BEAVER-POND SEQUENCES IN NORTHWESTERN MONTANA: MORPHOLOGY AND SEDIMENTATION

THESIS

Presented to the Graduate Council of
Southwest Texas State University
In Partial Fulfillment of
the Requirements

For the Degree

Master of Applied Geography

By

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San Marcos, Texas
May 13, 2000

ACKNOWLEDGEMENTS

I give my heartiest thanks to those who understood that this project was about more than beavers. Teachers and friends Diana Gonzales and Kathy Rocha encouraged me to embark on this new path. Robert, Thomas, Sue, and Larry Coleman of Kiowa, Montana adopted me into their fold, fed me huckleberry ice cream, and introduced me to the land and people around Glacier National Park. Thad Hunter and Lisa DeChano ably assisted in the field. Forrest Wilkerson and Ginger Schmid provided valuable contacts and advice as I headed to the field, and friendship when I returned.

Committee members David Butler, Richard Dixon, and Pamela Showalter offered thoughtful suggestions that improved this thesis, and insights that improved my understanding of geography as a verb. I am indebted to David Butler for sparking (and fanning) my fascination with zoogeomorphology, and for sharing with me his remarkable creativity and humor.

Generous professors aided my exploration of geography through extended discussions. Early on, Lawrence Estaville showed me the geography light in 5309. Richard Earl and Fred Shelley also broadened my perspective and influenced my path. Particularly memorable are the Butler-Dixon-Bigler conversations over buckets o' noodles where I learned much about science, sports, and even walruses in Hawaiian shirts.

My family has been an unending source of encouragement and beaver figurines. My parents, Lois and Bob Bigler supported my fieldwork and tolerated the transformation of their guest bathroom into a muddy laboratory. As always, my sister Heidi patiently offered me fresh perspectives and humor when I needed them most.

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BEAVER-POND SEQUENCES

IN NORTHWESTERN MONTANA:

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Beaver ponds are prominent features in many mountain streams; in places occurring as sequences resembling stair steps. Beaver-pond sequence morphology and sedimentation patterns are poorly represented in the literature. I documented the morphology of two beaver-pond sequences in northwestern Montana by describing the sequences, mapping the ponds, and developing longitudinal profiles. I collected data on sediment depth, and took sediment samples along longitudinal and cross-pond transects. I analyzed the data for longitudinal and lateral patterns of sediment texture within ponds, and found no patterns. I further analyzed the data for correlation between distance from the head of each sequence and the percentage of sand in each sediment sample, and found no relationship. Finally, I found that older ponds sequester more sediment than younger ponds. Based on these results, I suggest additional research questions.

CHAPTER I

INTRODUCTION

Mountain streams are complex systems that are not fully understood in terms of their form or their function in transporting and storing sediment. In comparison with their lower elevation counterparts, mountain streams are more likely to have their flow obstructed or diverted by material introduced into the stream channel. These materials include boulders or large woody debris incorporated into the stream and maintained or modified through a variety of physical processes. Beaver dams represent unique obstructions to flow because they impound relatively large volumes of water, are persistent channel features, and are created and maintained by animals. The processes involved in dam establishment and subsequent landscape evolution, and impacts on stream hydrology and morphology are not well studied, particularly over long time periods.

Studying the role of beaver dams in mountain streams has potential application beyond gaining scientific insight into landscape dynamics. Understanding the flow of water and materials has potentially important applications in flood prediction and control. Human-engineered flood control often hinges upon the principle of reducing stream energy through dam construction. Beaver-pond sequences step down stream energy as evidenced by the accumulation of sediment in ponds. By studying the rates and patterns of sediment, we gain insight into the use of beaver ponds as a natural method of flood control. Beaver ponds can also represent a natural hazard as they change stream dynamics. Ponds can directly flood roads, railways, farmland and structures. Changes in the water table can kill surrounding timberlands. Understanding pond morphology and spatial arrangement may aid in managing human-beaver interactions.

Despite the growing populations of beaver in North America, few studies have characterized beaver pond form or beaver pond sediments. Gurnell (1998, 184) notes the need for additional research from a physical geography standpoint: "Most of the [beaver pond] literature has been written from a biological perspective, so that many of the important hydrogeomorphological characteristics of beaver activity are not described in detail." This thesis will characterize beaver pond morphology and function in a northwestern Montana mountain stream.

Although beaver pond sequences are found in a variety of environments, their spatial and morphological characteristics are poorly described either qualitatively or quantitatively. Furthermore, little is known regarding how sequences of beaver ponds function in terms of trapping sediment. In this light, my research will address four related questions:

1) What are the morphological characteristics of beaver-pond sequences?
2) What is the spatial distribution of sediment within individual ponds?
3) What is the spatial distribution of sediment within a pond sequence?
4) Is the quantity of sediment related to apparent dam age?

The answers to these questions will provide new information for those studying the geomorphology and hydrology of mountain streams. Patterns, or the lack of patterns, may spur additional research or insights. In addition, the data I collected may provide a baseline for future studies.

CHAPTER II

LITERATURE REVIEW

Through their ability to dam streams and create ponds, beavers are considered a keystone species. Their impact on both the biotic and abiotic character of the environment is out of proportion to their numbers (Naiman 1988, Naiman et al. 1988, Jones et al. 1994, Gurney and Lawton 1996). The morphology and sediment-trapping function of beaver pond sequences are integral components of some mountain stream systems. Accordingly, I will examine the literature pertaining to beaver impact on the biotic and abiotic aspects of the stream environment through their dam-building activities. Areas examined will include: published literature reviews, historical and modern beaver distribution, beaver constructions, beaver pond impacts on hydrology and geomorphology, and beaver pond influences on biodiversity and landscape ecology

Published literature reviews

Several reviews of beaver pond literature exist. Although none is comprehensive, taken together they have been a valuable source of information and further references. Hammerson's (1994) review focuses on ecosystem impacts and on beaver management. Naiman et al. (1988) emphasize the role of beaver as a keystone species, and the importance of historical population fluctuations in interpreting this role. Butler (1991a, 1995) provides general reviews, emphasizing geomorphic impacts of beaver. Olson and

Hubert (1994) primarily focus on the effects of beavers on western ecosystems, especially rangelands. They describe the problems that beavers can cause, as well as suggestions for their management. Olson et al. (1994) provide citations for 293 references pertaining to beaver ecology and management. Medin and Torquemada (1988) annotate 206 references from 1966-1988, emphasizing the western United States and Canada. Gurnell (1998) provides extensive citations and discussion in her review of beaver impacts on hydrology and geomorphology.

Historical and modern beaver distribution

Because this study has potential implications for interpreting beaver impacts over a broad spatial and temporal scale, I will address the literature concerned with the historical distribution of beavers in North America. Before European settlement, beaver inhabited most of North America north of the U.S.-Mexican border, with the exceptions of the Florida peninsula and the arid regions of the Southwest (figure 1). Naiman et al. (1988) place initial population estimates at 60-400 million beavers. Primary historical accounts reveal that beaver concentrations varied a great deal over time and space (Bailey 1905, Alter 1925, Russell 1955, Pattie 1988).

Hunted for their fur and castoreum, beaver populations began to decline in the early 17th century, nearing extinction by the turn of the 19th century. Krech (1999) states that between 1800 and 1900, beaver harvests fell ninety percent. Rue (1967) credits the Englishman Beau Brummel with establishing the fashion for beaver felt hats in the early 1800s. Once common features of streams across the country, beaver populations declined due to direct hunting pressure and changes in population structure. Johnson and

Figure 1: Historical beaver distribution

Chance (1974) hypothesize that drastic reductions in Pacific Northwest populations between 1835-1850 resulted from fewer reproducing adults.

The change of millinery fashion from beaver felt to silk, in combination with protective laws, resulted in decreased hunting pressure (Ray 1975, Novak et al 1987). Marsh recognized the link between fashion and landscape at a time when beaver populations were beginning to rebound:

> This animal—whose habits, as we have seen, are an important agency in the formation of bogs and other modification of forest nature—immediately began to increase, reappeared in haunts which he had long abandoned, and can no longer be regarded as rare enough to be in immediate danger of extirpation. Thus the convenience or the caprice of Parisian fashion has unconsciously exercised an influence which may sensibly affect the physical geography of a distant continent. (Marsh 1864, 76-77)

Beaver populations have since increased throughout much of its original range. In many areas of beaver extirpation, recolonization has taken place naturally through dispersal or by human-mediated reintroductions (Butler 1991b, Davis and Schmidly 1994).

Contemporary beaver distribution closely resembles the historical distribution, with modern population estimates ranging from 6-12 million beavers (Naiman et al. 1986). Overall population density is thought to be less than one-tenth pre-European settlement density, although local densities can be quite high (Naiman et al. 1986). Because people have altered much of the former beaver habitat, beaver populations are unlikely to rebound to pre-European settlement numbers. Naiman et al. (1988) note that a large percentage of the wetlands filled since the mid-1800s was former beaver habitat.

Globally, the range of *Castor canadensis* has expanded through intentional introductions to Finland (Lahti and Helminen 1974), and Tierra del Fuego (Lizarralde

1993). Investigations of these populations may augment what is known about the species from a North American viewpoint.

Changes in beaver population have implications for those interpreting stream morphology and processes. Investigators may neglect considering beavers' historical or current presence, and thus omit an important influence on stream dynamics. Ives (1942, 198) cautions that "changes in beaver populations make estimates of the present magnitude of beaver work subject to a rather large probable error." Naiman et al. (1986, 1254) point out that "current concepts of the organization and diversity of unaltered stream ecosystems in North America should recognize the keystone role of beaver, as drainage networks with beaver are substantially different . . . than those without beaver."

The history of beavers in North America is rich and complex. Particularly within the study area, the historical context of present day beaver populations should be considered in interpreting the results of my research. The present landscape and level of beaver activity may or may not reflect past conditions.

Beaver constructions

The North American beaver, *Castor canadensis*, builds dams to a greater extent than its European relative *Castor fiber* (Jenkins and Busher 1979, Gurnell 1998). Beavers create ponds for protection against predators (Zeveloff 1988, Johnston et al. 1993). Because they do not hibernate, the pond must be of sufficient depth to not freeze solid in winter in order to allow the beaver access to food (Ingles 1965, Lawrence 1977).

To build dams, beavers require stream flow that is permanent, relatively constant, and usually greater than 0.5 cubic foot per second (Olson and Hubert 1994). Naiman et al. (1986) observe that beavers typically build dams on second- to fourth- order streams. Although they will attempt to build dams on larger streams, they will abandon their efforts if stream flow is too high (Naiman et al. 1986, Carlson 1999). Beaver will also abandon a dam when it fails to impound water, as in the case of intermittent streams (Olson and Hubert 1994) or when built on karstic terrain (Cowell 1984).

Beavers typically build dams on streams with gradients less than twelve percent (Allen 1983), and with the optimum slopes less than three percent (Olson and Hubert 1994). Streams with rocky or bedrock bottoms are less favored than alluvial channels, possibly because this lithology would limit their ability to excavate bank burrows and canals (Hill 1982, Gurnell 1998).

Appropriate vegetation must be available to supply the beavers' herbivorous diets and for dam material. Beavers strip and eat the bark of aspen, willow, cottonwood, and alder, in addition to grazing on herbaceous plants (Allen 1983, Gurnell 1998). When these plants are not available, beaver will cut and eat conifers (Van Gelder 1982).

The sight and sound of running water triggers the beaver's dam-building instinct (Olson and Huber 1994). Once stripped of their bark, branches are placed in the stream with the thickest portions upstream and often forced into the streambed (Warren 1927, Lawrence 1977). Fortified and weighted down with brush, stones, or even bottles, the dam is then sealed with mud excavated from the stream banks or bed (Bailey 1927, Banfield 1974). Beavers promptly repair leaky dams soon after leaks develop (Bailey 1927, Hodgson 1952), even in winter (Reid et al. 1988).

Spatial and morphological characteristics of beaver dam arrangement vary dramatically over time, in part as a function of whether the beaver are new inhabitants or if they are reworking existing dams (Naiman et al. 1988). Bailey (1927) states that larger dams can be the work of many generations of beaver and persist for over 100 years. Lawrence (1977) and Warren (1927) describe dam morphology, giving examples of straight, curved concave upstream, concave downstream or highly angular dams. Warren (1927) cites Mills (1913) as describing a 2140 foot-wide [700m] dam on the Jefferson River in Montana.

Beaver may build isolated, single dams or construct a series of dams. Lawrence (1977) and Ryden (1989) give detailed descriptions of how beaver pond sequences develop over time. Beavers also build secondary dams downstream to capture leaks from upstream dams (Ives 1942, Lawrence 1977). Woo and Waddington (1990) devise a classification scheme for dams based on water movement through, over, or under the dam.

In addition to creating ponds, beaver also modify their habitat through the construction of canals. Canals are excavated in shallow portions of the pond extending into the pond's banks. Beavers use these water-filled canals to transport food and dam-building material, to divert water (Cowell 1984) as well as to escape predators encountered away from the pond (Bailey 1927, Olsen and Hubert 1994). Hodgson (1952, 21) describes the longest canals as reaching "extraordinary length of one thousand feet [300m] with a width of from two to three feet [0.6-1.0m] and depth of one to three feet [0.3-1m]", but more typically canals are between 1-100m long (Gurnell 1998).

Dens or lodges are not ubiquitous beaver pond features, but where they are found they consist of sticks and mud built on a earth floor that is about four inches [10cm] above the water level (Olsen and Hubert 1994). Although the internal dimensions of a lodge are usually 1.3-1.7m across and 1m high, one lodge measured 2m high and 12m in diameter (Fitzgerald et al. 1994). Generally, the lodge is situated so that the deepest water in the pond will surround it with one or two underwater entrances (Bailey 1927). This arrangement allows passage from the pond to food caches even when more shallow areas of the pond are frozen solid (Dunmire 1986). Dieter and McCabe (1989) found that bank slope was the most important physical factor in the siting of lodges, with the steepest banks offering the best protection of lodge entrances.

Beavers build dams and lodges only under suitable environmental conditions. Where beaver do not have access to suitable dam-building material or stream flow, they forgo dam building and instead burrow into stream banks (Hodgson 1952, Cowan and Guiguet 1965, Naiman et al. 1986). Most beaver in the Midwestern Plains excavate bank burrows instead of building dams and lodges, presumably because of the paucity of suitable building material (Robel and Fox 1993, Robel et al. 1993). Beaver inhabiting lakeshores (Carney 1999) and large rivers also build bank burrows (Barnes and Dibble 1988, Brown 1997). Bailey (1927, 7) describes the largest bank burrows as "Forty to fifty feet long [13-16m] and large enough for a man to crawl into."

The variety, structure, and function of beaver constructions ultimately determine pond morphology and the extent of stream environment alteration. Complete morphological descriptions of beaver ponds should include descriptions of beaver constructions.

Beaver pond impacts on hydrology and geomorphology

The activities of beaver alter and complicate both the surface and subsurface hydrology of stream channels. Dams decrease stream velocity as they impound water.

Meentemeyer and Butler (1999) collected data from ten ponds in Glacier National Park, Montana, and found that older dams reduced stream velocity and discharge more than young dams. The reduction in discharge is also observed during flood events along dammed streams. Flood hydrographs from dammed streams exhibit a lower rate of increase of discharge and a decrease in the magnitude of peak discharge compared to streams without dams (Williams 1988, Gurnell 1998). In extreme flood events, beaver dams can be washed out (Rutherford 1953, Butler 1989). Gurnell (1998) points out that the large quantities of water required for catastrophic dam failure will typically be available infrequently and then, only on low gradient streams. Olsen and Hubert (1994) point out that pond water storage also reduces downstream flooding during peak runoff periods, while Burns and McDonnell (1998) suggest that surrounding wetlands can retain as much water from a large precipitation event as the pond can store.

Water is stored not only in the pond, but in the banks and floodplain as well. This subsurface storage leads to a rise of the water table, increasing summer flows (Wilde et al. 1950, Gurnell 1998). Beschta and McNamara (1997) monitored sixty shallow wells over the course of a year to determine that subsurface flow moved from the beaver pond, into the subsoils of the floodplain, and then flowed back towards the channel downstream of the beaver pond. They also noted that in summer, the relatively warm surface water cooled as it moved through the subsurface environment, taking two to three months to return to the channel. In winter, the pattern reverses with warmer water returning to the channel. The ramifications of this temperature moderation are not known.

Gurnell (1998) generalizes that downstream effects of beaver ponds on channel morphology depend upon the concentration of flow. Where flow is primarily through broad seepage across the floodplain, wetlands develop. Areas of concentrated flow may result in stream channel excavation. Drainage networks, particularly in wide, low gradient floodplains can develop complex, dynamic braided channel networks (Townsend 1953, Woo and Waddington 1990). Coleman and Coleman (1999) noted that following Spring flooding in 1998, beavers rebuilt dams in different locations altering channel morphology.

The dynamic nature of the spatial arrangements of ponds is reflected in complex channel morphology over time. Malanson (1993) points out that while the initial effects of beaver dams are similar to human-built structures, beaver dams tend to be less permanent components of the landscape. Pullen (1975, 17) observed water levels in twelve beaver ponds over a two-year period in east-central Alabama. He notes that water level "varied greatly from pond to pond and in some cases from time to time within an individual pond" apparently due to differences in maintenance and meteorological conditions. Using a Geographical Information System, Johnston et al. (1993) concluded that changes in beaver population density altered hydrology over a substantial portion of the Kabetogama Peninsula, Minnesota.

The complexity of water movement through ponds is reflected in complex patterns of sediment deposition. Beaver ponds act as sediment sinks for two reasons. First, as a stream's velocity decreases, so does its ability to transport sediment. Much of the sediment transported from upstream is deposited as the stream slows and becomes a pond. Secondly, the mud-sealed dam structure itself acts as a filter, preventing the passage of some sediment and other materials. Like all lakes and ponds, beaver ponds have a finite life span. As they infill with sediment, ponds become shallower. Eventually, the ponds may freeze solid in winter or fail to provide the beavers with the benefits of protection from predators. Either of these outcomes can eliminate the beaver or cause them to disperse. Abandoned dams gradually weaken and then fail to impound water. Grasses and sedges colonize the sediment resulting in a unique landform: the beaver meadow (Marsh 1864, Warren 1905, Warren 1927, Lobeck 1939, Ives 1942, Butler and Malanson 1994, Moore, 1999). Ruedemann and Schoonmaker (1938) and Ives (1942) observe that geologists overlook the beaver as a factor in meadow formation by classifying the meadows as post-glacial lake bottoms.

In the low-energy environment of beaver dams, stream gradient is decreased and can take on stair-step morphology (Apple et al. 1985, Anonymous 1997, Gurnell 1998). Ruedemann and Schoonmaker (1938) posit that beaver change the river grade from a series of small descending steps to a gently graded, even valley plain. Moore (1999) notes these meadows can persist for at least seventy years, and that secondary succession to woodlands appears to be arrested by localized nutrient deficiencies or the persistence of an elevated water table.

Although the process of sedimentation is key in the formation of beaver meadows, only a limited amount of research has been done on beaver pond sedimentation (Butler and Malanson 1995, Gurnell 1998). Butler and Malanson (1995) measured sedimentation rates in eight ponds in Glacier National Park, Montana. They calculated volume by multiplying pond area by average sediment depth. They determined pond age by examining historical aerial photographs and maps and by personal observation, and calculated sedimentation rates ranging from 2.1-27.9 centimeters per year.

Although the primary geomorphic influence of beavers is depositional in nature, beavers also act as agents of erosional change. Beavers excavate canals, slides, and bankburrows. Meentemeyer et al. (1998) identified 288 bank burrows and 27 slides along Bolin Creek, North Carolina and estimated an erosion rate of 0.0054 cubic meters per meter of stream length per year. Butler and Malanson (1994) note that bank burrows can extend several meters into the bank, at times leading to erosion of additional bank material through slumping as well as treefall and the concomitant creation of tree-tip mounds.

Whereas the effects of beaver ponds as a land-building process are gradual and local, beaver pond removal can have immediate, far-reaching effects. Marston (1994) describes the impact of beaver removal as an agent for river entrenchment in the western United States. When dams are no longer maintained, they are subject to failure, with sudden increase in stream power responsible for the rapid downcutting of the channel. Downstream dams may fail due to the surge of water, exacerbating the impact.

The limited literature documenting the hydrology and geomorphology of beaver ponds will be augmented by this study. The need for my study is underscored by the virtual absence of literature describing sequences of beaver ponds or their patterns of sedimentation.

Beaver pond influences on biodiversity and landscape ecology

Beaver ponds increase structural diversity of vegetation, as well as overall species biodiversity (Anonymous 1997). Barnes and Dibble (1988) discuss changes in tree species due to beaver along the lower Chippewa River in west central Wisconsin. As the water table rises, trees surrounding the pond become waterlogged and die, while shrub vegetation increases (Mitchell and Niering 1993). Citing the importance of seedbanks in plant community dynamics, Le Page and Keddy (1998) document seedbank species richness in beaver ponds in Gatieneau Park, Quebec.

Stock and Schlosser (1991) document changes in fish and aquatic insect diversity before and after a catastrophic collapse of an upstream beaver dam on Gould Creek near Lake Itasca, Minnesota. Snodgrass and Meffe (1998) conclude that beaver ponds increase species richness and that the pattern of beaver pond establishment and abandonment is necessary for the maintenance of this diversity. France (1997) demonstrates that richness and abundance of ten benthic macroinvertebrate taxa, fish and amphibians increases near beaver lodges in the boreal headwater lakes of northwestern Ontario. Apple et al. (1985) report an increase in avian species of twenty percent following beaver reintroduction and pond-building in Wyoming.

While species-diversity studies usually focus on the scale of a single pond, landscape ecology studies usually cover a much larger area. Recent work on the spatial dynamics of beaver ponds takes advantage of Geographical Information Systems. Johnston and Naiman (1990a) use a GIS based on historical maps to spatially analyze the recolonization of Voyageurs National Park, Minnesota over a 46-year history. Similarly, Townsend and Butler (1996) document the increase in beaver activity in the Roanoke River floodplain of eastern North Carolina following the transfer of lands into conservation ownership.

Dam density can vary over time as a reflection of population levels (Peterson 1999), and over space as reflected in different habitat types. Naiman et al. (1986) report densities of 8.6-16.0 dams per kilometer in Quebec.

Butler and Malanson (1994, 78) state that beaver ponds represent "an example of complex process-response landscape development". By building dams, beavers create patches of habitat and increase landscape heterogeneity (Johnston and Naiman 1990b, Snodgrass 1997). Remillard et al. (1987, 112) studied vegetation succession around beaver ponds in the Adirondacks, and concludes "successional stage replacement related to beaver activity is multidirectional and nonlinear."

Understanding the impacts of beaver and other animals on river ecosystems is important to consider in improving conservation management (Naiman and Rogers 1997). Through their impact on nutrient cycling (Webster et al. 1975 cited in Naiman et al. 1988) and spatial heterogeneity (Reichle et al. 1975), beaver ponds may increase a stream system's resistance to disturbance (Naiman et al. 1986, Naiman et al. 1988).

This study, while focused on the scale of the pond or pond sequence, can also be viewed in terms of the landscape. The pond sequences I examine in this study may impact not only the downstream hydrology and geomorphology, but also the flood plain adjacent to the ponds. Few landscape-scale studies of beaver ponds mention beaver-pond sequences specifically. My research will provide information that could be integrated into future landscape-scale studies.

CHAPTER III

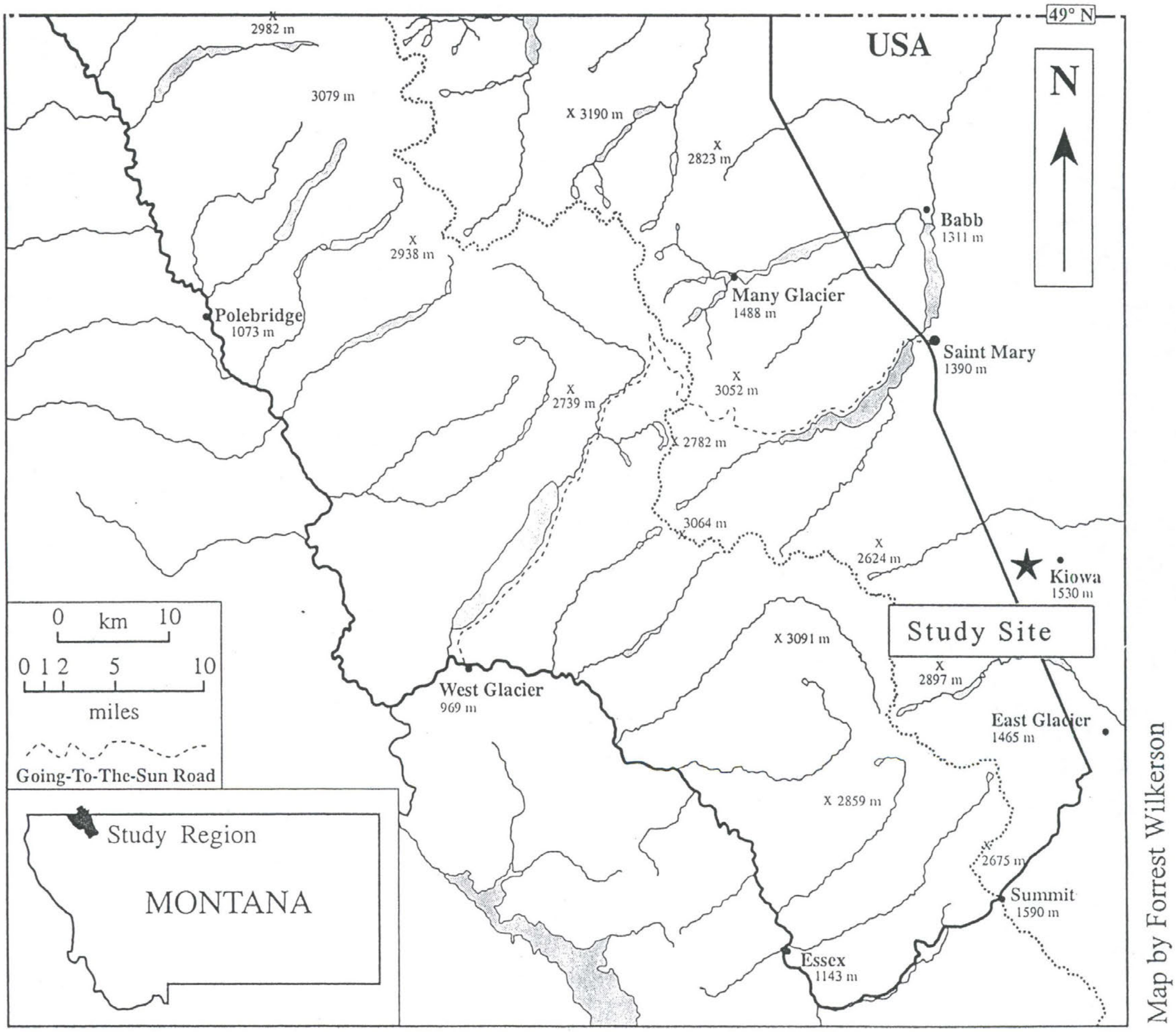
STUDY AREA

With jagged peaks carved by Pleistocene glaciers, the northern Rocky Mountains dominate the landscape of northwestern Montana. Elevations range from over 3000m along the Continental Divide to 1000m in the glacial valleys. Many of the glacial valleys along the eastern slope are oriented southwest-northeast. Valley floors consist of unsorted glacial till deposited as ground morraine, and valley slopes are modified through slumping.

The orientation and relief of the Rocky Mountains is a major controller of climate. The Continental Divide catches much, but not all, of the precipitation carried east by moist maritime air masses. Snowfall ranges from 75 centimeters in West Glacier, to 2000-2500 centimeters along the Continental Divide, to 65 centimeters in Saint Mary (Rockwell 1995). The eastern slope is dominated by dry continental air masses. In the winter, Arctic air masses rush southward, lowering temperatures to –40° to -45°C. Chinooks, winds that spill west over the Divide and heat through compression, rush down the mountain slopes and cause 17°-22° C increases in temperatures.

The foothills represent a transition zone between the high mountain peaks of the Continental Divide and the northwestern Great Plains. Glacier National Park's eastern border is roughly aligns with the westernmost extent of the foothills (figure 2). This transition zone, or ecotone, provides for the movement of water and materials within the larger landscape. Like other ecotones, the foothills represent the edge of ranges for a

Figure 2: Location map of Glacier National Park

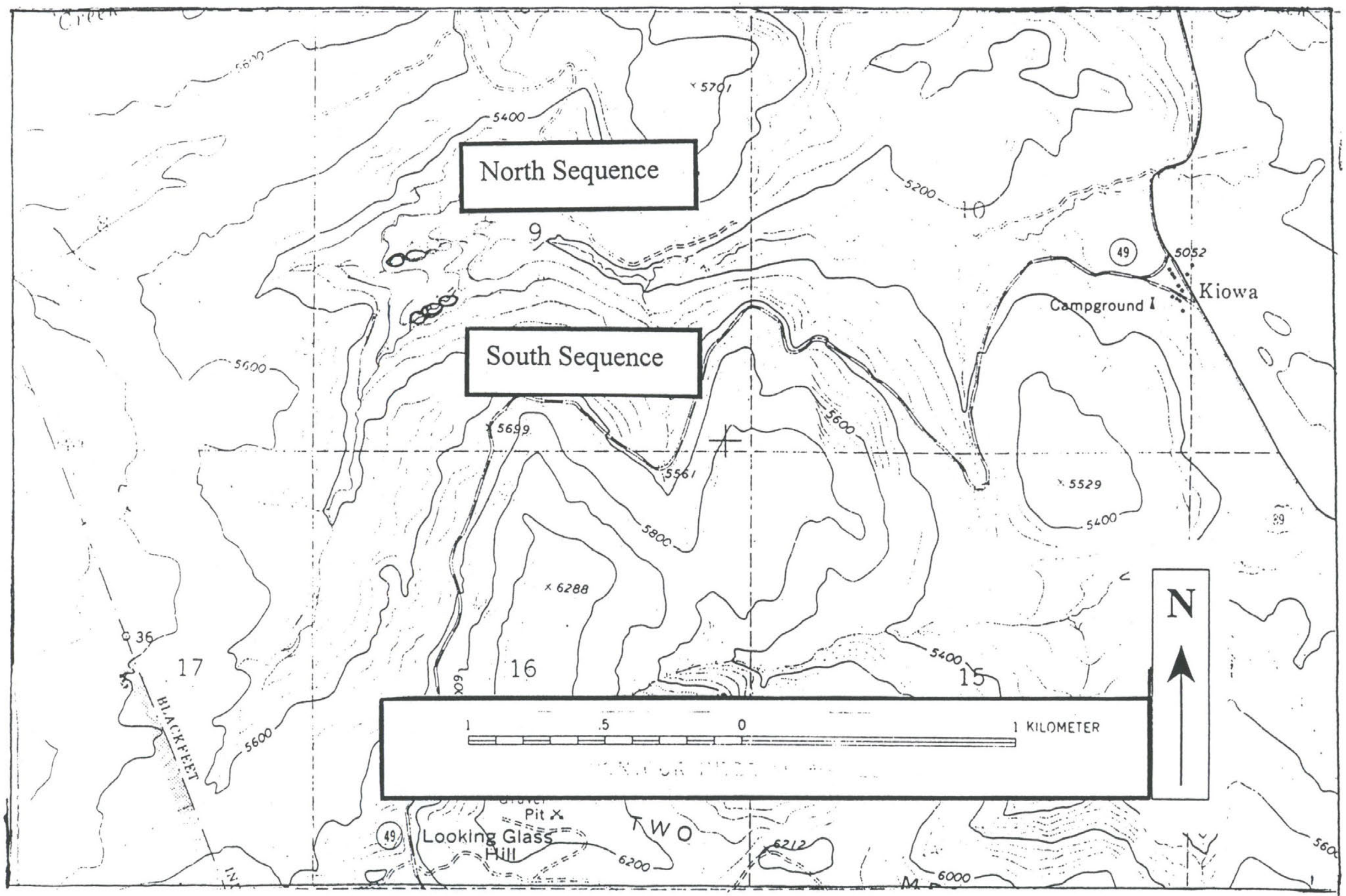


variety of species and thus is a region of high biodiversity. Habitats comprising the foothills' aspen parklands biotic community include patches of coniferous woodlands, grasslands, brushy thickets and aspen groves (Rockwell 1995). In addition to beaver, these diverse habitats support a variety of wildlife including elk, grizzly bears, wolves, moose, lynx, coyotes, weasels, grouse, bald eagles, wolverines, martens and badgers. Until they recently recolonized the area, gray wolves were the only missing member of the pre-European settlement predator assemblage. The east-west orientation of the major river valleys provides important wildlife movement corridors (Glacier National Park 1999).

The study site for this investigation consists of two tributaries of Lake Creek that flow roughly west-east through the foothills (figure 3). Their headwaters lie within Glacier National Park, and flow onto the Blackfeet Indian Reservation where they are impounded by sequences of beaver dams. Stream bed material consists primarily of gravel and cobbles in free-flowing reaches. The streams are fed by snowmelt from the east face of Spot Mountain and supplemented by spring flow. The northern sequence consists of seven ponds; most of which are small and relatively young as evidenced by new dam construction. The southern sequence also consists of seven ponds, which are larger and older than those in the north sequence.

Beaver ponds are conspicuous elements of the foothills landscape. Rockwell (1995, 77) states "In the parklands, you can consider anything within 500 feet [150m] of a stream to be good beaver habitat." Presumably beavers have been active along area streams for a long time, although their population density around the turn of the century is unclear.

Figure 3: North and south sequences along Lake Creek.



USGS 7.5 Minute Series Topographic Map, Kiowa Quadrangle

When most of the western United States was trapped out for beaver, this area may have provided a refugium for remaining beaver for two reasons. First, the Blackfeet Indians vigorously guarded their territory against white traders (Graves 1994). Beals (1957, 5) states: "even the sturdiest of the Mountain Men left the Glacier Region to the brave Blackfeet. It remained an island through much of the fur period." Secondly, the Blackfeet religion fostered a need to protect the beavers because they figure prominently in their creation myths (Wissler and Duvall 1995, McClintock 1999, Dragonfly 1999, Carlson 1999). Some modern Blackfeet maintain the cultural belief that harming the beaver, or even talking about the beaver within earshot of the animal, is an action that could bring them harm (Carlson 1999, Ground 1999). Carlson (1999) commented that the Blackfeet only rarely, and then reluctantly, traded beaver skins to the white fur traders. These conversations would indicate that hunting pressure on the beavers was limited throughout historical times. While stationed at the Cut Bank Creek Ranger Station, Doris Huffine described seeing "lots of beaver" in the spring of 1928 (Fraley 1998, 99).

More recently, Meentemeyer and Butler (1995) conclude that based on studies of historical maps and aerial photography, beaver populations have remained stable in northeastern Glacier National Park from 1966 to 1991. Lechleitner (1955, 65) reports "recent estimates" of Glacier National Park beaver at approximately one thousand individuals, and states that they are quite common in the lower elevations of the park.

There is evidence, however, that people did trap beaver in the region around the turn of the century and trapping continues today. Blackfoot author Beverly Hungry Wolf (1982, 57) quotes her grandmother: "beaver tails are my favorite of these wild things.

You put the tail on a stick and roast it over an open fire." This anecdote indicates that not everyone held the same cultural reverence for the beaver. Buchholtz (1976) recounts naturalist George Bird Grinnell meeting Kutenai Indian beaver trappers camped between the St. Mary Lakes. Bailey Peterson, a local trapper, has trapped in the region since the mid-60s and he notes that beaver populations and dam density have both increased in the basin since that time in spite of continued harvesting (1999). Determining precise population densities over time is clearly problematic.

Local land uses potentially affects beaver populations, their ponds, and the hydrology of the streams (Trimble 1994). Although the headwaters of the streams lie within Glacier National Park, the boundary is largely unfenced and unmonitored. Cattle and horse grazing, as well as poaching of furbearers, regularly take place within park boundaries (Peterson 1999, Shay 1999, Smith 1999).

The Blackfeet Indian Reservation is comprised of a checkerboard of lands held in common, managed for the benefit of tribal members, and lands allotted to individual tribal members following the Dawes Act of 1887. Privately owned inholdings, such as the one through which Lake Creek flows, came about as allotted lands were sold or lost in tax sales (McFee 1972, Carlson 1981, Ground 1999). In general, reservation lands and private inholdings are managed with the primary goal of income production. Major land uses in the foothills are timber harvest, cattle ranching and limited oil and gas exploration. In most cases, land is either ranched by the owner or leased for grazing. The pastureland surrounding the Lake Creek beaver-pond sequences is heavily grazed with some evidence of cattle contributing directly to bank deterioration. This soil disturbance may result in higher rates of sedimentation compared to an undisturbed site.

I selected these two sequences because they are comparable to each other in climate, topography, discharge, land use, and lithology. Additionally, because there are no additional beaver ponds immediately upstream of either sequence, interpretations of sedimentation patterns can be made disregarding any influence upstream dams would have. Unlike other more complex sites I considered, the sequences are discrete and form linear chains of ponds. The study site is also easily accessible, and both watersheds are clearly visible from Looking Glass Overlook along Highway 49 which parallels the tributaries to the east.

CHAPTER IV

METHODS

I investigated the four research questions using a variety of methods as described below.

1. What are the morphological characteristics of beaver-pond sequences?

I documented the morphology of the two Lake Creek beaver-pond sequences through photographs and qualitative descriptions of each pond and dam. I measured each pond's length and width, and determined the difference in water surface elevation of adjacent ponds with a measuring tape. I illustrated the quantitative data through planimetric maps and longitudinal profiles of each sequence.

2. What is the spatial distribution of sediment texture within individual ponds?

I sought to determine if there are longitudinal or lateral patterns of sediment deposition within ponds. To describe these patterns, I collected approximately ten equally spaced sediment cores per pond. In some instances I was able to extract sediment cores using a soil probe. In some locations overhanging vegetation or extreme water depth precluded the use of the soil probe, so I collected grab bag samples instead. I documented the location of each sample with a field-drawn map. Using the La Motte Soil Texture Unit, I determined the percentage of sand, silt, and clay for each sample. Next, I classified longitudinal samples as "head," "middle," or "foot." I ran a one-way ANOVA to analyze the data for relationships between each class of sediment texture and location class. Similarly, I classified samples as "thalweg," "intermediate," or "margin" to determine lateral patterns. I then ran a one-way ANOVA to determine if lateral patterns of sediment emerged.

3. What is the spatial distribution of sediment textures within a pond sequence?

Using the Pearson correlation coefficient, I further analyzed the data collected in step two to determine if there is a relationship between sediment texture and distance from the head of each sequence.

4. Is the quantity of sediment related to apparent dam age?

I measured sediment depths at approximately thirty evenly spaced locations within each pond. Pond age was approximated in the field by examining willow growth along the dam. Ponds were classified as either "young" if they supported no willow growth or "old." if willows grew on the dam. I calculated the mean depth of sediment for each pond, and ran a t-test for equality of means between young and old ponds.

CHAPTER V

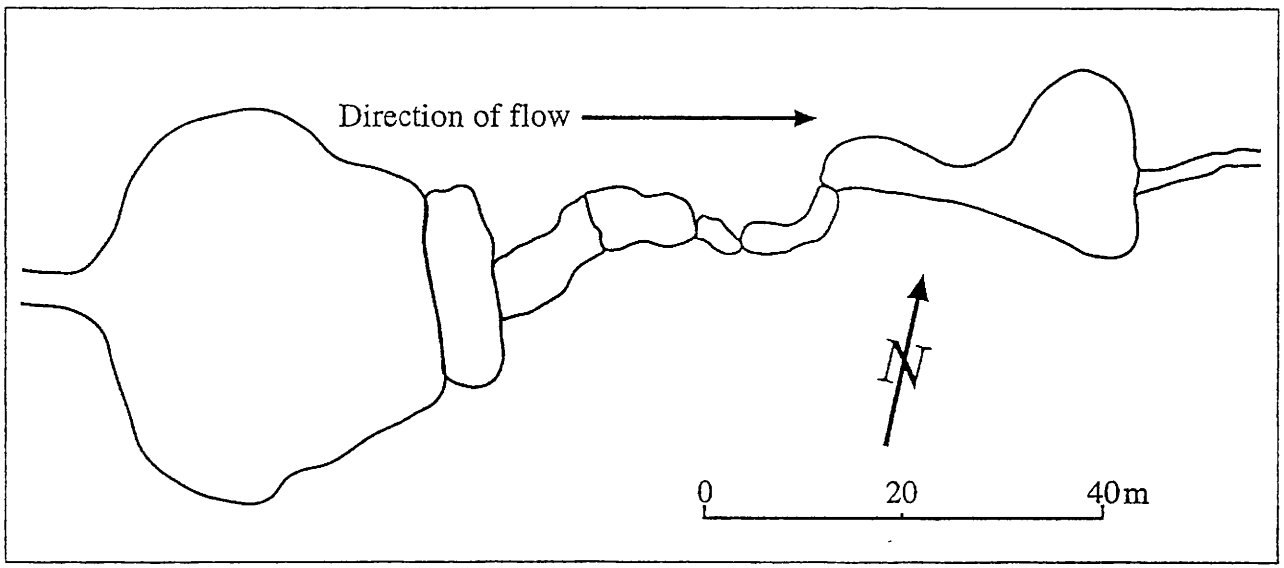
RESULTS AND ANALYSIS

1. What are the morphological characteristics of beaver-pond sequences?

I examined two beaver-pond sequences, each consisting of seven ponds, along two tributaries of Lake Creek in July 1999 (Figure 3). The north sequence is 108m long, while the south sequence has a total length of 141m. Planimetric maps (Figures 4 and 5) show the shapes and relative sizes of the ponds within each sequence. Maps are redrawn from field notes. Most ponds are surrounded by dense willow brush and marshy areas, which made determining the pond margin difficult. For mapping and measurement purposes, I defined the pond margin as bordering open water without vegetation. Flowing water, however, can extend past this defined boundary into the wetlands that surround the pond. The dams provided the clearest margins to map, while small ponds surrounded by brush growth were the most difficult to delineate. I defined the upstream margin of the head ponds in each sequence as the line where stream flow became imperceptible as it enters the pond. Because dense vegetation made direct measurement of ponds difficult and crossing the dams was hazardous, most dimensions are visual estimates.

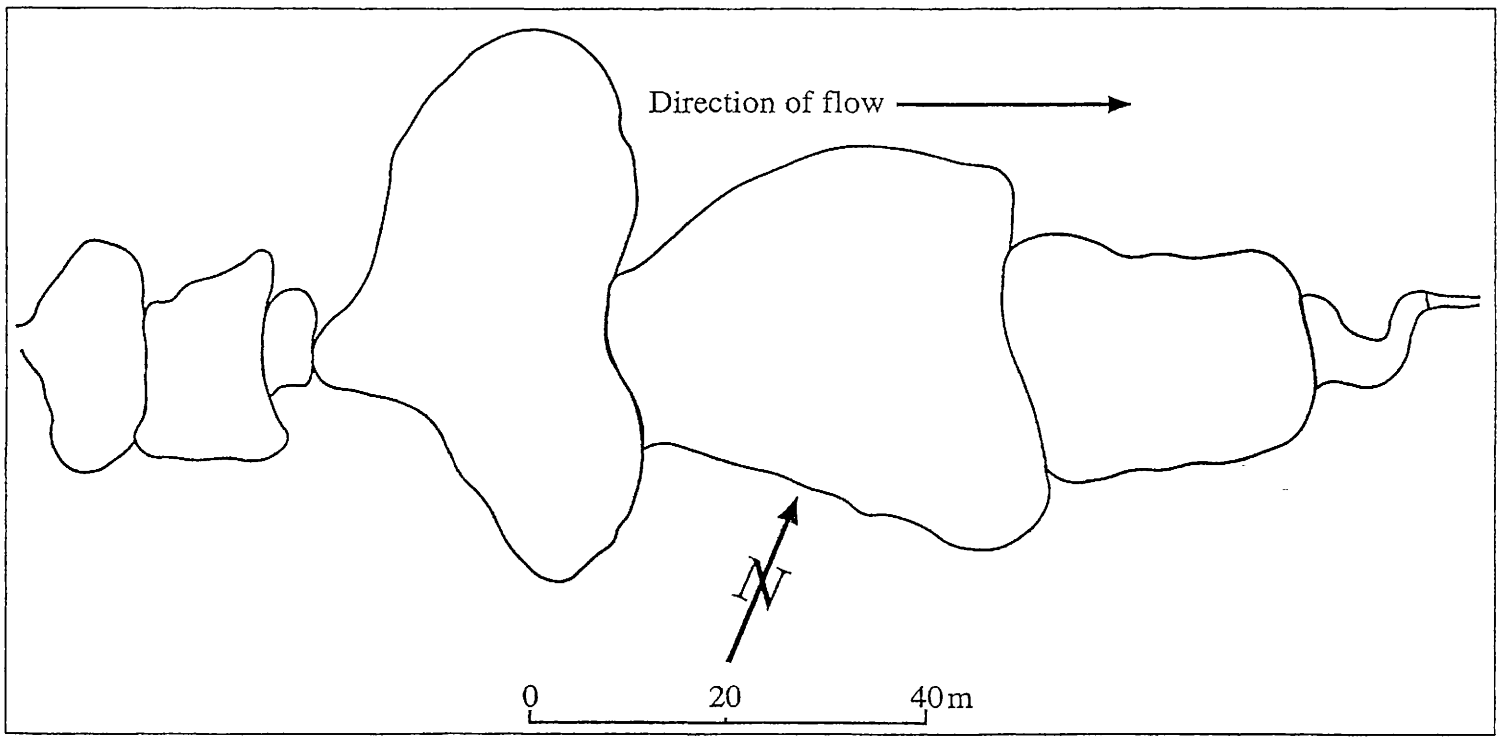
Tables 1 and 2 summarize pond descriptions and measurements for each pond. Freshly cut twigs and logs are characterized by a moist, greenish color to the wood. In some cases of very recent work, unwilted leaves were still attached to dam material. Older material is often dry and cracked, with the oldest logs weathering to a light gray.

Figure 4: North sequence planimetric map.



Map by Kris Norman

Figure 5: South sequence planimetric map.



Map by Kris Norman

Table 1: North sequence ponds (ponds numbered in sequence from upstream to downstream).

Pond	Dimensions (length x width) m	Pond characteristics	Dam characteristics
1	35 x 15	Head and north margin vegetated with brush	2m willows growing in dam, recent repairs
2	6 x 6	Thick willow growth on all banks	Small (1m wide), unstable dam, entirely comprised of recent cuttings. No vegetation growing in dam.
3	10 x 6	Thick willow growth along banks; recently drowned vegetation	Fresh cuttings, recent mud in dam. No vegetation growing in dam.
4	12 x 3	Thick willow growth along banks	Recent work. No vegetation growing in dam.
5	6 x 4	Thick willow growth along banks, drowned tree.	Small (1.5m wide), unstable dam. No vegetation growing in dam.
6	9 x 1.5	Thick willow growth along banks	Small (1m wide), unstable dam. No vegetation growing in dam.
7	30 x 6	Long, sinuous pond surrounded by thick willow growth.	Recent dam. No vegetation growing in dam.

Table 2: South sequence ponds (Ponds numbered in sequence from upstream to downstream).

Pond	Dimensions (length x width) m	Pond characteristics	Dam characteristics
1	25 x 12	Eight drowned trees at center of pond. Well-defined banks grassy with conifers along south margin.	Young willow growing in dam, no sign of recent repair, dam very stable.
2	20 x 12	Willows and other wetland vegetation growing into the pond especially along south margin.	Willow growth, recent mud repairs to dam, very stable.
3	10 x 5	Willows growing into pond along northwest margin. Drowned tree near dam.	Young willow growth, very stable, old logs.
4	30 x 25	Willows and other wetland vegetation along north margin. Drowned trees along south bank.	2m willows growing along entire length of dam, recent mud repairs, very stable.
5	40 x 60	Drowned trees near center of pond; heavy willow vegetation along southeast margin.	1-2m willows growing along most of dam, very stable.
6	30 x 30	Drowned trees throughout pond, heavy vegetation along south margin	Recent mud repairs to dam, willows in dam.
7	12 x 12	Newly drowned vegetation including willow and timothy grass.	New construction.

In general, the north sequence consists of small ponds surrounded by dense willow growth (Figure 6). Construction on most of these dams is recent, and most of the dams do not appear stable (Figure 7). Instead of creating large impoundments for protection, these dams probably function to control water flow and provide safe foraging along a substantial length of the stream. Flow from pond to pond variously occurs through the entire dam (most often in newly constructed, weak dams), through one place towards the top of the dam (most of the older dams), or underneath the dam (some of the older dams).

In contrast, the dams in the south sequence are older, as evidenced by willow growth in the dams and the apparent age of the dam material itself (Figure 8). The ponds tend to be larger and deeper, and are partly surrounded by open grassy land (Figure 9). In both sequences, the ponds show a stair-stepped morphology with one pond immediately adjacent to, and lower than, the preceding pond. In each case, I measured the elevation differences between the water surfaces of sequential ponds with a measuring tape. Figure 10 shows the stair-stepped longitudinal profile of the beaver-pond sequences. Steps ranged in height from 20-240cm. Larger steps tended to be older, more stable dams, while the newest dams usually created smaller steps.

2. What is the spatial distribution of sediment texture within individual ponds?

I extracted eleven evenly spaced sediment cores from each pond, and mapped each core's location. I used a standard soil probe to extract sediment cores. Where the use of the probe was not possible because of deep water (south sequence pond 4) or overhanging vegetation (north sequence ponds), I took grab-bag samples using small

Figure 6: Dense willow growth typical of north sequence ponds.

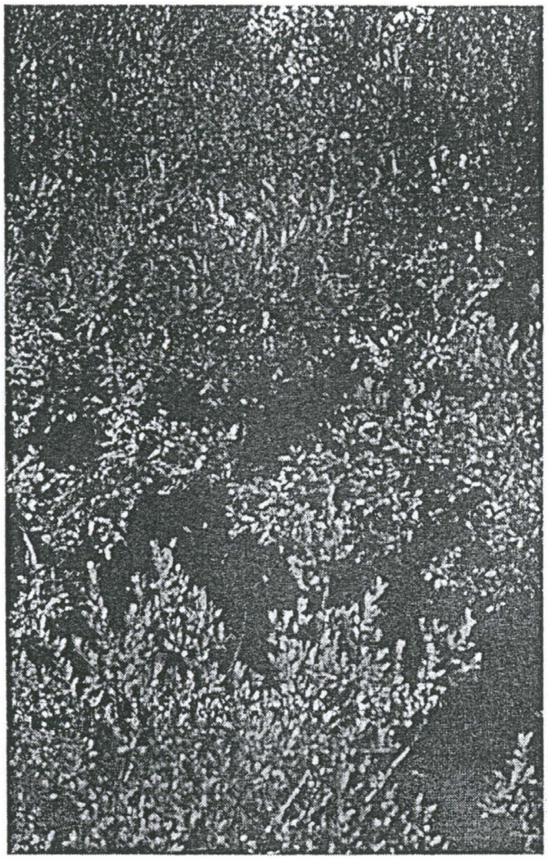


Figure 7: Typical recent dam in north sequence.

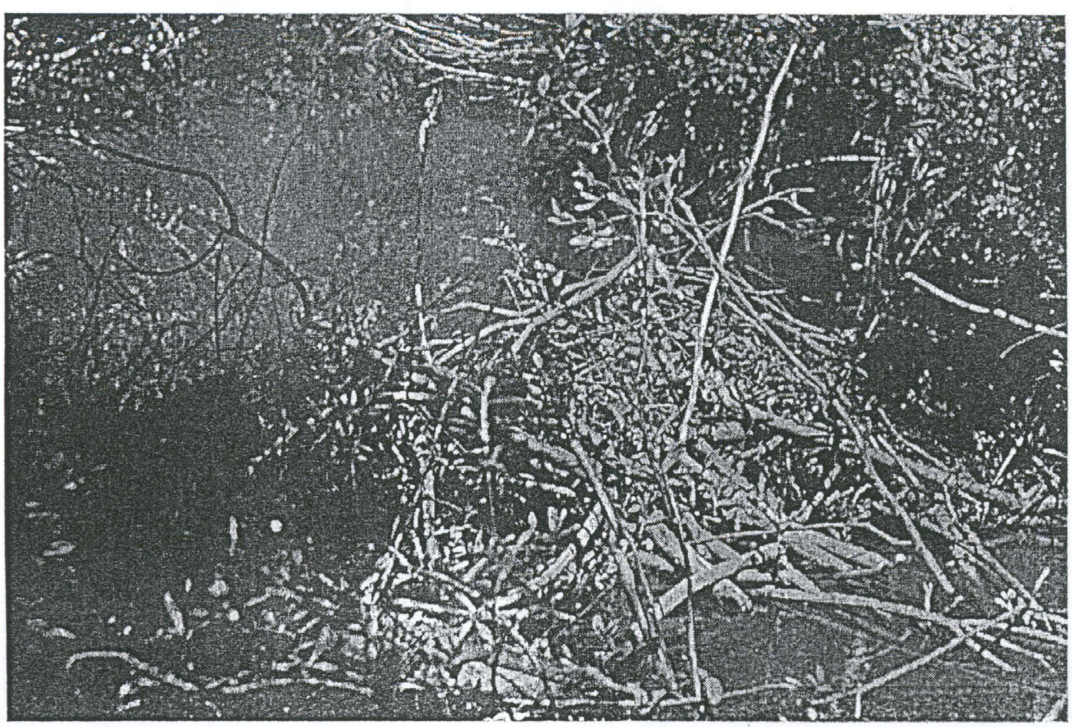


Figure 8: Older dam with 2m willows in south sequence.

Figure 9: South sequence pond flanked by relatively open grasslands.

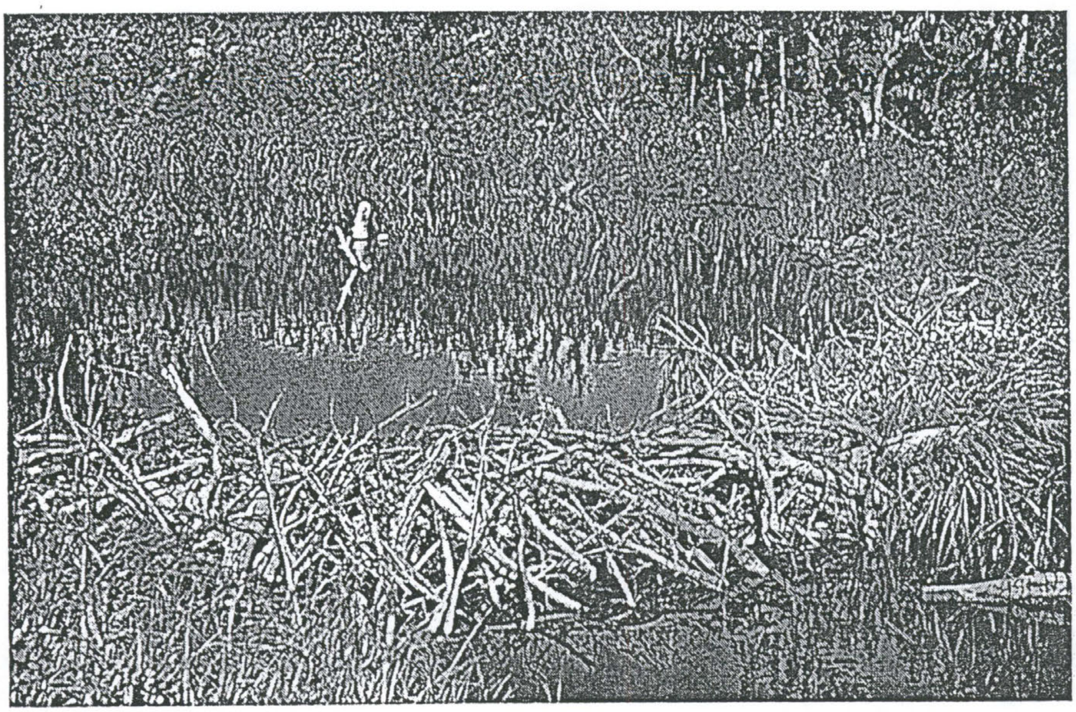
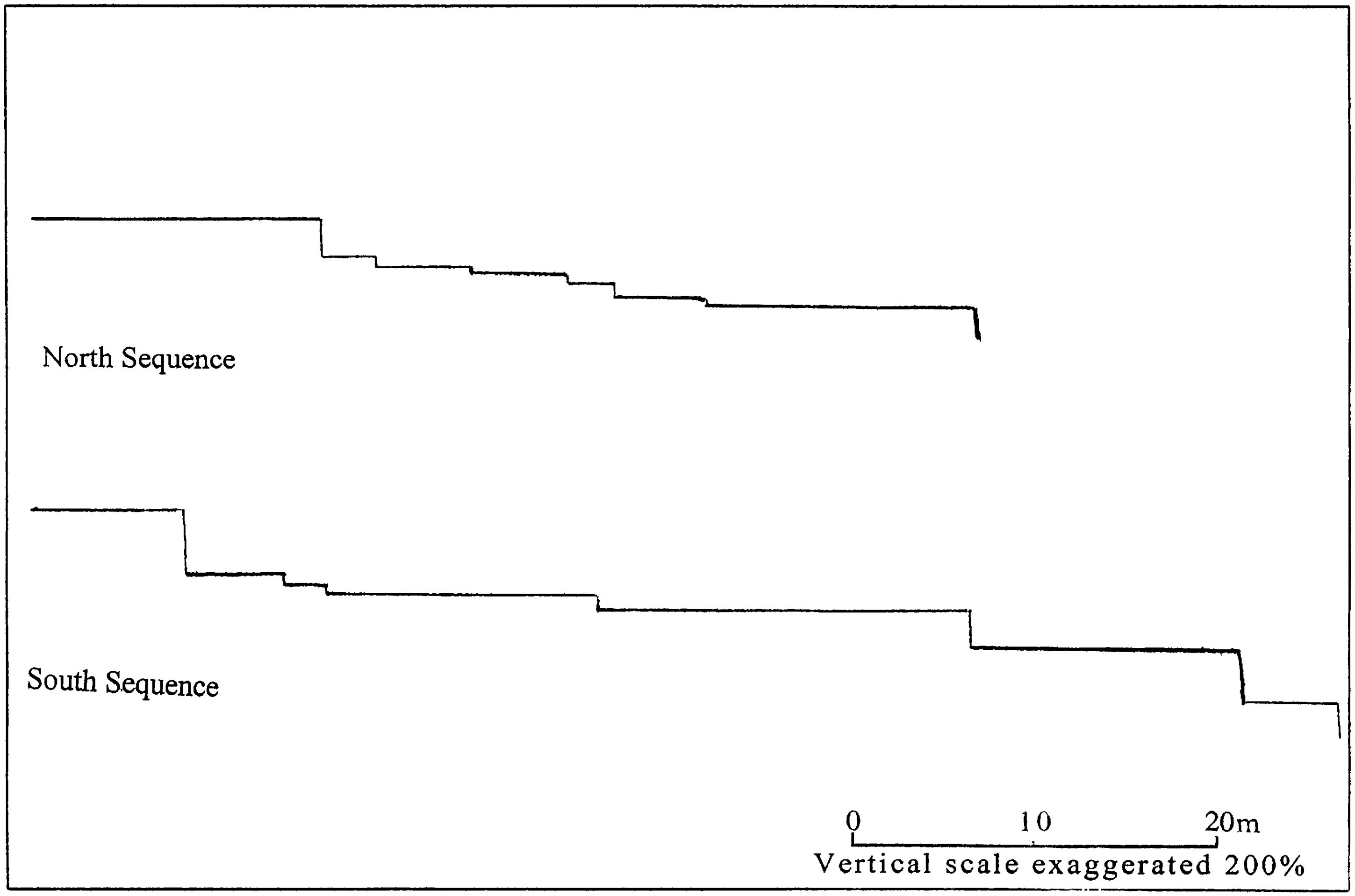


Figure 10: Longitudinal profiles of north and south sequences.



ANOVA using percentage sand as the variable, and found (p=.771) that there is no difference in sediment texture across a beaver pond. The data are displayed in Table A2 in the appendix.

3. What is the spatial distribution of sediment texture within pond sequences?

Using the texture data from question two, I plotted percent sand, silt, and clay versus distance from the head of the sequence for forty-two points (Figures 11, 12, and 13). I expected to find that the percentage of sand would decrease downstream, while the percentages of silt and clay would increase downstream. However, there were no discernable patterns. The Pearson correlation between percent sand and distance downstream was –0.087 (p=.583); for percent silt and distance downstream –0.027 (p=.867) and percent clay and distance 0.088 (p=.581). Thus, there is no statistically significant linear pattern of sedimentation within these beaver-pond sequences.

4. Is the quantity of sediment related to apparent dam age?

The classic model of beaver ponds and landscape evolution holds that beaver ponds gradually infill with sediment over time. Thus, I expected to find that ponds behind older dams contain more sediment than do ponds behind younger dams. Because of the small sample size (N=14 ponds), I divided the ponds into two categories. Young ponds are defined as having no vegetation growing in the dam, while old ponds have vegetation (typically willow) growing within the dam. In the north sequence, one pond was "old" and six were "young," while in the south sequence six ponds were "old" and one was "young," for a total of seven "young" and seven "old."

I used the average sediment depth as a proxy for the quantity of sediment present in each pond. Using an aluminum pole calibrated in ten-centimeter increments, a field assistant measured sediment depth as the maximum depth of penetration into the pond substrate. I assume that all of the material penetrated is sediment trapped by the existing dam, and that the underlying glacial till prevents further penetration of the measuring rod. We recorded thirty evenly spaced measurements per pond, except where small pond size limited the number of measurements. Table 3 shows descriptive statistics for sediment depths of each pond.

The high standard deviations indicate that sediment is not deposited evenly. This observation may be the result of uneven topography of the substrate, disturbance by cattle, changes in flow patterns over time, or a combination of factors.

I ran a t test for equality of means between the young and old ponds, and found that average sediment depth is greater in older ponds ($p<.05$). This result corroborates findings by Butler and Malanson (1995). By using historical maps and personal observation, they established age ranges for eight ponds. Plotting age vs. sediment volume, they found a statistically significant linear relationship with older ponds collecting larger sediment volumes.

Figure 11: Percentage of sand versus distance from head of sequence.

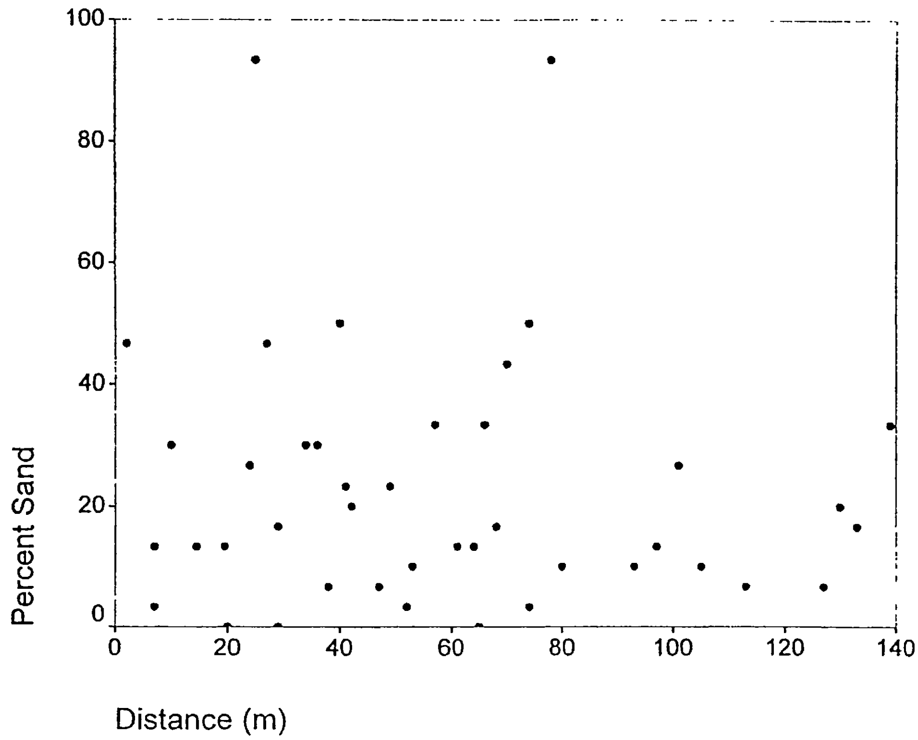


Figure 12: Percentage of silt versus distance from head of sequence.

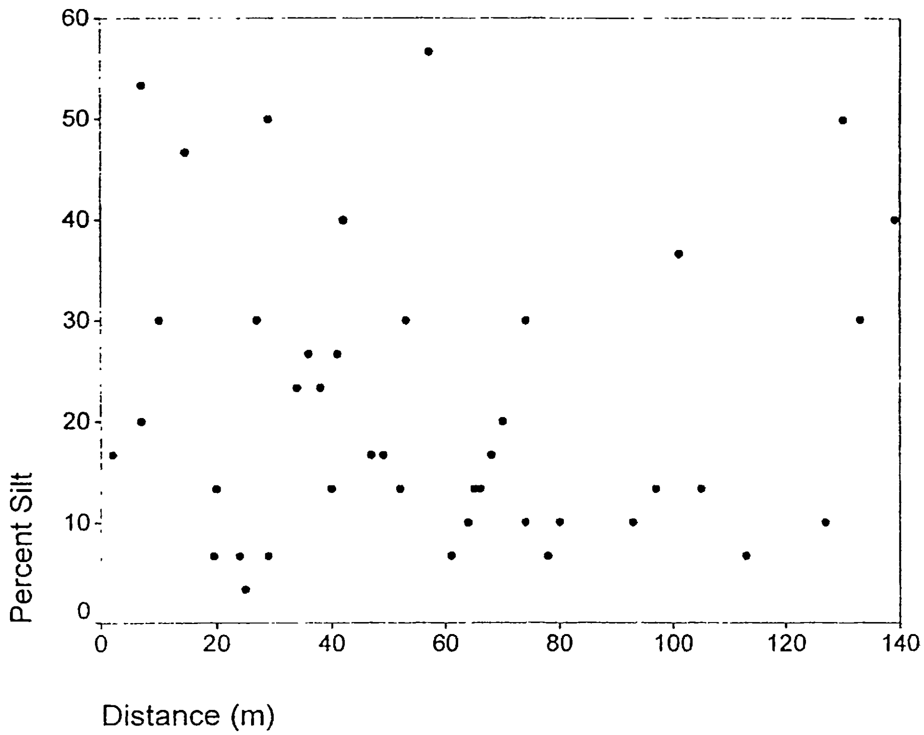
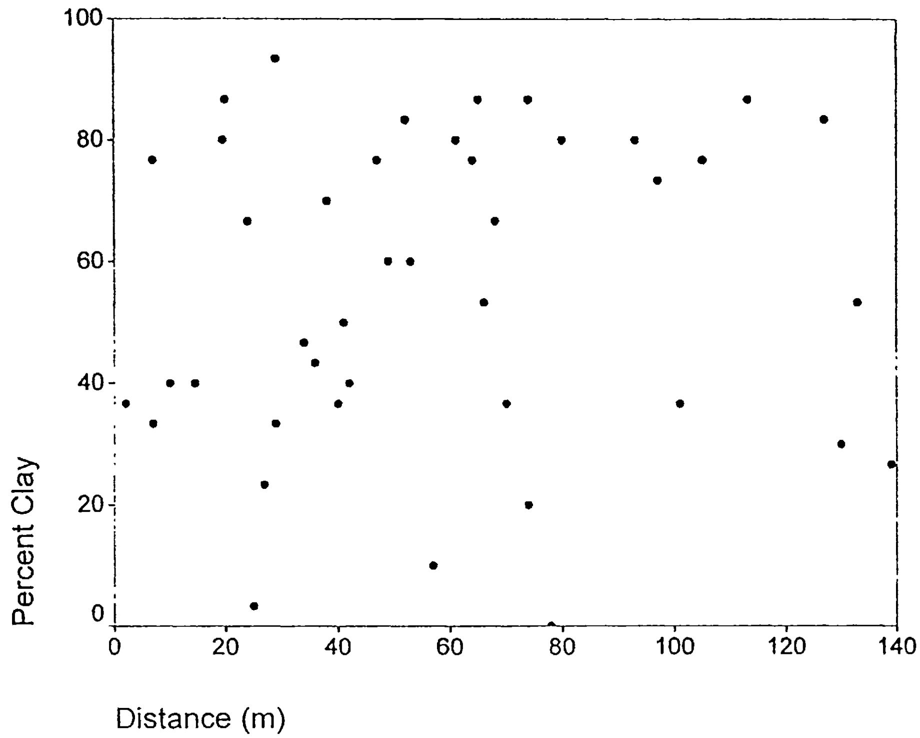


Figure 13: Percentage of clay versus distance from head of sequence.



I used the average sediment depth as a proxy for the quantity of sediment present in each pond. Using an aluminum pole calibrated in ten-centimeter increments, a field assistant measured sediment depth as the maximum depth of penetration into the pond substrate. I assume that all of the material penetrated is sediment trapped by the existing dam, and that the underlying glacial till prevents further penetration of the measuring rod. We recorded thirty evenly spaced measurements per pond, except where small pond size limited the number of measurements. Table 3 shows descriptive statistics for sediment depths of each pond.

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Table 3: Sediment depth descriptive statistics.

Pond Age	Pond sequence and number	Number of depth measurements	Minimum Depth (cm)	Maximum depth (cm)	Mean depth (cm)	Standard deviation
Young	North 2	28	1	70	23	16.3
Young	North 3	29	1	60	17	14.4
Young	North 4	30	1	60	19	13.9
Young	North 5	22	4	90	35	21.6
Young	North 6	22	0	36	8	8.0
Young	North 7	29	1	45	17	13.5
Young	South 7	31	0	63	12	18.1
All Young		191	0	90	19	15.1
Old	South 1	30	7	85	41	20.6
Old	South 2	30	10	106	45	25.8
Old	South 3	25	0	76	22	18.2
Old	South 4	29	10	85	41	22.2
Old	South 5	30	16	150	60	30.8
Old	South 6	30	0	115	56	27
Old	North 1	30	1	140	37	30.6
All Old		204	0	150	43	25.0

CHAPTER VI

CONCLUSION

This thesis represents a preliminary investigation of beaver-pond sequence form and function in mountain streams. I addressed my first research question, "What are the morphological characteristics of beaver-pond sequences?" by measuring two seven-pond sequences. Both sequences exhibited stair-step morphology with each pond lower than, and immediately adjacent to, the preceding pond. Steps ranged from 0.20-2.40m high, with ponds ranging in length from 6-40m long. In general, larger steps tended to be older and more stable than smaller steps.

My preliminary observations of these sequences lead to several questions for future research. These questions include:

1. Where do beaver pond sequences occur, and what factors (gradient, bank slope, stream flow, vegetation) influence their location?
2. How do beaver pond sequences affect stream flow in terms of channel roughness, and how does this change stream power?
3. Do terraced beaver ponds influence hyporheic flow differently than single beaver ponds?
4. How do beaver pond sequences moderate floods?

In terms of beaver-pond sequence function, I asked two questions: "What is the spatial distribution of sediment within individual ponds?" and "What is the spatial distribution of sediment within a sequence?" In both cases, I expected sediment to be sorted with finer particles deposited downstream. My analysis showed that there is no linear pattern for the distribution of sand, silt, or clay. I based my expectation of sorting on several assumptions: the stream flow was constant in magnitude and direction; sediment samples represent material transported from upstream; post-deposition disturbance was minimal; and that the samples I collected represented sediment collected with the present dam sequence in place. From my observations and those of others, beaver dams are not static structures. Flow through a dam can change in magnitude and direction on a frequent basis. Because beavers actively excavate canals and bank burrows within and adjacent to the pond, not all deposited sediment originates upstream. Cattle and other animals may wade into and across ponds, stirring up sediment. Finally, reconstructing the temporal history of a beaver-pond sequence is complicated because new dams are built and existing dams can be modified or washed out. The fact that the beaver-pond sediment was not deposited as predicted is valuable because it raises important questions. These include:

1) What are the dynamics of stream flow through a pond?
2) How does the sediment load of a stream differ upstream and downstream of a beaver-pond sequence?
3) What are the causes and extent of animal-induced disturbance in beaver-pond sediment?
4) How do beaver-pond sequences change spatially over time?

My final question, "Is the quantity of sediment related to apparent dam age?", yielded statistically significant results. I found that older dams collected deeper sediment than younger dams ($p<.05$). This conclusion corroborates findings from other investigations. Larger questions to pursue include:

1. How and where are stream profiles changed by beaver-pond sedimentation over long periods of time?
2. How does the accumulation of large amounts of sediment affect stream biogeochemistry and nutrient cycling within a watershed?
3. Are morphological studies of streams within the historic range of beavers interpreted with the consideration of beaver impacts?

Although beaver ponds are common, widespread stream features in much of North America, they have been largely overlooked in stream studies. Determining where and how beaver ponds influence mountain streams is not simple because beaver-pond sequences are temporally and spatially dynamic. I have provided an initial description and analysis of beaver-pond sequence form and function. By addressing the questions raised by this thesis, future researchers will gain a clearer understanding of mountain stream dynamics.

APPENDIX

Table A1: Longitudinal data used in ANOVA

Location within Pond	Pond	% Sand	% Silt	% Clay
Head	North 1	3.33	20	76.67
Head	North 2	30	26.67	36.67
Head	North 3	20	40	40
Head	North 4	3.33	13.33	83.33
Head	North 5	13.33	0	76.67
Head	North 6	43.33	20	36.67
Head	North 7	10	10	80
Head	South 1	46.67	16.67	36.67
Head	South 2	13.33	46.67	40
Head	South 3	93.33	3.33	3.33
Head	South 4	30	23.33	46.67
Head	South 5	0	13.33	86.67
Head	South 6	26.67	36.67	36.67
Head	South 7	20	50	30
Middle	North 1	0	13.33	86.67
Middle	North 2	6.67	23.33	70
Middle	North 3	6.67	16.67	76.67
Middle	North 4	33.33	56.67	10
Middle	North 5	333.33	13.33	53.33
Middle	North 6	50	30	20
Middle	North 7	10	10	80
Middle	South 1	13.33	53.33	33.33
Middle	South 2	13.33	6.67	80
Middle	South 3	46.67	30	23.33
Middle	South 4	23.33	26.67	50
Middle	South 5	3.33	10	86.67
Middle	South 6	6.67	6.67	86.67
Middle	South 7	16.67	30	53.33
Foot	North 1	0	6.67	93.33
Foot	North 2	50	13.33	36.67
Foot	North 3	23.33	16.67	60
Foot	North 4	13.33	6.67	80
Foot	North 5	16.67	16.67	66.67
Foot	North 6	93.33	6.67	0
Foot	North 7	10	13.33	76.67
Foot	South 1	30	30	40
Foot	South 2	26.67	6.67	66.67
Foot	South 3	16.67	50	33.33
Foot	South 4	10	30	60
Foot	South 5	13.33	13.33	73.33
Foot	South 6	6.67	10	83.33
Foot	South 7	33.33	40	26.67

Table A2: Lateral data used in ANOVA

Location within Pond	Pond	% Sand	% Silt	% Clay
Thalweg A	North 1	0	13.33	86.67
Thalweg B	North 1	40	46.67	13.33
Thalweg A	South 1	13.33	53.33	33.33
Thalweg B	South 1	20	53.33	26.67
Thalweg A	South 2	13.33	6.67	80
Thalweg B	South 2	3.33	10	86.67
Thalweg A	South 3	46.67	30	23.33
Thalweg B	South 3	6.67	10	83.33
Thalweg A	South 4	23.33	26.67	50
Thalweg B	South 4	23.33	26.67	50
Thalweg A	South 5	3.33	10.27	86.67
Thalweg B	South 5	3.33	3.33	93.33
Thalweg A	South 6	6.67	6.67	86.67
Thalweg B	South 6	6.67	6.67	86.67
Intermediate A	North 1	3.33	6.67	90
Intermediate B	North 1	23.33	40.00	36.67
Intermediate A	South 1	10	6.67	83.33
Intermediate B	South 1	10	50	40
Intermediate A	South 2	6.67	20	73.33
Intermediate B	South 2	23.33	6.67	70
Intermediate A	South 3	53.33	23.33	23.33
Intermediate B	South 3	10	40	50
Intermediate A	South 4	23.33	36.67	40
Intermediate B	South 4	16.67	26.67	56.67
Intermediate A	South 5	3.33	20	76.67
Intermediate B	South 5	13.33	6.67	80
Intermediate A	South 6	3.33	6.67	90
Intermediate B	South 6	30.00	60	10
Margin A	North 1	13.33	10	76.67
Margin B	North 1	0	20	80
Margin A	South 1	6.67	30	50
Margin B	South 1	26.67	23.33	50
Margin A	South 2	10	3.33	86.67
Margin B	South 2	13.33	30	56.67
Margin A	South 3	60	16.67	23.33
Margin B	South 3	13.33	13.33	73.33
Margin A	South 4	40	16.67	43.33
Margin B	South 4	26.67	23.33	50
Margin A	South 5	3.33	10	86.67
Margin B	South 5	36.67	30	33.33
Margin A	South 6	6.67	63.33	30
Margin B	South 6	0	33.33	50

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VITA

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