*Research Report*

**BC Journal of Ecosystems and Management**

# Changes in riparian area structure, channel hydraulics, and sediment yield following loss of beaver dams

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## Abstract

Channel structure, riparian zone structure, and sediment transport capacity were investigated for Sandown Creek, a stream in the East Kootenay region of British Columbia where beaver dams were removed in the late 1980s to "improve" fish passage and flood conveyance. A series of historical aerial photographs taken over a 36-year period between 1968 and 2004 recorded the physical changes to a 3-km section of the stream valley following removal of 18 beaver dams. In the 16 years following beaver dam removal, channel pattern changed from a multi-thread to single-thread form. The riparian area structure also changed from 69% open areas and 9% beaver ponds to 90% closed vegetation. The change in channel structure in Sandown Creek resulted in an estimated 5-times increase in the mean flow velocity and an additional 648 $m^3$ of sediment available for transport. These findings provide the empirical data needed to verify long-standing assumptions about the ability of beaver ponds to effectively trap sediment and reduce bankfull flow velocity. The results of this study also underscore the speed and magnitude of alterations in the channel and riparian area structure in response to beaver loss in British Columbia's mountain valleys.

While the physical removal of beavers and beaver dams may be a practice of the past, wildland managers may still be inadvertently compromising the sustainability of beavers and associated wetlands in many areas of British Columbia by failing to adequately manage riparian areas to maintain beaver habitat.

**KEYWORDS:** *beaver dams, channel hydraulics, dam removal, flow velocity, mountain stream, riparian area structure, sediment yield, wetlands.*

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Green, K.C. and C.J. Westbrook. 2009. Changes in riparian area structure, channel hydraulics, and sediment yield following loss of beaver dams. *BC Journal of Ecosystems and Management* 10(1):68–79. ***www.forrex.org/publications/jem/ISS50/vol10_no1_art7.pdf***

## Introduction

Within the ecology community, beaver (*Castor canadensis*) are widely known to have dramatic effects on the hydrology, geomorphology, and ecology of riverine systems. By building dams, beaver form upstream ponds that increase water storage in stream channels; decrease stream velocity; elevate the local water table; trap nutrients and sediments, which reduces downstream turbidity and improves water quality; increase riparian vegetation diversity; and create and maintain riparian wetlands (Naiman et al. 1988; Gurnell 1998; Butler and Malanson 2005; Rosell et al. 2005). Despite their critical role in ecosystems, few studies have actually quantitatively described the influence of beaver dams on stream flow, sediment yield, channel hydraulics, and riparian structure, particularly across the breadth of the beaver's geographic range. The lack of quantitative research on the importance of beaver dams in the creation and maintenance of wetlands in many parts of British Columbia makes the beaver vulnerable to direct and indirect impacts from forestry activities, cattle grazing, as well as other development activities that can compromise the sustainability of beavers and their habitat (Ott and Johnson 2000; BC Ministry of Environment, Lands, and Parks 2001).

The beaver population in North America was estimated to have been between 60 and 400 million prior to the arrival of European settlers (Naiman et al. 1986). Beaver habitat covered most of the continent ranging from northern Mexico to the Arctic and from the Pacific to Atlantic Oceans (Jenkins and Busher 1979). Intense trapping and habitat destruction through draining of wetlands for settlements and agriculture resulted in a rapid decline of beaver to near extinction by the early 1900s (Naiman et al. 1986). Conservation efforts have allowed beaver to recover to about 10% of their original population size across most of their original range (Naiman et al. 1986).

In several regions of North America, such as British Columbia, beaver dams were routinely destroyed up until the late 1980s as they were believed to be a barrier to fish migration. Dam removal in Sandown Creek in the late 1980s provided an opportunity to examine the resulting changes to the fluvial landscape. The objective of this study was to assess long-term landscape alteration by beaver. Specifically, we determined the effects of beaver dam removal on (1) riparian structure, (2) channel hydraulics, and (3) sediment yield in a British Columbia stream where beaver dams were removed to "improve" fish passage. We used GIS coupled with historical aerial photography and field surveys as a means of evaluating changes to landscape and stream channel structure over a 36-year period. Further, published empirical models were used in combination with field studies and GIS methods to estimate temporal changes in sediment yield.

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## Methods

### Study area

The study was conducted along a 3-km reach of Sandown Creek, which drains a 72-$km^2$ area in the eastern Purcell Mountains directly west of the Rocky Mountain trench in southeastern British Columbia (Figure 1). Approximately 18 beaver dams were removed from this stream reach in the late 1980s in an effort to improve fish passage to Copper Lake. Currently the stream reach has a bankfull width of 4 to 6 m, an average gradient of 0.01 m/m, and a riffle-pool morphology. The floodplain is 50 to 100 m wide and averages about 1.1 m in elevation above the channel bottom. Fine-textured glaciofluvial and glaciolacustrine sediment underlies the main valley of Sandown Creek from Copper Lake to the confluence with Skookumchuck Creek.

Sandown Creek drains an area with a semi-arid climate. November, December, and June tend to be the wettest months of the year. The long-term mean annual precipitation is 660 mm recorded at Environment Canada's Kimberley, BC station (No. 1154203), 40 km southwest of Sandown Creek. Over half of the total annual precipitation falls as snow between the months of November and March. Mean monthly temperatures range from a low of −8.6°C in January to a high of 17.4°C in July. Peak flows in Sandown Creek occur in response to snow melt from May to late June and average 2.65 $m^3/s$ based on long-term gauging in nearby Mather Creek.

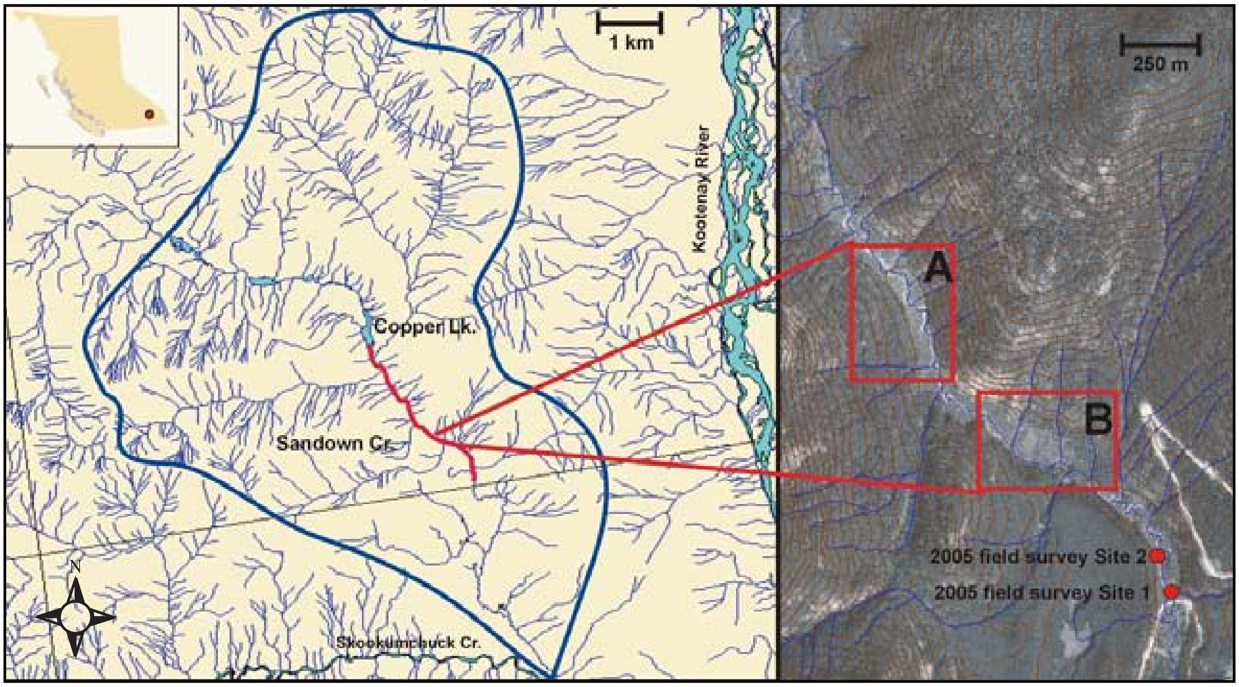


**FIGURE 1.** Location of Sandown Creek with the bold channel section showing the 3-km reach included in this study. The enlarged orthophoto shows the locations of study areas A and B and the 2005 field survey sites 1 and 2.

## Riparian area structure

Two channel segments (Areas A and B in Figure 1), totalling 1 km of stream length and 13 ha of floodplain area, were selected for a detailed investigation of temporal and spatial changes in beaver pond sites and floodplain vegetation. Aerial photography was obtained for 6 different years spanning 1968 to 2004 (Figures 2 and 3). Three photographs covered the 20-year period before the dams were removed (1968, 1975, and 1988), and three photographs covered the 16 years following dam removal (1995, 1997, and 2004). For the analysis, five of the aerial photographs (1995 photo was excluded due to poor resolution) at nominal scales of between 1:15 000 and 1:20 000 were scanned and enlarged to a scale of 1:5000 so that individual shrubs, trees, and dams were clearly visible. Locations of beaver dams and the extent of each land cover type, including beaver pond, open vegetation (sedges and grasses), and closed vegetation (shrubs and trees), were delineated on each photograph by hand. A digital planimeter was used to determine the total area of each land cover type on each of the five photographs in both study areas.

## Channel hydraulics

The change in mean velocity and cross-sectional stream power of the bankfull flow was estimated for a 500-m channel section in Area A by using channel surveys, air photo analysis, and Manning's equation to compare the hydraulic geometry of the channel with and without the dams. The historical air photographs provided a visual record of the change in channel form following removal of the beaver dams. Area A was chosen for this analysis because of the relative ease of measurements.

Bankfull flow or discharge ($Q_b$) in $m^3/s$ is related to channel cross-sectional area ($A$) ($m^2$) and average velocity ($v$) (m/s) by:

$$Q_b = A \times v \quad [1]$$

Equation 1 is also equivalent to:

$$Q_b = w \times d \times v \quad [2]$$

where $w$ is bankfull channel width (m), and $d$ is average bankfull channel depth (m). The influence of the dams on channel hydraulic geometry can be determined by assuming that $Q_b$ is equivalent with dams ($Q_{bD}$) and without dams ($Q_{bND}$). This is a reasonable assumption because, in the 1988 photo, the 3 km section of Sandown Creek below Copper Lake was occupied by beaver dams and accounted for an area of 0.35 km$^2$ or just less than 1% of the 45.6 km$^2$ total catchment area; in other words, an area too small to influence the flow regime of the catchment (Novitzki 1979, 1985). Therefore, if $Q_{bD}$ is equivalent to $Q_{bND}$ then:

$$w_D d_D v_D = w_{ND} d_{ND} v_{ND} \quad [3]$$

such that changes in the cross-sectional area of the bankfull channel will affect the stream mean velocity.

The effect of dam removal on stream mean velocity was estimated using Manning's equation. Manning's equation relates velocity ($v$) (m/s) to channel geometry (Henderson 1966):

$$v = \frac{R^{2/3} S^{1/2}}{n} = \frac{\left\{\frac{A}{P}\right\}^{2/3} S^{1/2}}{n} \quad [4]$$

where $R$ is hydraulic radius (m), $S$ is the surface slope of the water (m/m), and $n$ is Manning's roughness coefficient, a dimensionless value that accounts for the roughness of the channel bed and banks, and ranges from 0.025 to over 0.15 in natural alluvial channels (Henderson 1966; Acrement and Schneider 1989). The hydraulic radius is also equal to the cross-sectional area, $A$, divided by the wetted perimeter ($P = w + 2d$).

Manning's $n$ is estimated using the method outlined in Acrement and Schneider (1989) where total n is calculated in an additive manner such that:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m \quad [5]$$

where $n_b$ = base $n$ value; $n_1$ = addition for surface irregularities; $n_2$ = addition for variation in channel cross-section; $n_3$ = addition for obstructions; $n_4$ = addition for vegetation; and $m$ = ratio for meandering.

Stream power ($\Omega$) (W/m) is defined by Bagnold (1977) as the energy available in flowing water to do work such as transporting sediment and eroding channel boundaries. The effect of dam removal on stream power per unit length of channel is expressed as:

$$\Omega = \gamma QS \quad [6]$$

where $\gamma$ is the specific weight of water (N/m$^3$), $Q$ is bankfull flow or discharge (m$^3$/s), and $S$ is the surface slope of the stream water (m/m). The influence of the beaver dam removal on cross-sectional stream power ($\omega$) (W/m$^2$) was calculated as:

$$\omega = \gamma v d S \quad [7]$$

where $v$ is stream velocity and $d$ is depth.

The mean cross-sectional area of the bankfull channel with the beaver dams was calculated from the mean width of all the beaver dams in Area A multiplied by a mean depth of 0.6 m, which is consistent with the mean height of beaver dams in a similar physiographic setting in Glacier National Park, Mont. (Meentemeyer and Butler 1999). Dam widths were measured by hand on the 1988 air photograph enlarged to a scale of 1:2000. While the beaver dams were intact, stream velocity and cross-sectional stream power were determined using Equations 4 and 6, respectively, with mean surface water slope along the 500 m channel length calculated as 0.0028 m/m, assuming an average valley slope of 0.016 m/m and a dam height of 0.6 m. Valley slope was determined using GIS and a 25-m resolution digital elevation model (DEM) for the 3-km reach below Copper Lake.

Following removal of the dams, the mean cross-sectional area and wetted perimeter of the bankfull channel were determined using data from 2005 field surveys at Sites 1 and 2 (Figure 1; Table 1).

**TABLE 1.** Channel structure based on the 2005 survey data from field sites 1 and 2.

| | Station no. | | |
|---|---|---|---|
| | **1** | **2** | **Mean** |
| Stream gradient[a] (%) | < 2 | < 2 | |
| Bankfull width (m) | 5.2 | 4.5 | 4.9 |
| Bankfull depth (m) | 0.28 | 0.35 | 0.33 |
| $D_{50}$[b] (mm) | 10 | 15 | 12.5 |
| $D_{90}$ (mm) | 35 | 30 | 32.5 |

[a] Channel gradient was measured with a hand-held clinometer with an accuracy of ± 2%. Gradients less than 2% (0.02 m/m) are reported as < 2.

[b] Particle-size distribution was estimated using the Wolman pebble count method traversing from bank top to thalweg. D50 means that 50% of particles were smaller than or equal to 10 and 15 mm at stations 1 and 2, respectively.

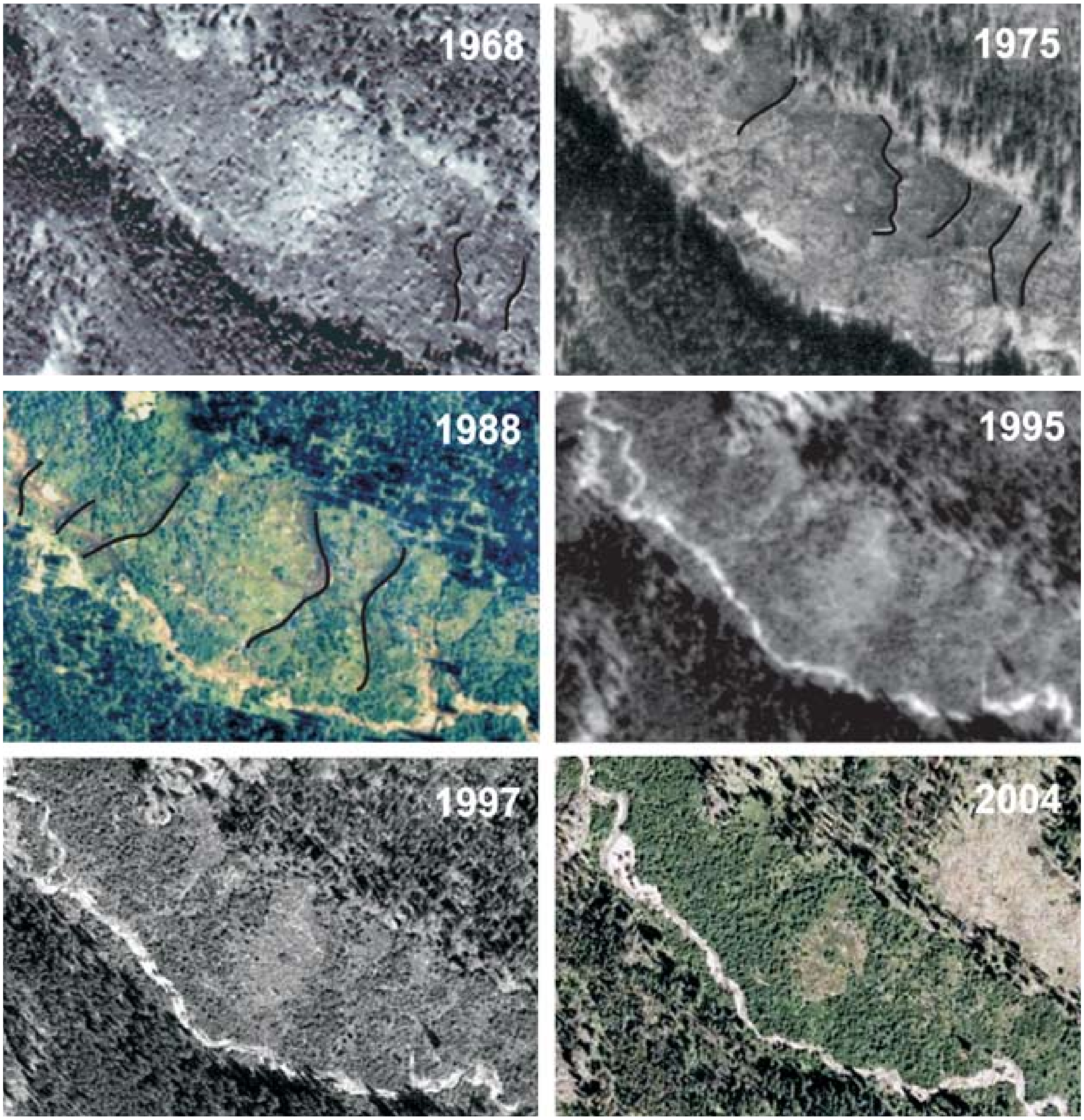


**FIGURE 2.** A series of six air photographs from Area B (scale approximately 1:10 000) spanning 36 years and documenting the physical changes to the channel and floodplain following removal of the beaver dams in the late 1980s. Black lines highlight beaver dams that contain ponds. The greatest change in channel and floodplain structure occured between 1988 and 1995. Higher-resolution air photos were used in the actual analysis.

For Sandown Creek, which has a width that is much greater than its depth, *R* is approximately equal to stream depth, *d*. Bankfull width was measured where well-defined, vegetated banks confined the channel. Bankfull depth was measured at the thalweg, which was the deepest point across the channel cross-section. For average velocity and cross-sectional stream power calculations, the mean surface slope was equivalent to the average valley slope of 0.016 m/m.

### Sediment yield

Two methods were used to estimate the total amount of sediment stored behind the 18 dams that were present in 1988 along the 3-km channel section below

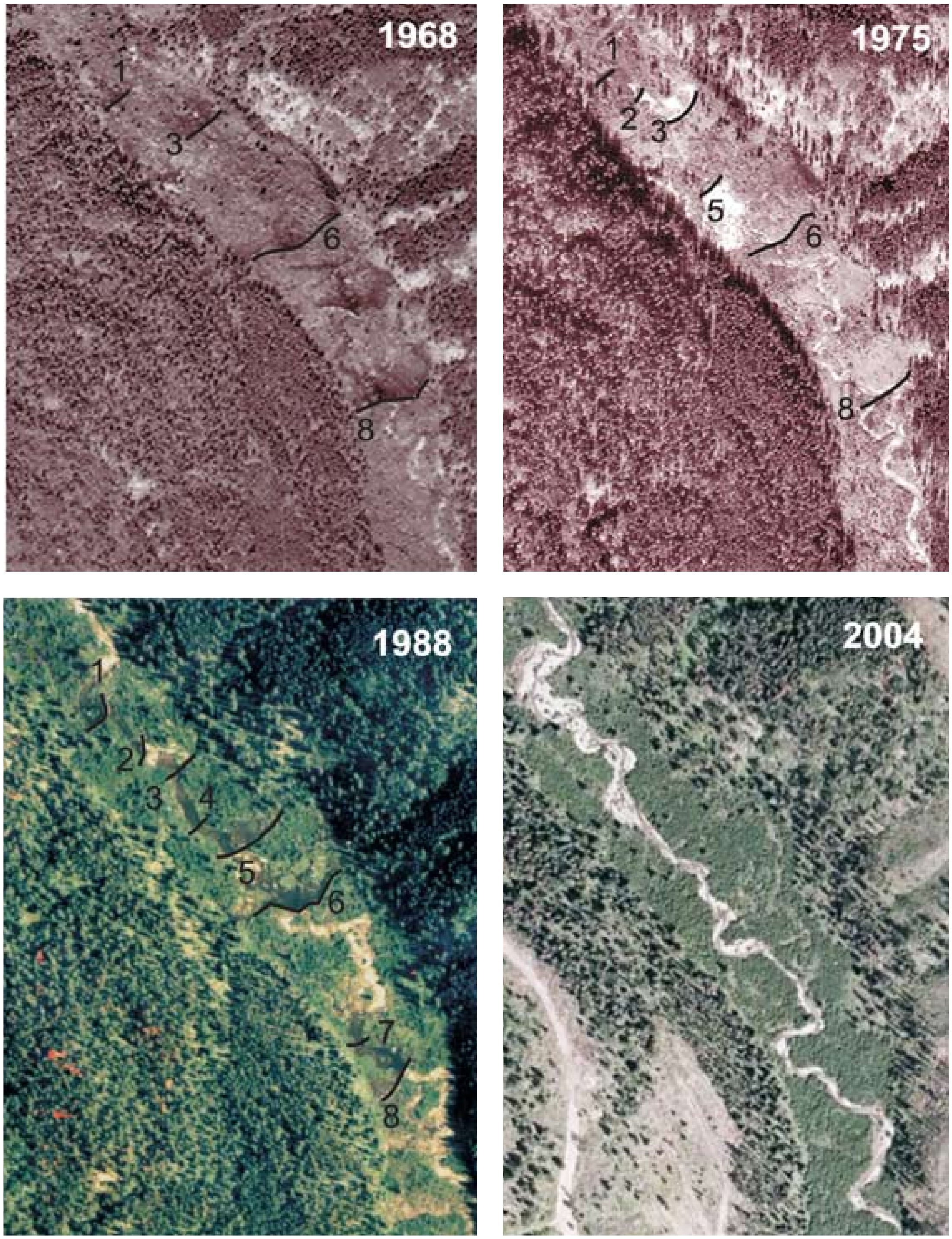


**FIGURE 3.** Historical air photographs for Area A (scale approximately 1:10 000) indicate that dams 1, 3, 6, and 8 were present from 1968 to 1988. Dams 2 and 5 were evident in the 1975 photo. Dams 4 and 7 were only evident in the 1988 photo. None of the dams in the 1975 photo contained water, and dams 2 and 5 appeared to have released sediment. The 1997 air photograph was included in the riparian structure analysis but is not shown in this figure.

Copper Lake. Estimates were based on the 8 beaver dams in the 500-m channel section of Area A. For the first method, sedimentation rate was set at 3.7 cm per year, which is consistent with sedimentation rates for beaver ponds from similar physiographic settings (Butler and Malanson 1995). In addition, historical air photographs and peak flow data from the nearby long-term hydrometric station at Mather Creek were used to determine the age and disturbance history of the dams. Mather Creek is 20 km south of Sandown Creek and has a similar basin geology, topography, and climate.

For the second method, the total volume of sediment stored in the 500-m channel of Area A was estimated by applying the regression equation developed for Glacier National Park, Mont., a site with a similar physiographic setting to Sandown Creek. This equation relates total volume of sediment ($S_d$) to pond area ($A_p$) for an estimation of m$^3$ of sediment per pond (Butler and Malanson 1995):

$$S_d = -84.082 + 0.62502A_p \quad [8]$$

The pond areas associated with the eight beaver dams in Area A were measured with a digital planimeter on the 1988 air photograph enlarged to 1:2000.

## Results

### Riparian area structure

Following beaver dam removal, the floodplain of Sandown Creek below Copper Lake was converted from a wide wetland area with ponds, open vegetation, and a multi-thread channel pattern to a single-thread channel with dense shrub cover. Historical air photographs from Area B indicated this conversion occurred over a very short time period between 1988 and 1995 (Figure 2). The floodplain in Areas A and B was occupied predominantely by open vegetation (69%) and beaver ponds (9%) during the 20 years preceding dam removal (Figure 4). In the 16 years following removal of the dams, the open areas were replaced by dense vegetation consisting of willows and coniferous saplings. No beaver ponds were present in the 1997 or 2004 air photographs, and less than 10% of the floodplain riparian area consisted of open vegetation areas of sedges and grasses (Figure 4).

### Channel hydraulic geometry

Several methods were used to determine the influence of the beaver dams on channel hydraulic geometry

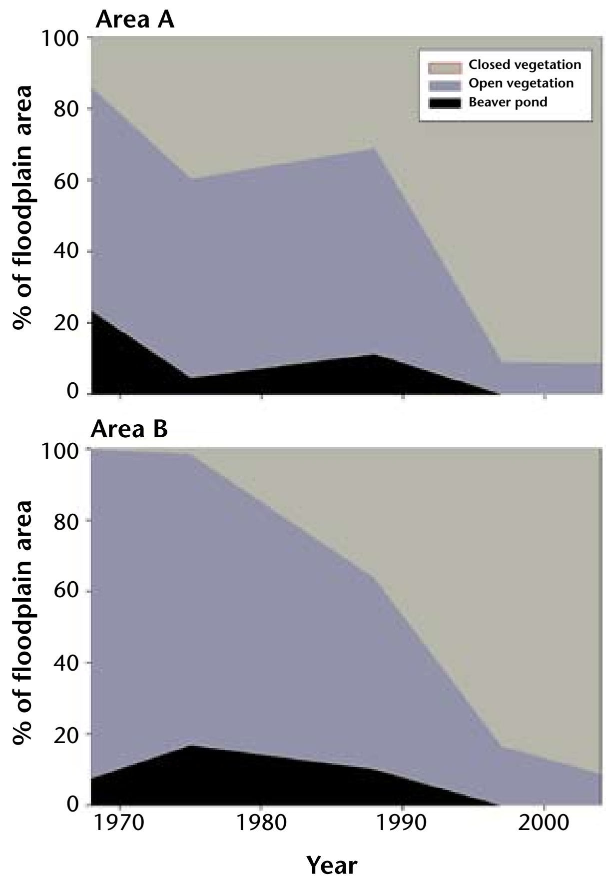


**FIGURE 4.** Changes in riparian area structure in Areas A and B over a 36-year period. Beaver dams were removed in the late 1980s.

(Table 3). Obvious changes in channel form, including a decrease in average channel width and a loss of beaver ponds, were apparent through visual inspection of the historical air photographs from Areas A and B (Figures 2 and 3). A comparison of the hydraulic geometry of the channel in Area A with and without the beaver dams indicated that dam removal decreased average cross-sectional area of bankfull flows by over 12 times (Table 2). The loss of beaver dams also resulted in a substantial decrease in Manning's roughness coefficient from 0.176 to 0.053. The combined effect of reduced cross-sectional area and reduced roughness coefficient translated into a 5-times increase in mean bankfull stream velocity and a 12-times increase in cross-sectional stream power. In other words, relative to current channel conditions, beaver dams likely reduced the mean velocity of bankfull discharge by approximately 81% and reduced average cross-sectional stream power by up to 92%.

**TABLE 2.** Influence of beaver dams on Sandown Creek channel hydraulics in Area A.

| Channel hydraulic parameter | Dams present | Dams absent |
|---|---|---|
| Bankfull cross sectional area ($m^2$) | 20.4 | 1.7 |
| Manning's roughness coefficient, *n* | 0.176 | 0.053 |
| Stream velocity at bankfull (m/s) | 0.221 | 1.14 |
| Stream power ($W/m^2$) | 0.43 | 5.46 |

### Sediment yield

The 8 beaver dams present in the 1988 aerial photograph of Area A ranged from 9 to 81 m wide and 23 to 53 m long (Table 3). The dams had a cumulative pond length of 320 m and an estimated mean surface water gradient of 0.0028 m/m. The historical air photographs showed that dams 1, 3, 6, and 8 were present from 1968 to 1988 (Figure 3). Dams 2 and 5 were evident on the 1975 air photograph, whereas dams 4 and 7 were only present on the 1988 air photograph. None of the dams contained water in the 1975 air photograph.

The Log Pearson III flood frequency analysis of annual peak flows for nearby Mather Creek (Water Survey of Canada Station 08NG076) indicated that a flood with a return interval of 8 years occurred in June 1974. Detailed analysis of the historical air photographs determined that only some of the dams in Sandown Creek failed in response to the 1974 flood. All the dams in Area A emptied of water, but only dams 2 and 5, which were the most recently constructed, appeared to have failed and released sediment. None of the peak flows recorded on Mather Creek between 1975 and 1988 had a return interval greater than 8 years. Based on the air photographs and flood history, dams 1, 3, 6, and 8 were approximately 20 years old; dams 2 and 5 were roughly 12 years old, assuming they had been repaired within 2 years of the 1974 flood; and dams 4 and 7 were estimated to be 2 years old (Table 3).

Using an average sedimentation rate of 3.7 cm per year (Butler and Malanson 1995), 406 $m^3$ of sediment was estimated to be stored behind the 8 beaver dams in Area A in 1988 (Table 3). However, if all the dams present in 1975 released their sediment during the 1974 flood, then the total volume of sediment stored by the dams in 1988 would be reduced to 283 $m^3$ or 35 $m^3$ per dam averaged over 8 dams. If the pond area regression method (Equation 8) was used to compute the volume of sediment, a total of 290 $m^3$ (36 $m^3$ per pond) was available for transport in 1988 along the 500 m section of Sandown Creek in Area A.

Eighteen beaver ponds were visible in the 1988 air photographs along the 3 km stretch of Sandown Creek below Copper Lake. Using a mean sediment volume of 36 $m^3$ per pond, the total volume of sediment available for transport was roughly 648 $m^3$ or approximately 22 cm of sediment if distributed evenly along the 3 km length of channel.

## Discussion

The aerial photograph analysis showed that beaver are important agents of stream ecosystem change as they affect riparian structure and channel hydraulic properties. Removal of beaver dams in Sandown Creek has resulted in a change in riparian vegetation from a variety of vegetative cover types to low riparian complexity comprised almost exclusively of dense shrubs and conifers. Dam removal also changed channel structure from multi-thread channels and ponds with high complexity to a meandering single-thread channel with no ponds. These changes resulted in a 5-fold increase in stream cross-sectional velocity and a 12-fold increase in stream power. The decrease in stream power associated with the presence of beaver dams was estimated to have resulted in the accumulation of over 600 $m^3$ of sediment or roughly 22 cm of sediment along a 3-km section of Sandown Creek.

Beaver may influence 20–40% of the total length of North American headwater streams (Naiman and Melillo 1984), and their dams are thought to be important structural elements within the channel because they create steps in the elevational profile (Gurnell 1998). The pools created upstream of dams cause stream water to flow via new pathways around dams and across forested riparian areas, which increases the amount of open canopy (Hammerson 1994). Since beaver dams contribute to the formation of multi-thread channel patterns (Woo and Waddington 1990; Westbrook et al. 2006) and cause channel avulsions (Cooper et al. 2005), one would expect that removal of beaver dams would cause the channel pattern to revert to a single-thread and allow the riparian forest to grow. Indeed, observations at Sandown Creek provided support for this hypothesis. Within 16 years, Sandown Creek changed from a wide multi-thread

**TABLE 3.** Estimates of available sediment stored in beaver ponds on a 500-m reach of Sandown Creek in Area A.

| | Dam no. | | | | | | | | Total (to nearest m$^3$) | Avg. m$^3$ per pond |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | |
| Dam age (yrs) | 20 | 12 | 20 | 2 | 12 | 20 | 2 | 20 | | |
| Dam width (m) | 30 | 12 | 28 | 9 | 53 | 81 | 9 | 48 | | |
| Pond length (m) | 44 | 48 | 23 | 53 | 28 | 51 | 25 | 48 | | |
| Pond area (m$^2$) | 99 | 405 | 388 | 502 | 952 | 1482 | 291 | 1109 | | |
| DEPOSITION RATE METHOD | | | | | | | | | | |
| Sediment depth (m)[a] | 0.74 | 0.44 | 0.74 | 0.07 | 0.44 | 0.74 | 0.07 | 0.74 | | |
| Sediment volume (m$^3$) | 81.4 | 53.3 | 42.5 | 9.8 | 31.1 | 94.4 | 4.6 | 88.8 | 406 | 51 |
| REGRESSION METHOD | | | | | | | | | | |
| Sediment volume (m$^3$) | 478 | 169 | 158 | 230 | 511 | 842 | 98 | 609 | | |
| Sediment depth (m) | 0.53 | 0.42 | 0.41 | 0.46 | 0.54 | 0.57 | 0.34 | 0.55 | | |
| Channel length (m) | 33 | 26 | 26 | 29 | 34 | 36 | 21 | 34 | | |
| Sediment volume in channel (m$^3$) | 44.2 | 27.2 | 26.2 | 32.7 | 45 | 50.5 | 17.7 | 47.1 | 291 | 36 |

[a] Sediment accumulated in beaver pond during dam life.

channel to a single-thread channel following beaver dam removal. Also, shrubs invaded the riparian area following dam removal, changing the vegetation cover from predominantly open to predominantly closed. However, the observations from Sandown Creek contrasted with those reported in the literature where most researchers found that beaver-affected areas persist as grass- and sedge-dominated open areas for decades to centuries (Ruedemann and Schoonmaker 1938; Ives 1942; Johnston and Naiman 1987). The succession sequence is frequently stalled because shrubs and trees seldom invade riparian areas affected by beaver activities (McMaster and McMaster 2000). Potential causes for this may be higher shrub production when beaver are present (Neff 1957; Baker and Hill 2003), or a lack of ectomycorrhizal fungi on conifer species due to the fatal effects of prolonged flooding on fungi survival (Terwilliger and Pastor 1999). The processes driving rapid shrub and tree invasion in Sandown Creek require further investigation, but may be associated with post-dam groundwater dynamics in the relatively high-gradient mountain valleys of western North America.

Several studies have determined that the primary influence of beaver dams during peak flow periods is reduced flow velocity (Woo and Waddington 1990; Devito and Dillon 1993; Johnston and Naiman 1987; Hillman 1998; Meentemeyer and Butler 1999; Novitzki 1978, 1985). Similar to jams of large woody debris, beaver dams typically form a series of step–pools along the length of a stream (Naiman et al. 1988; Butler and Malanson 1995). Observations of the hydraulic influence of large woody debris jams demonstrated that resistance associated with jams decreases with increasing flow depth as the jams become submerged by rising peak flows (Shields and Gipple 1995). However, well-maintained beaver dams generally extend up to or beyond the height of the adjacent floodplain, and discharge peak flows uniformly over the top of the dam so that the effect of beaver dams as roughness elements is maintained during peak flow periods (Woo and Waddington 1990; Gipple 1995).

Beaver dams have been reported to reduce flow velocity by up to 100% during low-flow periods, depending on their age, state of repair, and number in sequence along the stream channel (Burns and McDonnell 1998; Meentemeyer and Butler 1999). The calculations from Sandown Creek suggested that functioning beaver dams likely reduced the mean velocity of bankfull discharge by approximately 81%. Increases in bankfull width at the dams enable greater discharges to be transported in the channel before the floodwaters overtop the stream banks. This means that the removal of beaver dams in Sandown Creek either severed or greatly reduced the hydrologic connection between the stream and the riparian zone. Hydrological consequences of this disconnection include lowered water tables and decreased soil moisture in the riparian zone (Cooke and Reeves 1976). Ecological changes include a vegetation shift from riparian species to more xeric species and a decrease in the width of the riparian zone (Bryan 1928; Hendrickson and Minckley 1984).

Beaver dams have a substantial impact on sediment transport rates in a watershed, and act as long-term storage areas for both suspended and bed load sediment. Reported rates of sediment deposition behind beaver dams range from 2.5 cm per year in low relief areas of the Canadian Shield to upwards of 27.9 cm per year in the mountainous areas of Glacier National Park, Mont. (Devito and Dillon 1993; Butler and Malanson 1995). Although some study models suggest gradual pond infilling and the eventual formation of meadows, a more likely process is periodic beaver dam failure associated with basin flooding and at least partial release of stored sediment, especially in higher-energy mountainous environments (Butler and Malanson 2005). Our analyses for Sandown Creek revealed that some of the beaver dams on a 1-km reach of Sandown Creek failed in response to a flood that had an 8-year return interval. However, only two dams appeared to release substantial volumes of sediment. Our observations also suggested that sediment transport and storage dynamics in streams with beaver dams were complex. During large-magnitude floods, beaver dam failure can result in extensive disturbance to channel banks and portions of the adjacent riparian area, and can cause scour and (or) or aggradation below the washed-out dam. Smaller magnitude floods that cause limited dam failures likely result in local channel aggradation and degradation as sediment is redistributed through the channel network (Kondolf et al. 1991; Hillman 1998). Where dams have failed, stream base levels drop and the channel creates an incision in the fine sediments stored behind the dams (Fouty 2003).

## Management implications

Beaver dams are important hydrogeomorphic structures that can influence channel and floodplain structure, channel hydraulics, and sediment budgets of watersheds. The disappearance of beavers and beaver dams from Sandown Creek in southeastern British Columbia has resulted in substantial increases in flow velocity, increased sediment yield, and decreased wetland area, which, in turn, has caused channel entrenchment, bank erosion, and increased rates of sediment transport along the lower reaches of Sandown Creek.

Although the importance of beaver activities on the fluvial environment has been widely recognized in the ecology literature, beavers and their dams were still being destroyed in British Columbia during the late 1980s to improve flood conveyance and fish passage. Numerous studies from North America and Europe have since established the beneficial function of beaver ponds for many aquatic species including fish (Snodgrass and Meffe 1998; Schlosser and Kallemeyn 2000; Pollock et al. 2004). However, many fluvial systems across British Columbia remain in a degraded state due to the removal of beavers and their dams. While riparian management zones are a legislated requirement along fish-bearing streams (BC Ministry of Forests and Range 1995), there are no guidance documents or legislation available to British Columbians that recognize the importance of managing or enhancing beaver habitat to preserve wetlands in many parts of the province. This study was motivated by the desire to improve our understanding of the importance of beavers in a healthy, functioning ecosystem.

## Acknowledgements

Tembec, Inc. is graciously acknowledged for their support during the initial field assessment of Sandown Creek. Bruce Pope, RPF, of Tembec is also thanked for his assistance in filling in some of the data gaps for this study. The detailed review and comments provided by one anonymous reviewer were greatly appreciated. This project was completed as part of the course requirements for Geography 503, University of British Columbia, and, for this reason, we thank Marwan Hassan, PhD, and Rob Millar, PhD, PEng, who provided the incentive and the inspiration for this project. Finally, thanks to the beavers that once inhabited Sandown Creek and whose past engineering efforts remain a legacy to teach us the importance of responsible environmental stewardship.

## References

Acrement, G.J. and V.R. Schneider. 1989. Guide for selection of Manning's roughness coefficients for natural channels and flood plains. US Geological Survey, Washington, D.C. Water-Resource Paper 2339.

Bagnold, R.A. 1977. Bed load transport by natural rivers. Water Resources Research 13:303–312.

Baker, B.W. and E.P. Hill. 2003. Beaver (*Castor canadensis*). *In* Wild mammals of North America: biology, management, and conservation, 2nd edition. G.A. Feldhamer, B.C. Thompson, and J.A. Chapman (editors). The Johns Hopkins University Press, Baltimore, Md.

British Columbia Ministry of Environment, Lands, and Parks. 2001. Beaver management guidelines, draft version. BC Ministry of Environment, Lands and Parks, Vancouver Island Region, BC. ***wlapwww.gov.bc.ca/vir/pa/Beaver-Guide.pdf***

British Columbia Ministry of Forests and Range. 1995. Riparian management area guidebook. BC Ministry of Forests and Range, Forest Practices Branch, Victoria, BC.

Bryan, J. 1928. Change in plant associations by change in ground water levels. Ecology 9:474–478.

Burns, D.A. and J.J. McDonnell. 1998. Effects of a beaver pond on runoff processes: Comparison of two headwater catchments. Journal of Hydrology 205:248–264.

Butler, D.R. and G.P. Malanson. 1995. Sedimentation rates and patterns in beaver ponds in a mountain environment. Geomorphology 13:255–269.

Butler, D.R. and G.P. Malanson. 2005. The geomorphic influences of beaver dams and failures of beaver dams. Geomorphology 71:48–60.

Cooke, R.U. and R.W. Reeves. 1976. Arroyos and environmental change in the American Southwest. Oxford Clarendon Press, Gloucestershire.

Cooper, D.J., J. Dickens, N. Thompson Hobbs, L. Christensen, and L. Landrum. 2005. Hydrologic, geomorphic and climatic processes controlling willow establishment in a montane ecosystem. Hydrological Processes 20:1845–1864.

Devito, K.J. and P.J. Dillon. 1993. Importance of runoff and winter anoxia to the P and N dynamics of a beaver pond. Canadian Journal of Fisheries and Aquatic Science 50:2222–2233.

Fouty, S.C. 2003. Current and historic stream channel response to changes in cattle and elk grazing pressure and beaver activity. PhD thesis. University of Oregon, Eugene, Ore.

Gipple, C.J. 1995. Environmental hydraulics of large wood debris in streams and rivers. Journal of Environmental Engineering 121:388–395.

Gurnell, A.M. 1998. The hydrogeomorphological effects of beaver dam-building activity. Progress in Physical Geography 22:167–189.

Hammerson, G.A. 1994. Beaver (*Castor canadensis*): Ecosystem alterations, management, and monitoring. Natural Areas Journal 14:44–57.

Henderson, F.M. 1966. Open channel flow. MacMillan Publishing Co., New York, N.Y.

Hendrickson, D.A. and W.L. Minckley. 1984. Cienegas – vanishing climax communities of the American Southwest. Desert Plants 6:131–175.

Hillman, G.R. 1998. Flood wave attenuation by a wetland following a beaver dam failure on a second order boreal stream. Wetlands 18:21–34.

Ives, R.J. 1942. The beaver-meadow complex. Journal of Geomorphology 5:191–203.

Jenkins, S.H. and P.E. Busher. 1979. *Castor canadensis*. Mammalian Species 120:1–8.

Johnston, C.A. and R.J. Naiman. 1987. Boundary dynamics at the aquatic terrestrial interface: The influence of beaver and geomorphology. Landscape Ecology 1:47–57.

Kondolf, G.M., G.F. Cada, M.J. Sale, and T. Felando. 1991. Distribution and stability of potential salmonid spawning gravels in steep boulder-bed streams of the western Sierra Nevada. Transactions of the American Fisheries Society 120:177–186.

McMaster, R.T. and N.D. McMaster. 2000. Vascular flora of beaver wetlands in western Massachusetts. Rhodora 102:175–197.

Meentemeyer, R.K. and D.R. Butler. 1999. Hydrogeomorphic effects of beaver dams in Glacier National Park, Montana. Physical Geography 20:436–446.

Naiman, R.J. and J.M. Melillo. 1984. Nitrogen budget of a subarctic stream altered by beaver (*Castor canadensis*). Oecologia 62:150–155.

Naiman, R.J., J. Melillo, and J. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). Ecology 67:1254–1269.

Naiman, R.J., C.A. Johnston, and J.C. Kelly. 1988. Alteration of North American streams by beaver. Bioscience 38:753–762.

Neff, D.J. 1957. Ecological effects of beaver habitat abandonment in the Colorado Rockies. Journal of Wildlife Management 21:80–84.

Novitzki, R.P. 1979. Hydrologic characteristics of Wisconsin's wetlands and their influence on floods, stream flow and sediment. *In* Wetland functions and values: the state of our understanding. P.E. Greeson, J.R. Clark, and J.E. Clark (editors). American Water Resources Association, Minneapolis, Minn.

Novitzki, R.P. 1985. The effects of lakes and wetlands on flood flows and base flows in selected northern and eastern States. *In* Proceedings of the Conference on Wetlands of the Chesapeake. Environmental Law Institute, Easton, Md.

Ott, G.D. and D.W. Johnson. 2000. Beaver influence on fisheries habitat: livestock interactions. A research review paper. Twisp, Wa. Unpublished report. ***www.okanogan1.com/ecology/beaver/index.htm***.

Pollock, M.M., G.R. Pess, T.J. Beechie, and D.R. Montgomery. 2004. The importance of beaver ponds to Coho salmon production in the Stillaguamish River basin, Washington, USA. North American Journal of Fisheries Management 24:749–760.

Rosell, F., O. Bozser, P. Collen, and H. Parker. 2005. Ecological impact of beavers *Castor fiber* and *Castor canadensis* and their ability to modify ecosystems. Mammal Review 35:248–276.

Ruedemann, R. and W.J. Schoonmaker. 1938. Beaver-dams as geologic agents. Science 88:523–525.

Schlosser, I.J. and L.W. Kallemeyn. 2000. Spatial variation in fish assemblages across a beaver influenced successional landscape. Ecology 81:1371–1382.

Shields, F.D. and C.J. Gipple. 1995. Prediction of effects of woody debris removal on flow resistance. Journal of Hydraulic Engineering 121:341–354.

Snodgrass, J.W. and G.K. Meffe. 1998. The influence of beavers on stream fish assemblages: Effects of pond age and watershed position. Ecology 79:928–942.

Terwilliger, J. and J. Pastor. 1999. Small mammals, ectomycorrhizae, and conifer succession in beaver meadows. OIKOS 85:83–94.

Westbrook, C. J., D. J. Cooper, and B.W. Baker. 2006. Beaver dams and overbank floods influence groundwater–surface water interactions of a Rocky Mountain riparian area. Water Resources Research 42:W06404, doi:10.1029/2005WR004560.

Woo, M.K. and J.M. Waddington. 1990. Effects of beaver dams on subarctic wetland hydrology. Arctic 43:223–230.

**ARTICLE RECEIVED:** **April 23, 2007**
**ARTICLE ACCEPTED:** **December 23, 2008**

# *Test Your Knowledge . . .*

***Changes in riparian area structure, channel hydraulics, and sediment yield following loss of beaver dams.***

**How well can you recall some of the main messages in the preceding Research Report? Test your knowledge by answering the following questions. Answers are at the bottom of the page.**

1. What ecosystem is closely linked to beaver dams in western North America?
2. How do beaver dams influence the velocity of bankfull flows?
3. How does channel pattern change following removal or loss of beaver dams?

## *ANSWERS*

1. *Wetlands.*
2. *Beaver dams reduce the velocity of bankfull flows by approximately 81%.*
3. *Channel pattern changes from wide, multi-thread pattern to narrow, single-thread pattern following loss of beaver dams.*