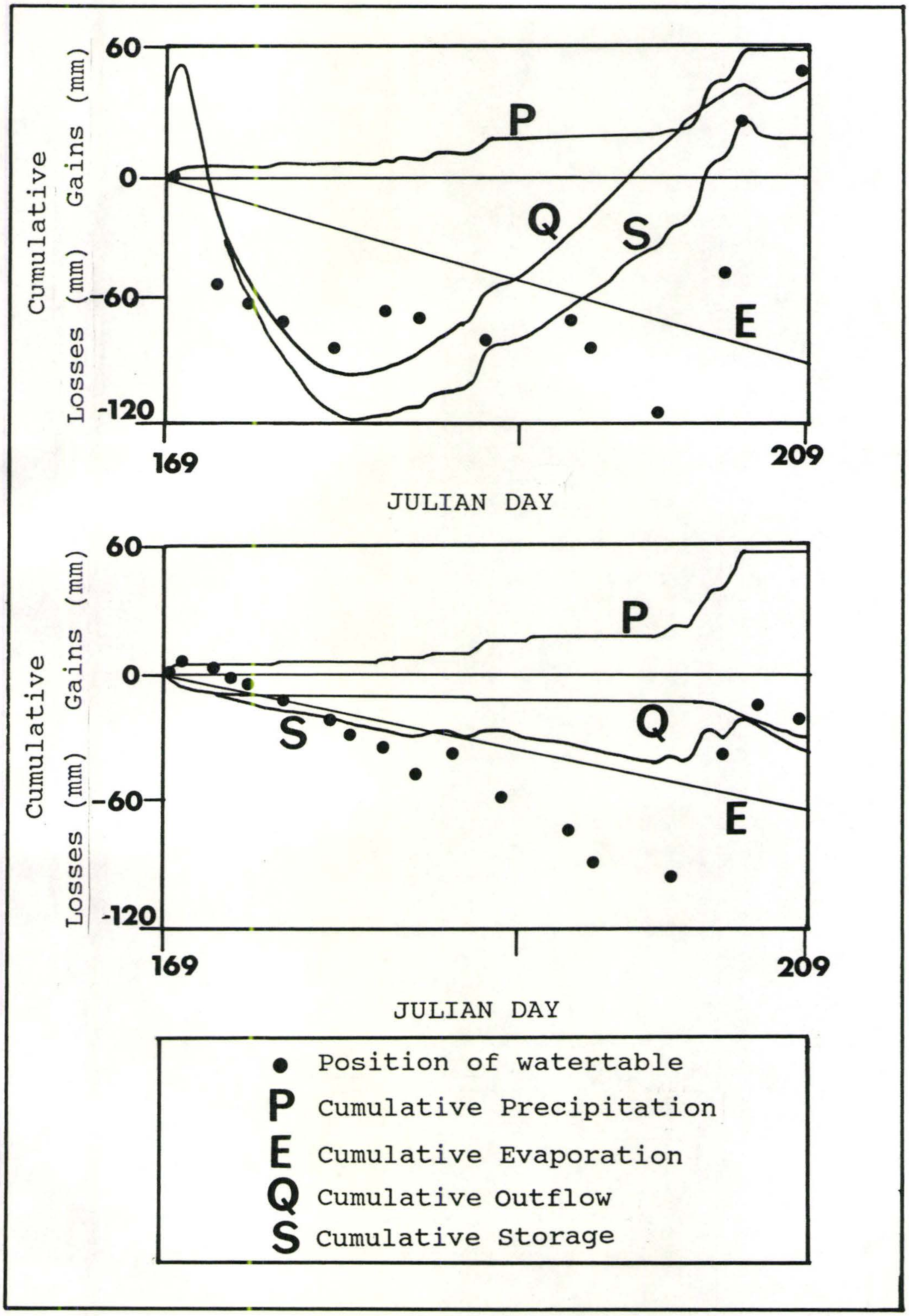

Figure 4.6 Components of the a) BDB and b) I-RW water balances.

CHAPTER V

CONCLUSIONS

Previous research in subarctic wetland hydrology have not dealt with the effects of animal habitat on the runoff. However, this study has dealt with the effects of beaver dams on the overall runoff from a coastal subarctic wetland on western James Bay. The conclusions drawn from this report will, therefore, provide important knowledge on the runoff patterns and processes to be expected during the summer months in subarctic wetlands that are complicated by beaver dams.

It was found that beaver dams can alter runoff in subarctic wetlands temporally, spatially, and to varying degrees depending on the geometry, type, and class of beaver dam. In general, the more recently built and well maintained dams have the greatest effects causing the impounded water to overflow the stream banks and divert to the surrounding wetland whereas, the dams in disrepair impound little water and divert no water to the wetland.

Larger upstream dams create large beaver ponds permitting water to flow to another channel and vacate its initial stream. This causes the response in the lower reaches of these coastal wetland streams to be no longer linked directly to inland regions, but to be controlled by the rise and fall of the water level in the beaver ponds.

During low flow, the overflow and gapflow type dams divert much water to the wetland while the underflow and throughflow type dams do not. At high flow the gapflow and overflow type dams continue to divert water to the wetland as do the underflow type. A water balance indicates that basins with beaver dams have an enhanced evaporation flux, decreased outflow, decreased groundwater flux, and an increased storage with respect to the basins without beaver dams.

CHAPTER VI

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