

# Effects of Beaver Dams on Subarctic Wetland Hydrology

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**ABSTRACT.** Beaver dams are ubiquitous in subarctic wetlands, where runoff in the flat terrain is highly prone to changes as the stream courses are modified by beaver activities. Depending on the state of preservation, stream flow can overtop or funnel through gaps in the dams, leak from the bottom of the dams or seep through the entire structure. Peak and low flows are regulated by these dams to a varying extent. The formation of beaver ponds causes local flooding, while the open water surfaces of the ponds increase water loss from the wetlands. Water spilled from the dams may cause diversion channels to produce complex drainage patterns. Comparing the water balance of basins with and without a beaver dam at its outlet confirms that the dammed basin lost more water to evaporation, suppressed the outflow and increased the basin water storage.

**Key words:** beaver, wetland, beaver dam, stream flow, basin storage, wetland drainage, Subarctic

**RÉSUMÉ.** On trouve des barrages édifés par les castors partout dans les terres humides subarctiques, là où l'écoulement en terrain plat est très souvent sujet à des changements, suite à la modification du lit des ruisseaux par la présence des castors. Selon l'état des barrages, le cours d'eau peut passer par dessus ou s'échapper par les interstices du barrage, passer en dessous ou filtrer à travers toute la surface. Jusqu'à un certain point, les barrages règlent la hauteur du cours d'eau. La formation d'étangs créés par les barrages de castors est la cause d'inondations locales, tandis que la plus grande surface d'eau en contact avec l'air augmente la perte d'eau dans les terres humides. L'eau qui se déverse des barrages peut amener les chenaux de diversion à créer une configuration de drainage complexe. La comparaison des bilans d'eau contenue dans des bassins avec et sans barrage de castor à leur sortie, confirme le fait que le bassin avec barrage perd plus d'eau par évaporation, n'a plus de débit et que la quantité d'eau contenue augmente.

**Mots clés:** castor, terres humides, barrage de castor, cours d'eau, quantité d'eau contenue dans le bassin, drainage des terres humides, Subarctique

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## INTRODUCTION

Beavers (*Castor canadensis*) are abundant in subarctic wetlands, and they have been extremely important historically in the fur trade (Newman, 1985:55-79). Beavers build dams and impound water along stream channels. These hydrological consequences have been observed (Beuch, 1985; Neff, 1957) but not systematically studied or even adequately quantified. An extensive bibliography compiled by Medin and Torquemada (1988) lists the North American publications pertaining to beavers, their activities and associated effects on the ecology. The hydrological aspect is not well represented, and certainly not so in terms of the beavers' impacts on the movement, storage, gains and losses of water in the vast wetland regions of subarctic Canada.

Studies in the mid-latitudes indicate that the construction of beaver dams increases the upstream storage and water supply, while decreasing stream velocity (Allred, 1980, 1981), causing the water table to rise and dampening the downstream runoff fluctuations (Duncan, 1984). Given the flat topography of many subarctic wetlands, changes in the stream courses will greatly affect the wetland drainage. Runoff modification is expected to be considerable when the streams are dammed by beavers.

Recent hydrological research in the subarctic coastal wetlands of Ontario has shown that the spatial and temporal changes in water supply (such as snow melt and rainfall) and water losses (such as evaporation and surface and subsurface discharges) control the fluctuation of wetland water levels (Price and Woo, 1988; Price *et al.*, 1988). The water level in turn governs the drainage mechanism, so that extensive overland flow occurs during the high-water period, but channelled and subsurface flows become relatively more important during the drier season (Woo and diCenzo, 1989). However, little is known about the roles played by beavers in regulating

the water level in the riparian zones and in altering the wetland stream patterns.

Visually, one can observe numerous beaver ponds when travelling over the wetlands of northern Ontario. A count carried out in a 1 km<sup>2</sup> area produced close to 60 beaver dams in various states of preservation. The abundance of such beaver activities should have notable impacts on the wetland hydrology. The purpose of this study is therefore to investigate systematically the effects of beaver dams and ponds on water movement, storage and the water balance of a subarctic coastal wetland. The results should be applicable to other wetlands in a similar environmental setting.

## STUDY AREA

Many beaver dams are found along several streams crossing the coastal wetland north of Ekwan Point, North Ontario (53°18'N, 82°08'W). In flying over the extensive wetlands and in examining the aerial photographs, it is clear that these streams are similar to many other small streams along western James Bay.

The area is influenced by a subarctic climate, with January and July average temperatures at Moosonee (250 km to the southeast) of -20.0 and 15.5°C respectively. Mean annual precipitation totals 727 mm, with summer rainstorms being quite frequent. The region is extremely flat (gradient is 0.9 m/km). Isostatic rebound after deglaciation has produced a series of raised beaches parallel to the coast, and wetlands occupy the depressions between these ridges (Fig. 1). The ridges rise several metres above the wetlands and are underlain by about 1.25 m of gravel on top of the silty clay. The dominant plant species include spruce (*Picea glauca*), tamarack (*Larix laricina*), mosses and lichen. The wetlands consist of 0.2 m of peat, on top of about 0.5 m of silt that lies above the marine clay. There, the major vegetation

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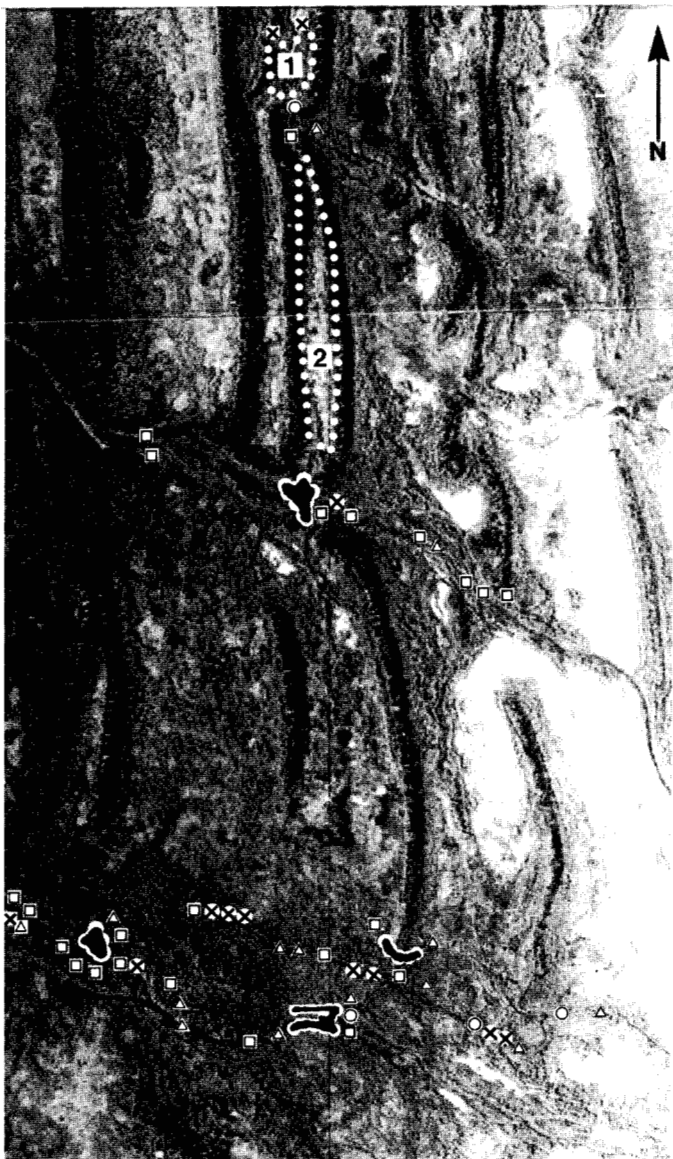
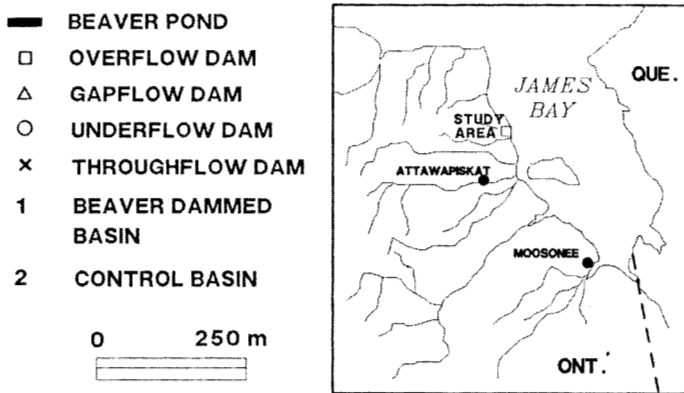


FIG. 1. Distribution of four types of beaver dams in the study area. Map shows location of study site north of Ekwan Point.

includes stands of willow (*Salix sp.*), marsh marigold (*Caltha palustris*), sedge (*Carex aquatilis*) and aquatic moss.

Two small basins in the area, one with a beaver dam and the other without, were instrumented for detailed studies. The dammed basin (area 8840 m<sup>2</sup>) occupies the lower section of a larger basin and is fed by a stream and two seepage zones.

The basin without a dam (area 18 620 m<sup>2</sup>) is bounded by two raised beaches, with the central zone being a wetland. There is no stream flow from this basin, but runoff takes the form of overland flow. The major vegetation cover in these basins are shown in Figure 2.

METHODS

This study was carried out mainly during the summer of 1988, with auxiliary data gathered in the previous summer. The field season was restricted to the summer, because in spring snow-melt runoff floods the entire coastal wetland (Woo and Heron, 1987), rendering the beaver dams ineffective in modifying its hydrology.

A meteorological site was set up to obtain air temperature, rainfall and short-wave radiation using a Campbell 101 temperature probe, a Weathertronics tipping-bucket rain gauge and an Eppley pyranometer and recorded by a Campbell Scientific CR21 data logger. A Middleton net radiometer was set up several weeks at a time over different types of wetland surfaces. The net radiation and temperature data thus obtained were used to compute evaporation, using the Priestley and Taylor (1972) method, which has been applied successfully to other wetland studies (Price and Woo, 1988; Rouse *et al.*, 1977).

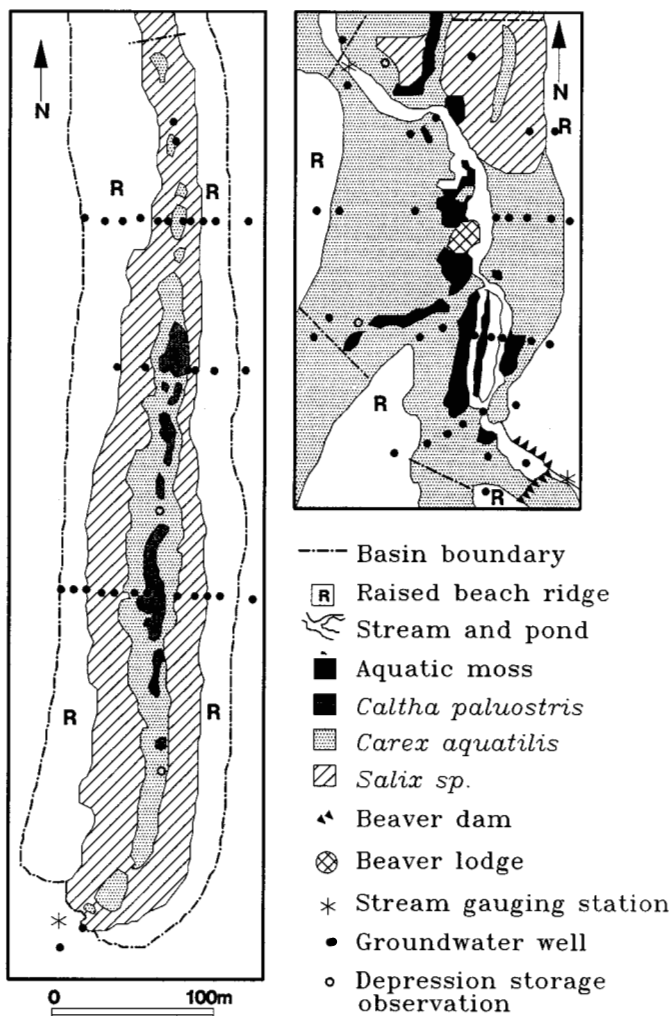


FIG. 2. Vegetation cover and instrumentation at two basins selected for water balance study.

Leupold-Stevens Type-F water level recorders were used to record stream levels below several types of beaver dams and at the outlets of two basins selected for the water balance study. Stream flow for the beaver-dammed stream was gauged periodically by the velocity-area method to establish rating curves with which water level records could be converted to discharge. Overland flow from the outlet of a basin without a dam was obtained using a method described in Woo and diCenzo (1989). Networks of groundwater wells were also set up (Fig. 2) using 19 mm i.d. perforated PVC pipes inserted into the ground. Groundwater levels were measured manually. The elevations of all the pipes were surveyed by a Kern level and related to an arbitrary datum. Hydraulic conductivity was determined using the "slug test" method described by Bouwer (1978). The water level data and the hydraulic conductivity values allowed the computation of groundwater flow according to the Darcy law. Differences in water level readings at the beginning and the end of the field season, when multiplied by the specific yield of the soil, permitted the computation of groundwater storage change. Specific yield was obtained by draining a saturated soil sample gravitationally for 24 h, and the water loss was then expressed as a volumetric fraction of the soil sample.

Depression storage was obtained by measuring the water depths at 20 points along 10 m transects set up at several wetland sites. These measurements were repeated during the summer to determine the change in depression storage. Storage change in the beaver pond located in the water balance study basin was computed by multiplying the water level changes by the areal extents of the pond.

BEAVER DAMS

Beavers construct dams with wood from alder, aspen thicket, leaves, mud, stones and other debris and secure them with rocks. When not maintained, a dam gradually loses its mud and finer debris, followed by the loss of stones and small twigs, until only some branches and sticks remain to mark the relict dam. Field survey of over 50 dams enabled the classification of beaver dams into eight categories based on the materials that constitute the dam and, therefore implicitly, the state of its preservation (Table 1). Class 1 and 2 dams consist of new branches, fresh mud, with or without stones, and these are dams in active use. Class 3 to 6 dams are in varying stages of decay, as varying amounts of mud, branches and stones are washed away. Classes 7 and 8 are relict dams with only the skeletal structure preserved.

As beaver dams undergo different stages of decay, the capability of impounding beaver ponds also changes. According

TABLE 1. Classification of beaver dams according to construction materials

Class	Materials	Preservation stage
1	stones, new branches, fresh mud	active
2	no stones, new branches, fresh mud	active
3	stones, old branches, mud and debris	old
4	no stones, old branches, mud and debris	old
5	no stones, old branches, some mud and debris remains	old
6	only large branches remain	old
7	only small branches remain	relict
8	most branches gone, only half of original structure remains	relict

to the way that the flow of water is affected, four types of dams are recognized (Fig. 3). Most active dams are relatively impervious to water flow, and any excessive amount of water in the beaver pond will be discharged by overtopping the dam

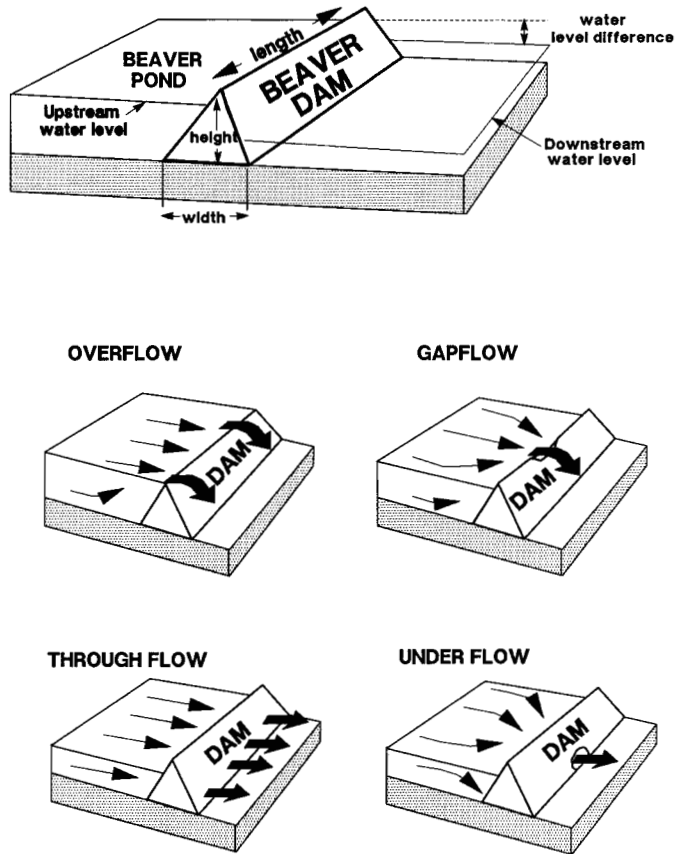


FIG. 3. Definition of beaver dam dimensions and diagrammatic representation of four types of flow across beaver dams.

(overflow type). Sometimes, the dam may be breached at certain points, and the flow is concentrated at these gaps (gap flow type). When the base of the dam is weakened, water leaks from the bottom of the dam (underflow type). Finally, when the dam becomes old, the whole dam becomes pervious and water seeps from the entire dam (throughflow). In general, active beaver dams are of the overflow type, older dams belong to the gap flow and underflow categories, while most throughflow dams are relict structures. Table 2 lists the characteristic dimensions of the dams surveyed, including the maximum, minimum and average length, base width and height and the water levels immediately above and below the dams on the days of survey. Variations in the size of dams within each category are considerable. However, the overflow dams tend to create the largest water level difference between the upstream and downstream sides of the dam, followed by the gap flow and underflow types, with the throughflow dams being the most ineffective in raising the water level upstream of the dams.

The distribution of beaver dams in the study area is shown on Figure 1. In our study area, the density of beaver dams on streams ranged from 5 to 19 dams/km, with an average of 14.3 dams per km length of stream. This compares closely with a density of 10.6 dams/km in southeastern Quebec but

TABLE 2. Dimensions<sup>a</sup> of beaver dams surveyed in the field area; all measurements are in m

Dam type		Length	Width	Height	Water depth		Difference
					Above dam	Below dam	
Overflow (20 samples)	mean	15.54	0.63	0.15	0.67	0.24	0.30
	max.	67.70	1.70	0.75	5.00	0.50	0.77
	min.	2.40	0.20	<0.05	<0.01	<0.01	<0.01
Gap flow (15 samples)	mean	11.24	0.80	0.15	0.49	0.34	0.14
	max.	40.50	2.00	0.40	1.20	0.80	0.40
	min.	1.00	0.26	0.03	0.16	0.05	0.01
Underflow (4 samples)	mean	11.52	0.79	0.15	0.19	0.17	0.15
	max.	35.80	1.55	0.40	0.25	0.35	0.40
	min.	2.50	0.40	0.02	0.15	0.05	0.02
Throughflow (15 samples)	mean	4.64	0.47	0.02	0.38	0.35	0.02
	max.	18.50	0.95	0.10	0.90	0.90	0.10
	min.	0.50	0.15	<0.01	0.05	<0.01	<0.01

<sup>a</sup> See Figure 3 for definition of dam dimensions.

<sup>b</sup> Mean, max. and min. refer to the average, maximum and minimum values obtained from the samples of dams surveyed.

is much higher than the density of 2.5 dams/km in northern Minnesota (Naiman *et al.*, 1988). There is no clear pattern of preferential occurrence of certain dam types along particular segments of a stream, though most large ponds are impounded by dams of the overflow and gap flow types. Some stream segments have a lower frequency of dams, partly because (1) our survey may have missed some relict dams, and (2) the presence of a large beaver pond precludes the need for building additional dams or could have drowned the older and smaller ones. The construction of beaver dams is an ongoing activity and it takes only several days for a dam to be completed and operational. An example of such an event and its effect on stream flow will be given in a later section.

#### HYDROLOGICAL EFFECTS

The construction of a beaver dam directly influences the hydrological behaviour of the wetland environment, including the creation of a pond and the alteration of the drainage pattern, the enhancement of water storage and evaporation losses, and the change of stream flow regime.

#### Beaver Ponds

Ponds are created when beaver dams are completed across a channel. Normally, deep ponds are formed when the dam is built along a channel incised in the wetland. The horizontal dimensions of the ponds vary according to the local extent that they can be flooded and are seasonally variable as the water level rises and falls. Once a beaver dam is built, the water level in the pond rises continuously as it is being filled. Such a pond was formed below the control basin for our water balance study. There, a beaver dam was created in early June. Figure 4 shows the gradual rise of water level as the pond was filled, and eventually a considerable portion of a wetland depression was flooded. Another example of pond filling is provided by Figure 5, which contrasts the water level in a stream segment during and after the construction of a beaver dam.

#### Drainage Pattern

Impoundment of water behind beaver dams alters the course of flow in parts of the wetland. Next to the dam, water at high stage will move around the dam as surface runoff,

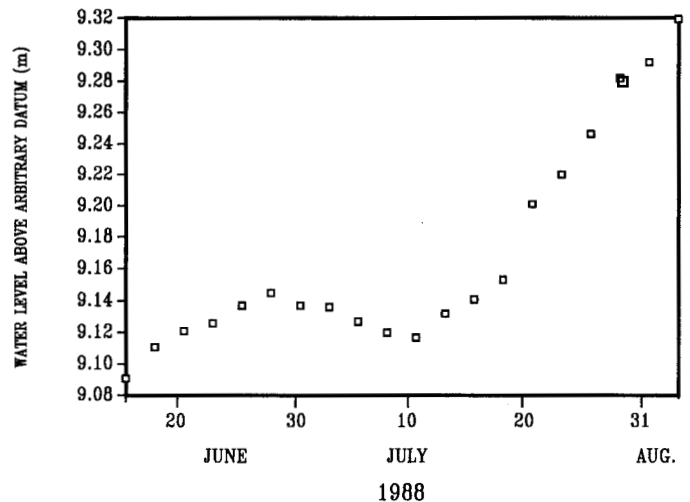


FIG. 4. Hydrograph showing the rise of water level in a stream channel as a beaver dam was constructed downstream.

groundwater seepage, or both. An example is given in Figure 6, which shows the pattern of overflow from a beaver pond into a wetland depression. This water spreads into the depression and mixes with the moisture in the wetland and the water in the wetland ponds. To illustrate, a one-time measurement was made of the electrical conductance of the ponds and the wetland water (Fig. 6). The wetland water was initially quite saline. As the fresher water from the beaver pond entered the wetland, there was a gradual mixing, which could be traced along the western fringe of the wetland depression. After entering the depression, the beaver pond water spreads northward and eastward, and eventually part of this flow, mixed with the wetland water, returned to the old channel below the dam; but part of the water drained northward, to end up in another stream.

In most cases, water spilled from the beaver pond returns to the channel at a short distance below the dam. In other situations, new flow diversion channels may be created that act as spillways when the ponds are full (Heron *et al.*, 1988). Then, water may not get back to the original channel until it has travelled tens or hundreds of metres downstream. When these diversion channels are reoccupied over a period of time, they may be sufficiently downcut to become permanent routes



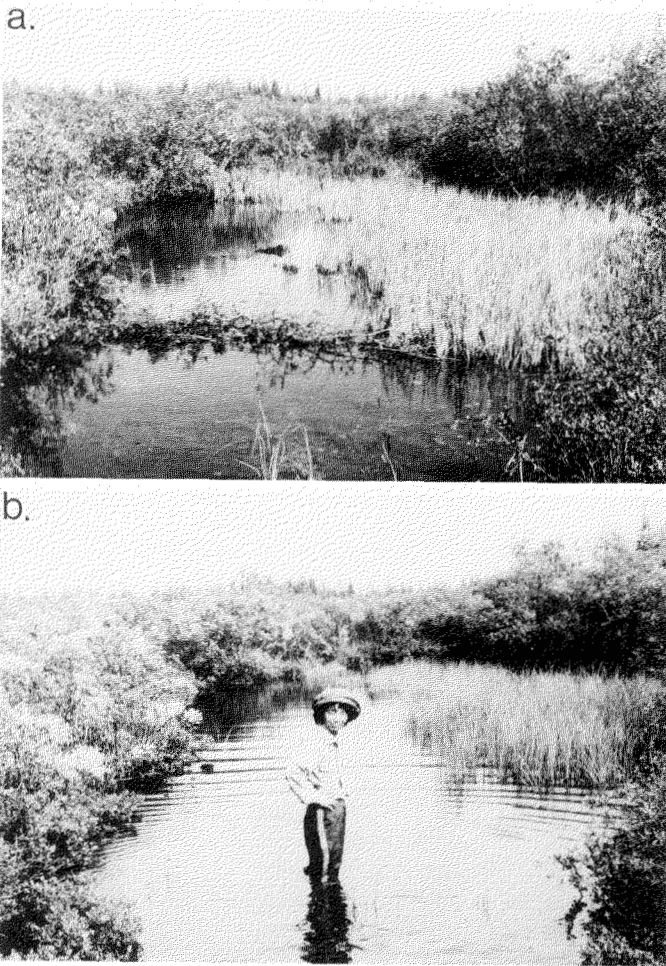


FIG. 5. Segment of a wetland stream during and after the construction of a beaver dam downstream. (a) A small beaver dam, exposed on 16 July 1988, was flooded on (b) 3 August, when another dam downstream was completed, to raise the pond level by over 1 m. The person in (b) marks the position of the flooded dam.

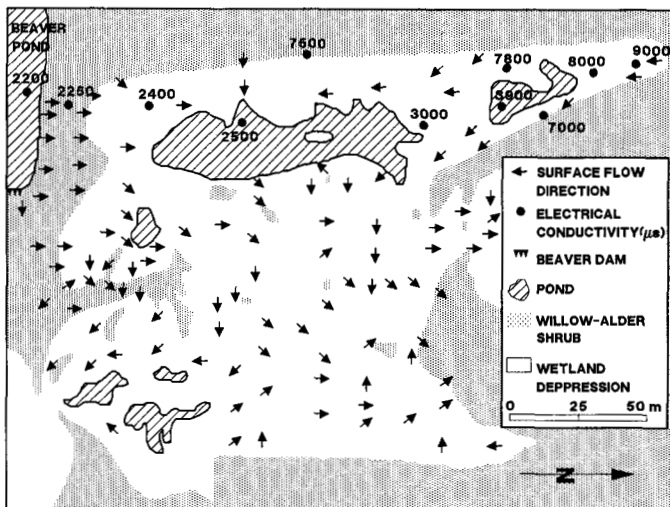


FIG. 6. Surface flow into and out of a wetland depression as water spilled from a beaver dam along a stream. Electrical conductance measurements show that the stream water diluted the more saline water in the depression as the former diffused through the wetland.

along which water will flow. The complex drainage pattern along the south edge of the study site exemplifies channel development perpetuated by the persistent spillage and diversion of flow (Fig. 1).

*Stream Flow*

Measurements of stream flow below three beaver dams show that the flow is regulated differently by each type of dam. Figure 7 shows the hydrographs before and after the rainfall events of July 1987. When 9 mm of rain fell on 15 July, the throughflow type of dam had minimal effect on the stream flow because the highly porous nature of the dam allows water to pass through readily, without creating effective storage upstream of the dam. The stream without a dam showed a rapid rise in response to the rain, and then declined at a moderate rate as water was shed from the wetland storage. The overflow type responded quickly to this storm because the pond behind the dam was already at a high level, and overflow commenced once the water level topped the dam crest. Once overflow occurred, the dam had little effect on modulating channel flows. This behaviour is similarly found downstream of the gap flow type of dam (not shown on Fig.

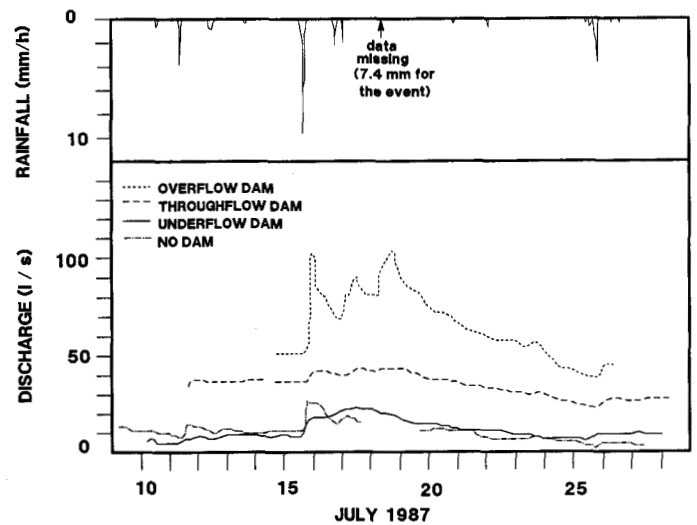


FIG. 7. Hydrograph responses of streams below three types of beaver dams (and a stream without any dam) to rainfall events in July 1987.

7). The underflow type of dam caused a longer delay to peak flow downstream because the hole in the dam restricts outflow. Once the maximum discharge permitted by the hole is attained, the dam still retains the increasing water supply from upstream, and the flow downstream is greatly moderated. At the conclusion of a storm, discharge below the dam will continue to rise as the ponded water is released, and this contrasts with the overflow and the gap flow dams, which cause steep hydrograph rises and fast recessions after the peaks.

Over the summer, the contrast in flow between streams with and without a dam can be seen from the hydrographs of Figure 8. Runoff from the control basin is fed by a wetland depression flanked by raised beach ridges. The stream in the other basin is blocked by an underflow type of dam and receives inflow from a gauged creek above the beaver pond. Difference in the inflow-outflow patterns reflects the storage influence of the beaver pond. For example, peak outflow

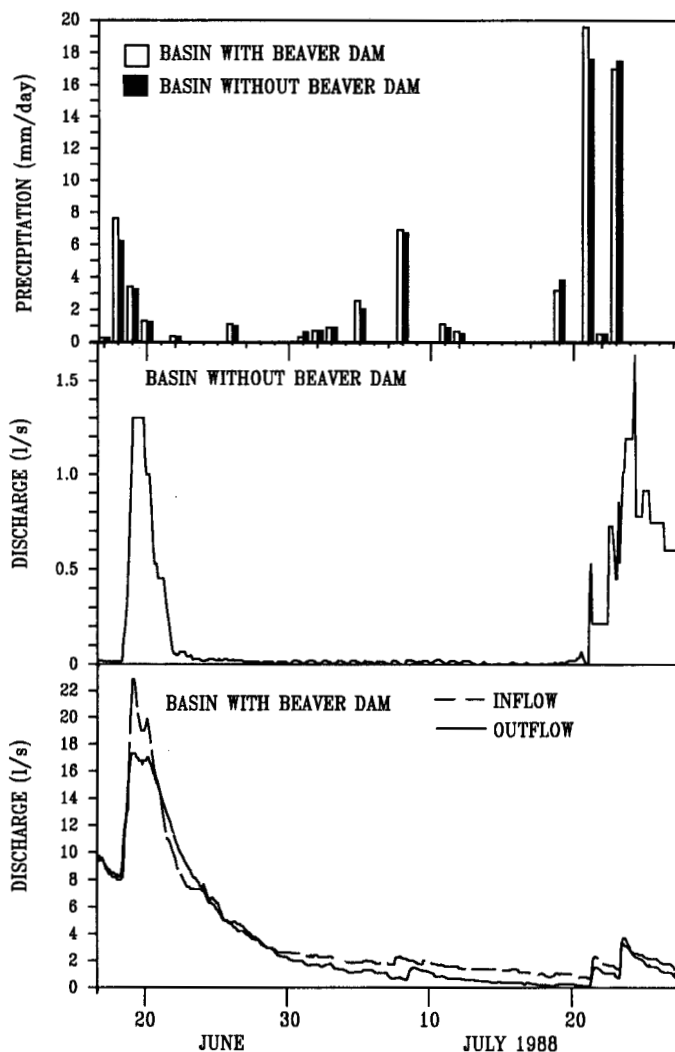


FIG. 8. Rainfall, evaporation and discharge for the basins without and with a beaver dam during the period 19 June to 28 July 1988.

lagged the peak inflow by 3 h on 21 June 1988; but after the inflow began to decline, the outflow continued to rise because the underflow dam was effective in altering the storage in the pond and thus regulating the outflow over a short term. In contrast, the control basin responded quickly to rainstorms, but the flow declined soon after because only wetland storage, and not pond storage, regulated the flow.

### Evaporation

The formation of a water body behind a beaver dam provides an unlimited supply of moisture to evaporation. In contrast, the water table in a wetland fluctuates, so that the wetland surface may not be saturated at all times. Consequently, the availability of moisture to evaporation is reduced. The replacement of the wetland surface by a beaver pond will enhance evaporation, as will be demonstrated in the following section.

### WATER BALANCE

The water balance of a drainage basin reveals quantitatively the various sources of gains, losses and storage status

of a drainage basin over a specific time interval. For a basin in the wetland during the summer period, the water balance equation can be written as:

$$P + Q_i + G_i = E + Q_o + G_o + \Delta S_d + \Delta S_p + \Delta S_g$$

where  $P$  is rainfall,  $Q$  and  $G$  are surface and groundwater flows,  $E$  is evaporation,  $\Delta S_d$ ,  $\Delta S_p$  and  $\Delta S_g$  are depression, pond and groundwater storages, and  $i$  and  $o$  denote inflow and outflow. Owing to their low values,  $G_i$  and  $G_o$  were combined to obtain the net groundwater contribution ( $\Delta G$ ).

For this study, water balance computations were performed for two basins, one with a beaver dam at its outlet, the other without a dam to serve as the control basin. The study period was 19 June to 28 July 1988 (Table 3). Rainfall for this period totalled 58 mm for the control basin and 60 mm for the dammed basin, and the main difference between these two values represents the localized spatial variation in storm precipitation. The largest rain event, occurring on 24 July, deposited 17.6 mm and 19.6 mm in the control and the dammed basins respectively, while the second largest event (on 26 July) yielded 16.6 and 17.0 mm in these two basins. These two events combined accounted for over half of the total precipitation for the study period.

The control basin has no surface inflow, and its surface outflow is entirely by overland flow. High flow occurred during periods of increased rainfall and the maximum instantaneous discharge was 1.3 L/s. Total runoff from this basin was 28 mm. Surface flow in the dammed basin also increased during the rainfall period, but as mentioned previously, the flow receded more slowly than in the control basin, because of enhanced storage. Cumulative surface inflow and outflow for the study period were 1263 and 1220 mm, representing 43 mm of water loss after the flow entered the study section.

The general patterns of groundwater flow, based on observed well elevations, are given in Figure 9. Groundwater discharges mainly into the basin from the raised beach ridges and from the upper wetland zones of the beaver-dammed basin. The flow rate is very low because of (1) the gentle hydraulic gradient in the wetland, being no more than 0.007, and (2) even on the steeper raised beach slopes, the low hydraulic conductivity is in the order of  $10^{-8}$  to  $10^{-6}$  m/s. Total groundwater flow for the study period, as computed using the Darcy flow law, was 0.5 mm in the controlled basin and 0.4 mm for the basin with the beaver dam.

Depression storage, measured as depth of water puddles in the micro-depressions in the wetland surface, was determined across several transects in each basin. Between the beginning and the end of the study period, the depression storage was depleted by 10 mm at the control basin, but the change was negligible ( $-0.4$  mm) for dammed basins. Groundwater storage change was obtained by comparing the water table positions at the beginning and the end of the study period and multiplying the mean water table difference

TABLE 3. Water balance for the period 19 June - 28 July 1988

	P	E	$Q_i$	$Q_o$	$\Delta G$	$\Delta S_d$	$\Delta S_p$	$\Delta S_g$
Dammed basin	60	91	1263	1220	0.4	-0.4	8	4
Control basin	58	65.5	0	28	0.5	-10	0	-25

Water balance:  $P - E + Q_i - Q_o + \Delta G = \Delta S_d + \Delta S_p + \Delta S_g$ .  
 Dammed basin:  $60 - (91) + 1263 - 1220 + 0.4 = 0.4 + 8 + 4$ .  
 Control basin:  $58 - (65.5) - 28 + 0.5 = -10 - 25$ .  
 All values in brackets are calculated as residuals in the equations.  
 All values are given in mm; see text for explanation of symbols.

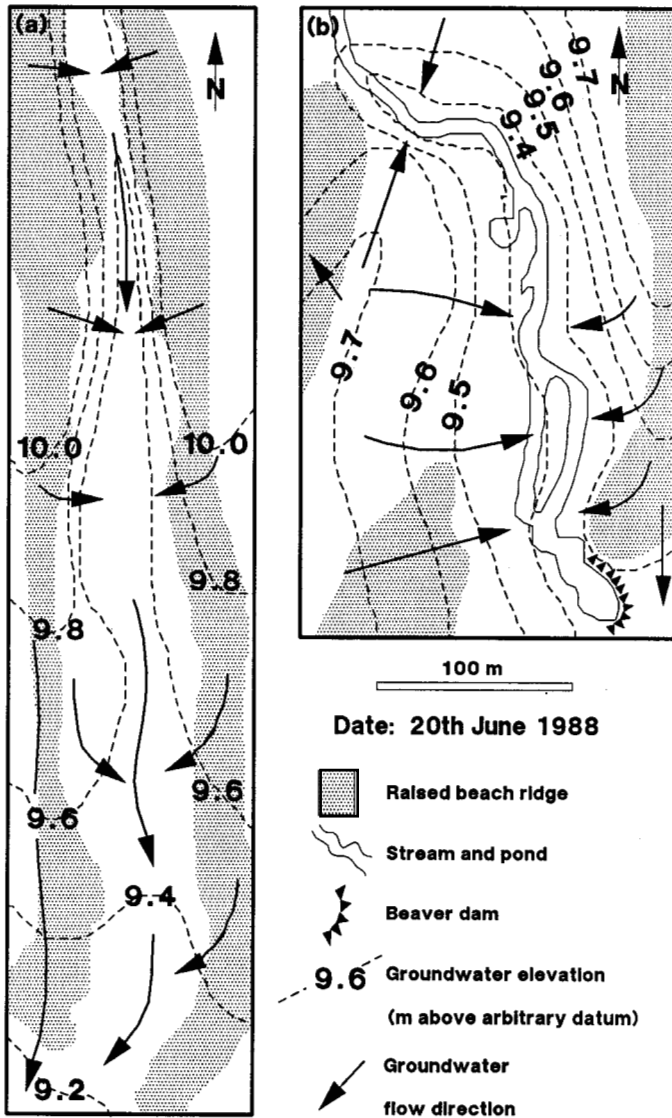


FIG. 9. Groundwater flow patterns at the basins (a) without and (b) with a beaver dam, 20 June 1989.

by the specific yield of the wetland soils. The measured specific yield (or the volumetric fraction of water that can be drained from a saturated soil) varied from 0.11 to 0.26, depending on the soil material. For the control basin, groundwater storage was depleted by 25 mm, but there was a groundwater storage gain of 4 mm in the dammed basin. There was no pond storage for the control basin, but for the beaver-dammed basin the beaver pond gained 71 m<sup>3</sup> of water at the end of the study period, representing a storage gain of 8 mm for the basin.

Basin evaporation was obtained as a residual in the water balance relationship and checked against values computed using the Priestley and Taylor (1972) equation, with an  $\alpha$ -coefficient of 1.26, as suggested by Marsh and Bigras (1988) and Stewart and Rouse (1976). Water balance calculations indicated 91 mm of evaporation from the dammed basin and 65.5 mm from the control basin. The Priestley and Taylor formula yielded 90 mm and 65 mm respectively. Both sets of values pointed towards a higher evaporation from the dammed basin. Table 4 shows that the control basin has a considerable *Salix* cover, while a large part of the dammed

basin is covered by *Carex aquatilis*. The larger coverage of *Carex* in the beaver-dammed basin reflects wetter conditions in the depression area surrounding the beaver pond, which occupies 9% of the basin area. With ample wet surfaces in this basin, higher evaporation was achieved.

Several effects of beaver dams upon basin water balance are apparent from this study: (1) Evaporation is larger in the beaver-dammed basin despite similar rainfall inputs. (2) Groundwater flow is very low in both basins because of the extremely gentle gradient. Surface flow constitutes a large component of the water balance. However, the beaver-dammed basin had a substantial inflow, which exceeded outflow. The net effect was that this basin had a gain in runoff, while the control basin experienced a loss. (3) The presence of a beaver dam increases basin storage, so that at the end of the study period, the dammed basin had a net storage gain while the control basin had a net loss.

TABLE 4. Vegetation types in beaver-dammed and control basins

Vegetation	Percentage cover	
	Dammed basin	Control basin
Open water	9.0	0.0
<i>Salix</i> sp.	18.5	69.0
<i>Caltha palustris</i>	0.0	5.5
<i>Carex aquatilis</i>	64.5	25.5
Aquatic moss	8.0	0.0

## CONCLUSIONS

Based on the results of this investigation, the following generalizations can be made regarding the impacts of beaver activities on wetland hydrology.

(1) Four types of dams are recognized, each of which affects the stream flow differently. Well-maintained dams often have stream flow overtopping (overflow dam) or funnelling through gaps (gap flow dam) in the dams. As the dams decay, water may move through the weakened bottom section (underflow dam) until eventually the entire dam becomes pervious and water seeps through the whole structure (throughflow dam).

(2) The presence of beaver dams in subarctic wetlands alters the hydrological landscape by creating ponds, diversion channels and multiple-surface flow paths. The construction of dams can be accomplished in several days, but once built, they will remain for years to permit the perpetuation of the new drainage pattern thus created.

(3) The flat topography of the wetlands renders groundwater flow ineffective, and the influence of beaver dams on groundwater flow is relatively insignificant. The extent to which surface flow is affected depends on the type of dam and the state of its preservation. In the dry period, the overflow and gap flow type dams retain the water in the beaver ponds, and downstream discharge is small. The throughflow type is unable to retain much water upstream and will be unable to alter the flow during the dry season. In contrast, the underflow type dam will continue to release water from the pond to sustain more uniform flow downstream.

(4) At high flows, the overflow and gap flow dams will hold back the water until the lowest points on the dam crests are overtopped. Above that stage, the dams will have no

control on flow. The throughflow dams will not be effective in altering high flows, but the underflow dams will dampen the peak and extend the flow recession.

(5) The aggregate effects of beaver activities on wetland hydrology can be quantified by the water balance. In summer, areas dammed by beavers undergo an enlargement of the open water and waterlogged surfaces, leading to an enhancement of evaporation. Where the dam is well maintained, water loss to runoff is drastically reduced, and this may offset the loss due to enhanced evaporation.

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#### REFERENCES

- ALLRED, M. 1980. A re-emphasis on the value of the beaver in natural resource conservation. *Journal of Idaho Academy of Science* 16:3-10.
- \_\_\_\_\_. 1981. The potential use of beaver population behaviour in beaver resource management. *Journal of Idaho Academy of Science* 17:14-24.
- BEUCH, R.R. 1985. Beaver in water impoundment: understanding a problem of water-level management. In: Knighton, M.D., compiler. *Water Impoundments for Wildlife: A Habitat Management workshop, 1982 August 31 - September 2, Bemidji, MN*. U.S. Department of Agriculture, Forest Service, General Technical Report NC-100:95-105.
- BOUWER, H. 1978. *Groundwater Hydrology*. New York: McGraw-Hill. 480 p.
- DUNCAN, S.L. 1984. Leaving it to beaver. *Environment* 26:41-45.
- HERON, R., WOO, M.K., and WU, K. 1988. Stream-related interaction in the coastal zone of the James Bay Lowland. In: Bardecki, M.J., and Patterson, N., eds. *Wetlands: Inertia or Momentum*. Don Mills: Federation of Ontario Naturalists. 323-327.
- MARSH, P., and BIGRAS, S.C. 1988. Evaporation from Mackenzie delta lakes, N.W.T., Canada. *Arctic and Alpine Research* 20:220-229.
- MEDIN, D.E., and TORQUEMADA, K.E. 1988. Beaver in western North America: An annotated bibliography, 1966 to 1986. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, General Technical Report INT-242. 18 p.
- NAIMAN, R.J., JOHNSTON, C.A., and KELLEY, J.C. 1988. Alteration of North American streams by beaver. *Bioscience* 38:753-762.
- NEFF, D.I. 1957. Ecological effects of beaver habitat abandonment in the Colorado Rockies. *Journal of Wildlife Management* 21:80-84.
- NEWMAN, P.C. 1985. *Company of Adventurers*. Vol. 1. Markham: Penguin. 565 p.
- PRICE, J.S., and WOO, M.K. 1988. Studies of subarctic coastal marsh: I. Hydrology. *Journal of Hydrology* 103:275-292.
- PRICE, J.S., EWING, K., WOO, M.K., and KERSHAW, K.A. 1988. Water movement, salinity, and vegetation patterns in a coastal wetland, south James Bay. *Canadian Journal of Botany* 66:2586-2594.
- PRIESTLEY, C.H.B., and TAYLOR, R.J. 1972. On the assessment of surface heat flux and evaporation using large scale parameters. *Monthly Weather Review* 100:81-92.
- ROUSE, W.R., MILLS, P.F., and STEWART, R.B. 1977. Evaporation in high latitudes. *Water Resources Research* 13:909-914.
- STEWART, R.B., and ROUSE, W.R. 1976. Simple models for calculating evaporation from dry and wet tundra surfaces. *Arctic and Alpine Research* 8:263-274.
- WOO, M.K., and diCENZO, P.D. 1989. Hydrology of small tributary streams in a subarctic wetland. *Canadian Journal of Earth Sciences* 26:1557-1566.
- WOO, M.K., and HERON, R. 1987. Breakup of small rivers in the subarctic. *Canadian Journal of Earth Sciences* 24:784-795.