AN ABSTRACT OF THE THESIS OF

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Robert L. Beschta

Esmond Creek is a tributary to the Siuslaw River located in the Oregon Coast Range. It is 18 km in length and drains a watershed area is 48.9 km^2. Average channel gradient of the study reach is 0.9%. In 1988 a landslide occurred in the Esmond Creek watershed involving approximately 250,000 cubic yards of material, of which a small portion was delivered to Esmond Creek.

In 1984 and 1991 8% and 17.5%, respectively, of the study reach was influenced by beaver ponds. The effects of the landslide, log jams and beaver dams on channel morphology were assessed by comparing width and depth data collected in 1984 (pre-slide) to width and depth data collected in 1991 (post-slide). In addition, sediment samples were analyzed to investigate landslide, beaver-pond and log-jam influences on particle size distributions.

Field observations in 1991 indicate the longitudinal influence of observed sediment deposition from the landslide extended approximately 2.5 km downstream from the slide input. These field observations concurred with analysis of 1990 aerial photograph. Statistical analysis

revealed no changes in channel width and depth associated with the landslide. However, reaches in which major changes in channel width and depth had occurred were associated with the occurrence of beaver dams and ponds. In general, the presence of beaver ponds tends to increase channel width and depth.

Particle size analysis of sediment from floodplain, point-bar and channel-bed locations revealed localized decreases in the geometric mean diameter of particles due to the interaction between sediment input from the landslide and instream structures (e.g., beaver dams and log jams). The channel bed, typically a zone of sediment transportation, was altered by these structures to function as a zone of fine sediment deposition upstream from the structures.

Influence of Hillslope and Instream Processes
On Channel Morphology of Esmond Creek
In the Oregon Coast Range

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INTRODUCTION

Channel morphology is a function of the complex interaction between inherent basin qualities (e.g. lithology, climate) and hillslope, fluvial, riparian, and biological processes. Also important are extrinsic forces such as anthropogenic influences within the basin.

Particularly important to channel morphology are sediments derived from hillslopes. Hillslope erosional processes include rill, gully and sheet erosion, soil creep, debris slides, torrents, and earthflows. In forested watersheds of the Pacific Northwest, sediment delivery to the stream channel is dominated by mass soil movements. Much less significant are surficial processes, such as those generated by overland flow (Swanson et al., 1987). This is due, in part, to high infiltration rates, dense canopy cover, and low intensity precipitation events (Harr, 1976).

Increased frequency and magnitude of mass soil movements on managed basins as apposed to undisturbed basins (Swanson et al., 1987) has increased interest in what mechanisms trigger these failures and how they might be related to management practices. Direct and indirect changes in channel morphology may be a manifestation of altered frequencies and magnitude of mass soil movements.

Studies at the H.J. Andrews Experimental Forest in the Oregon Cascades showed that the natural occurrence of mass failures in watersheds overshadows treatment effects directly related to logging. Thus, hillslope processes involving mass movements dominated the sediment budget, and mass-failure-related impacts persisted long after the event took place (Grant and Wolff, 1991).

The importance of understanding landslide impacts on stream channel morphology lies in the dominance of landslides on the sediment budget, the time over which impacts persist, and the intimate relationship between channel morphology and fish habitat. Life cycles of salmonids are adapted to spacial and temporal variability of their freshwater habitat (Sullivan et al., 1987). This variability is largely controlled by channel morphology and structural control. Complexity of habitat is afforded by roots, large woody debris, boulders, undercut banks, and side-channel pools, and functions to provide low velocity refuge sites for fish (Sullivan et al., 1987).

Combinations of channel units described as pools, riffles, runs, and cascades provide salmonids with spawning and rearing habitat. Changes in the sediment transport regime can alter quality and quantity of fish habitat. For example, increased proportions of fine sediment may decrease intragravel flow resulting in lower availability of dissolved oxygen to embryos and emerging fry (Everest et al., 1987). Pool numbers and depth can also be reduced when availability of sediment exceeds capability of the stream to transport the material. Aggradation of stream channels, in combination with a loss of complexity due to removal of large woody debris and decrease in large woody debris recruitment over time, can result in morphological changes which negatively affect salmonid habitat.

Beaver (*Castor canadensis*) are a source of natural alteration to stream systems that can further modify instream processes as well as the dynamics of adjacent riparian areas. Beaver activities alter hydrology, channel morphology and the transport of nutrients and sediment. Increased channel complexity and nutrient cycling afforded by beaver activity, augment the ability of a stream system to recover and/or resist perturbations and disturbances (Naiman and Melillo, and Hobbie, 1986).

OBJECTIVES

The purpose of this study was to evaluate channel morphology responses to landslide-delivered sediment. The influence of beaver ponds and large woody debris was also investigated.

Specific objectives include the following:

(1) Evaluate channel morphology in relation to the occurrence of a landslide into Esmond Creek;

(2) Evaluate the extent to which beaver dams and large woody debris influence channel morphogenesis; and

(3) Evaluate instream particle size distributions in relation to the landslide.

The first objective involved comparing channel morphology data from 1984 to data collected in 1991 after the 1988 landslide. Inherent in this investigation is an assessment of sediment input throughout the basin prior to data collection. Aerial photographs from 1979 and 1990 were utilized to establish a recent historical perspective. The second objective included an assessment of channel morphology influenced by beaver dams and log jams.

A particle size analysis was utilized to evaluate landslide influence on particle size composition of channel-bed, flood-plain and point-bar locations. The modification of trends in particle size distributions with respect to beaver ponds and log jams was also examined.

LITERATURE REVIEW

Channel morphology characteristics need to be considered in the context of their longitudinal distribution. Typically, changes in channel characteristics that occur in a downstream direction have been associated with increasing discharge, velocity, depth and width (Leopold and Maddock, 1953; Leopold, 1971). Such studies are based on the assumption that all sections of the channel are experiencing discharge of equal frequencies (Leopold, 1971). Leopold maintains that a discharge relationship is useful when analyzing channel changes which take place over a long period of time. Assessment of changes in channel morphology which occur over a short period of time may be related to other factors.

Since discharge is generally proportionate to basin area, it is reasonable to consider basin area in relation to channel form variables (Hack, 1957; Leopold and Bull, 1979). This technique, referred to as spatial interpolation, was used to analyze changes in channel morphology downstream from reservoirs and urban areas (Gregory and Park, 1974; Park, 1977). The relationship between basin area and channel-form variables was the basis for interpolation of probable channel dimensions below the site, had the activity not taken place. The result was a regression of a channel-geometry variable versus basin area. Deviations from the fitted line indicated a change in the relationship between basin area and channel geometry. Park (1977) maintains that if parameters which control channel morphology are modified, such as sediment transport, then channel changes will inevitably take place.

Changes in channel morphology in response to landslide-delivered sediment include decreases in pool-riffle ratios (i.e., where riffles are longer and more common than pools) and shifts in hydraulic conditions which control sediment transport and streambank erosion (Lisle, 1982; Hogan, 1986; Tripp and Poulin, 1986; Roberts, 1987). Different modes of water and sediment delivery to channels produce differing channel responses. However, common to most sediment supply mechanisms is a widening or enlargement of the channel (Grant et al., 1984). The extent to which these changes occur and persist can be modified by structural control. It is convenient to address reported changes in channel morphology under the categories of channel form, bed material, and structural control.

Channel Form

Channel form may be altered by increased sediment load in a number of ways. Studies have analyzed variables such as channel width, depth, roughness, sinuosity, slope, elevation, constriction, and channel unit sequences.

The effects of sediment availability and streamside landuse may exert a greater influence on channel morphology than possible flow changes brought about by management. Wide shallow stream channels can result from increased sediment loads, increased flow, decreased riparian vegetation, and mechanical damage. Beschta and Platts (1986) indicate increased sediment availability and transport may also lead to decreased sinuosity, decreased depth, and a loss of pools.

Changes in channel width and sinuosity of the Upper Middle Fork of the Willamette River were assessed in relation to landuse, floods, and mass failures (Lyons and Beschta, 1983). Increased channel width was a function of aggradation from mass failure-related sediment yield, rather than a direct response to peak flows.

Although channel dimensions depend upon a number of variables, discharge and sediment characteristics and availability have an important role. Since channel width increases faster than channel depth as flow increases, the width-to-depth (width/depth) ratio is expected to increase in a downstream direction (Richards, 1982). However, if bank stability increases in a downstream direction due to change in perimeter sediment composition of the stream banks, then depth may increase faster than width (Schumm, 1960, 1971). Schumm developed a conceptual model in which width/depth ratio, channel gradient and channel wavelength were directly proportionate to bedload discharge (Q_s), while channel sinuosity was inversely proportionate. Mean annual discharge (Q_w) was directly proportionate to width, depth, channel wavelength, and inversely related to channel slope. Thus, Schumm classified streams as either degrading or aggrading based on width/depth ratio, bank material and sinuosity.

Width/depth ratios may index channel stability and sediment transport regime. This was depicted qualitatively by Leopold and Maddock (1953) based on an empirical diagram derived from width, depth, velocity and suspended sediment data for several streams at a fixed discharge. The capability of the streams to carry a given load at the fixed discharge varied with velocity and channel form. For example, a wide shallow channel and a narrow deep channel may be capable of transporting the same volume of sediment. Furthermore, the banks of a wide shallow channel may be less stable than a narrow deep channel.

A change in channel slope may reflect an adjustment of the stream to accommodate a change in sediment load. However, appreciable changes in slope were not found to accompany aggradation or degradation in a study done by Leopold and Bull (1979).

There is generally a close relationship between channel roughness and slope (Leopold and Bull, 1979). Changes in width and depth, and an accompanied increase in mean velocity can persist through time as a result of reduced channel roughness (Lisle 1982). Overall channel roughness, often characterized by a coefficient such as Manning's n, is significantly influenced by vegetation during high flows, a time when channel morphology changes resulting from bank erosion are most likely to occur. Variations in streambank vegetation are translated to instream channels. The diversity in channel morphology resulting from the direct and indirect influence of streamside vegetation ranks streamside vegetation as the most important, single factor influencing hydraulic roughness (Sedell and Beschta, 1991).

Channel units are used to describe individual bed features, the two most common of these being pools and riffles. Bison et al. (1982) developed a more detailed system of defining channel units which takes into account the high variability in configuration and hydraulic properties. Distributions of channel units within a given reach, reflect the quality and quantity of fish habitat, and the processes which influence channel morphology.

Grant et al. (1990) suggest a hierarchical framework with which to assess channel morphology. Morphological features, ranging from a single particle to channel reach, are ordered or ranked on the basis of length or scale of the feature. Channel units are emphasized as a particularly important feature or scale of variation within the hierarchy. Grant et al. maintain that channel unit formation can not be attributed to a single cause. For example, hillslope erosion promotes cascade-pool sequences when large particles are delivered, yet favors riffle formation in the absence of large particles. Furthermore, where sediment supply is high and channels wide, distinct channel units do not form. Channel unit formation requires a graded bedload (i.e., discharges capable of transport of the largest particles), low sediment supply, small width/depth ratios and irregular, resistant boundaries (Grant et al., 1990).

Pool-riffle relationships provide a means of assessing stability of a stream system over time. Lisle (1986) defines riffles as bar formations which extend the width of the stream. Such features, because of their size and mobility, are adjusted to long-term trends in sediment and hydraulic conditions. A stream system that is in equilibrium with sediment supply and transportation such that neither degradation nor aggradation takes place is said to be graded (Leopold et al., 1979). Under such conditions very little adjustment of channel morphology is required to accommodate changes in sediment supply, and the channel is considered stable.

Conditions under which aggradation or degradation take place have been described in terms of availability of sediment and capability of the stream to transport material. Periods of low sediment availability and high transport capability are accommodated by release of sediment from channel-bed and bank storage, while periods of high availability and low capability result in deposition in established storage sites (Benda, 1989). Bars remain stable throughout these adjustments unless excessive aggradation takes place (Lisle, 1982).

Diminished pool-riffle morphology may result from heavy sedimentation and aggradation of channels (Lisle, 1982; Hogan, 1986). In Northern California, Lisle (1982) evaluated 13 streams and found that channels widened as they aggraded, decreased in mean depth and increased in mean velocity. The morphological contrast between pools and riffles was diminished.

A comparison of logged, unlogged and debris torrented streams on the Queen Charlotte Islands, showed no significant changes in channel morphology between recently logged and unlogged watersheds (Hogan 1986). However, older logged and debris torrented streams showed significant reductions in pool-riffle ratios. Larger riffles and smaller pools resulted from pool filling and riffle building. Hogan concluded that the channel morphology changes found in the older logged watersheds were due to "old" logging methods such as logging to the channel banks and direct disturbance of the channel.

Channel units can also be used to describe fish habitat. Riffle utilization by fish is temporally dynamic and dependent on the species (Sullivan et al., 1987). All salmonids construct redds at the tails of pools where continuous source of high-quality, intragravel flow is assured. Intragravel flow maintains a clean substrate, high levels of dissolved oxygen, and removal of waste products, thus providing a good habitat for egg development and emerging fry. Riffles function as rearing habitat for steelhead, a less velocity-sensitive species than salmon. Riffles are also the most productive portion of the stream channel in terms of food generation (Sullivan et al., 1987). Older and larger fish occupy deeper sites, and thus depth and number of pools may be an important variable influencing rearing habitat for older fish.

Bed Material and Hydraulic Characteristics

Hydraulic characteristics can often be represented in terms of unit stream power. Unit stream power is defined as the time rate loss of potential energy per unit mass of water (Beschta and Platts, 1986). This concept provides a basis for understanding the erosive capability of flowing water in open channel systems and subsequently, potential removal rates of landslide-deposited sediment in streams (Swanson et al., 1985).

Rate of removal, or sediment transport depends not only on unit stream power, shear stress, and size of particles, but the "clast position within bed microforms" (Reid and Frostick, 1987). A change in the median particle size and/or distribution of bed material can influence frequency and magnitude of bedload transportation. For example, increased deposition of fines in the interstices of gravel bed material was found to increase the unit stream power needed to entrain and transport larger gravel particles. The result was a delay in bedload transport at higher flows (Reid et al., 1985). Thus, Reid (1987) emphasizes that bedload transport can not be described as a simple relationship dependent on increasing shear stress nor size of particles.

Sediment deposition and aggradation of stream channels in general has been found to cause dewatering of the channel during low flows (Hogan, 1986; Tripp and Poulin, 1986). Dewatering is likely to occur for longer periods and greater proportions of the channel in small streams. The effects of dewatering on fish include entrapment, increased predation, and increased competition as fish populations become more concentrated into remaining habitat (Tripp and Poulin, 1986).

A decrease in the geometric mean diameter of bed particles occurred as a result of aggradation of the Upper Middle Fork of the Willamette River (Lyons and Beschta, 1983). Increases in percent fines may negatively impact fisheries, by decreasing the quality of spawning gravels (Everest et al., 1987). Sedimentation can result in interstitial spaces of gravels being filled with fine sediment. This decreases intragravel flow and subsequently the exchange of waterborne oxygen and nutrients from the water column to the substrate in which redds are constructed. Laboratory studies indicate that this may decrease the survival and emergence of salmonid embryos and alevins, and growth of salmonid fry (Everest et al., 1987).

Everest et al. (1987) describe a paradox in which a system devoid of sediment is less productive at every trophic level than one in which large amounts of sediment are stored in a channel influenced by large woody debris. Thus, they maintain that "a more holistic view of the role of sediment in stream ecosystems is needed".

Lisle (1982) found that periods of extreme aggradation not only showed increased velocity, but that velocities during the post-aggradation period continued to be sustained above the pre-aggradation period. A change in hydraulic characteristics (e.g., increased velocity) coupled with a decrease in mean grain size, results in an increase of bedload transport for low to moderate discharges (Lisle, 1982). Thus "low-flow" bedload transport becomes more effective at influencing channel morphology and "it is reasonable to expect that bars formed at low stages are reasonably small in amplitude." Lisle found the riffle-like characteristics of aggraded channels was perpetuated, particularly since a narrowing of channels was not occurring following aggradation.

Streambanks

Streambank erosion is an important factor influencing initial changes in channel morphology and long-term recovery. Streambank erosion may occur in response to aggradation by deflecting streamflow energy into banks and undercutting them. Subsequent delivery of sediment to the channel perpetuates the cycle (Roberts, 1987). This "positive feed-back" mechanism was used to describe the channel response to storm-generated sediment delivery in Redwood Creek of the Northern California Coast Range (Nolan and Marron, 1985). In Redwood Creek, sediment delivery during the storm overwhelmed transport capability thereby initiating streambank erosion and subsequent failure of inherently unstable hillslopes. Channel impacts were basin-wide and persisted for 5-10 years. In contrast, a similar evaluation (Roberts, 1987) reported only localized channel impacts in the Santa Cruz Mountains. Impacts included scour in low-order streams and moderate fill in high-order streams. The impacts did not persists in any of the locations for more than 3 years.

The "positive feed-back" mechanism was also reported in conjunction with streambed aggradation in logged watersheds on the Queen Charlotte Islands. Sediment wedges, formed from streambank- and landslide-generated sediment, were correlated with significant bank erosion (Roberts, 1987). Bank retreat occurred in areas flanking the sediment wedge and persisted in areas downstream from the wedge. The direct effects of such sediment wedges are a wider and shallower channel, particle size distribution and texture of the channel bed matching that of the adjacent banks, downstream propagation of these effects for many years, and a dewatering of the channel at low-flow (Roberts, 1987).

Although the phenomenon of severe bank erosion and sediment wedge development was not evident in unlogged watersheds (Roberts, 1987), occurrence of bank erosion may not be due to logging in general, but rather particular logging practices. Thus riparian erosion may be linked to riparian logging activities (Roberts, 1987). Such activities as felling and yarding across and through streams, machine operations near streams, and removal of riparian vegetation are associated with destabilization of streambanks (Chamberlin, 1982).

Streambanks enforced by the roots of woody species have greater resistance to erosion than those enforced by herbaceous species (Beschta and Platts, 1986). The mechanisms involved include a physical barrier to shear stress, increased surface roughness, and relative stability. Beschta and Platts maintain that quality of fish habitat is closely linked to the characteristics of channel banks. For example, undercut banks provide over winter habitat for coho salmon (*Oncorhynonus kisutch*) and steelhead trout (*Salmo gairdneri*).

The interaction between streamside vegetation and channel dynamics is complex. Streamside vegetation reduces effective channel area, increases hydraulic resistance and bank protection, and buffers banks from waterborne debris. Stability is afforded to banks by reducing water velocities and inducing sediment deposition (Sedell and Beschta, 1991).

Instream Processes and Structural Control

Structural elements which resist fluvial erosion function as morphological controls within stream systems and provide cover for fish. Large woody debris, boulders, rock outcrops, vegetatively stabilized landforms and beaver dams are examples of structural controls.

<u>Large woody debris and obstructions</u>. The interaction of large woody debris (LWD) and sediment is an important aspect to consider when evaluating temporal and spatial changes in channel morphology. The functions of LWD include: pool formation, stepped longitudinal profile and sediment transport control (Bisson et al., 1985). LWD increases channel roughness, retards downstream routing of bed sediments and increases the overall resident time of courser sediment (Beschta and Platts, 1986). The removal of LWD from stream channels results in decreased variability and complexity of fish habitat. This change is

linked to changes in the hydraulic and sediment regimes of a channel (Klien et al., 1987).

In 1986, Lisle reported on the spatial relationship between pools, bars and structural controls described as large obstructions. These include rock outcrops, root-defended banks, and LWD. Lisle reports that obstructions influence the behavior of a stream because they are commonly formed by or introduced by non-fluvial processes. Obstructions which are resistent to fluvial processes, control and stabilize gravel channels through the formation of stable bar-pool topography.

Characteristics of LWD in logged, unlogged and debris-torrented streams were compared in watersheds on the Queen Charlotte Islands (Hogan, 1986). Hogan reported a shift in debris size and orientation in logged versus unlogged streams. The mean debris loading was lower in logged watersheds, and there was a higher frequency of smaller material in logged and torrented channels. Logged and torrented channels both showed a greater tendency for LWD to be oriented parallel to the stream channel, whereas unlogged channels showed a preferred orientation diagonal to flow. The position considered most influential in storing clastic sediment is that which crosses the stream diagonally with the small end pointing up or downstream.

The change in size and orientation of LWD influenced pool and riffle shape (Hogan, 1986). Pool shape changed from long and narrow to short and wide in torrented and recently logged watersheds. Complexity of fish habitat, due to variability in channel width and pool-riffle sequences, was reduced in the channels with less LWD.

Robison and Beschta (1990) evaluated the orientation and influence of LWD on fish habitat. Influence zones were developed, defined in terms of functional aspects of LWD (Figure 1). They measured the volume of wood most likely to influence fish habitat (zone 1), channel roughness during high flows (zone 1 and 2), or eventually enter the wetted and bankfull channel (zone 3 and 4). In an undisturbed watershed in Southeast Alaska, they found that average debris length, diameter and volume increased with stream size. First-, second- and third-order streams had a higher degree of newly recruited LWD. In first- and second-order streams 80% of the debris was positioned in zones 3 and 4, while less than 40% was similarly positioned in forth-order streams.

Debris jams moderate energy dissipation and sediment discharge, by creating localized zones of scour and deposition (Beschta, 1991). A channel with frequent small or moderately sized debris jams has a slope which is locally adjusted to these features (Hogan, 1987). In logged and torrented channels the slope is adjusted to infrequent large jams. The failure of these could result in more catastrophic effects than the failure of a smaller

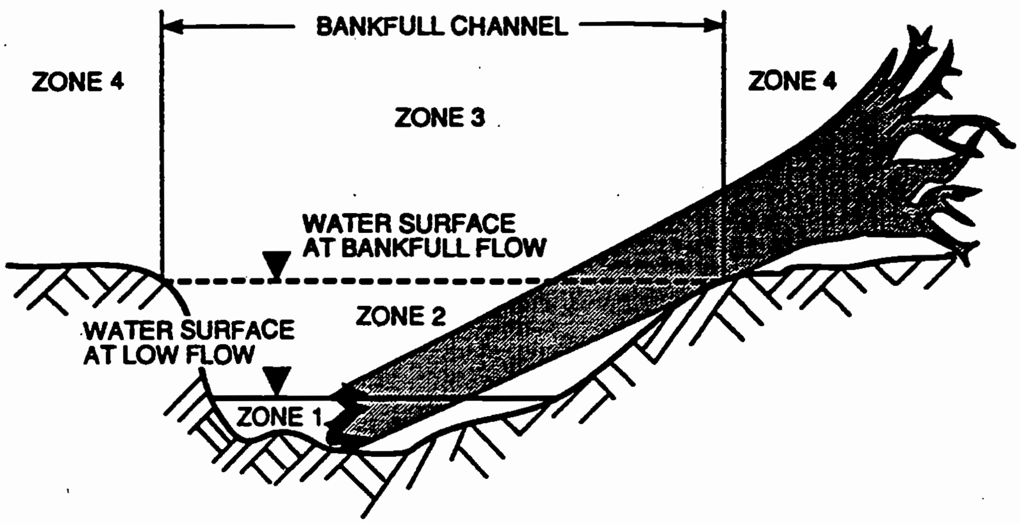


Figure 1. Influence zones of large woody debris. (Source: Robison and Beschta, 1990)

jam in systems of frequently occurring jams. The majority of sediment storage associated with the large jams is upstream, as opposed to smaller ones in unlogged basins in which sediment storage occurs both up and downstream from the logjam.

Tripp and Poulin (1986) showed that streams which are managed to maintain large amounts of woody debris are able to re-establish pre-aggradation pool-riffle relationships. This recovery was attributed to amount, size, and orientation of the LWD, and to the fact that aggradation was a result of sediment transport from upstream sites.

Depletion of quality and quantity of anadromous fisheries habitat may result from mass wasting-related channel changes. On the Queen Charlotte Islands, debris torrented streams experienced an estimated 20-24% reduction in pool depth, 38-45% reduction in pool area, loss of 57% of LWD cover, and a reduction of undercut bank cover by 76% (Tripp and Poulin, 1986). Riffle occurrence increased by 47-57% and most significant was 79% loss of over-winter habitat 79%.

Use of LWD structures to "rehabilitate" or "enhance" stream channels has become a growing management practice. Results include increased complexity, cover, pool depth and pool area (Tripp, 1986). Problems with this practice involve loss of structures to high flows and sediment movement. Problems stem from the permanent nature of these structures whereby the channel is prevented from making incremental changes in morphology over time (Beschta and Platts, 1986). This can be an economic loss and possibly an ecological loss if increased bank erosion occurs. In addition, the interaction of fluvial and non-fluvial process influenced by stream side vegetation are completely bypassed when instream structures are the individual focus of stream restoration.

Beaver Activity. Historically, the presence of beaver has been a more dominant variable contributing to the hydrologic and morphologic complexity of stream systems. Prior to European settlement in North America, the beaver population was estimated to be 60-400 million individuals, occupying a territory of 16 million km^2. By the 1900's beaver were virtually extinct in North America, and within that same time period, 195,000 to 260,000 km^2 of wetlands disappeared (Naiman et al., 1987). Currently the beaver population is estimated at 6-12 million individuals.

Stream ecosystems have been significantly altered by the removal of beaver, and consequently research may reflect an incomplete picture in terms of representing "natural" systems (Naiman et al, 1988). The influence of beaver extends beyond simple structural control.

Beaver modify stream morphology and hydrology by cutting wood and building dams, retaining sediment and organic matter and contributing to the creation and maintenance of wetlands. Wetland conditions, in turn, modify nutrient cycling and decomposition dynamics. In addition, structure and dynamics of the riparian zone, plant and animal community composition and dynamics, and discharge and sediment transport characteristics are also altered by beaver (Naiman et al., 1987).

Channel alterations due to beaver include local decreases in velocity, a stair-stepped channel gradient profile, increased area of flooded soils, and increased retention of sediment and organic matter. Creation of wetlands alters wildlife community development and productivity.

Sediment storage within beaver ponds represents an important modification to the sediment budget and nutrient cycling within a stream system. Naiman et al. (1987) measured sediment storage in ponds and found that sediment storage was proportional to surface area of adjacent meadows. They were unable to establish a relationship between size of beaver ponds and volume of sediment stored. Naiman et al. (1988) report as much as 2,000-6,500 m^3 in a dam constructed of 4-18 m^3 of material.

The importance of sediment accumulations and expanded wetted area include, reduction in allochthonous nitrogen and an increase in fixation of nitrogen by microbes (Naiman et al., 1984). Retention of nutrients, such as nitrogen and carbon, for longer periods of time in beaver ponds, increases ecosystem process efficiency.

The temporal influence of beaver can range from less than one year to centuries. Naiman et al. (1990) evaluated temporal trends of dam construction and found that 75% of all ponds and 90% of all pond sites had been established for at least 25 years. Older sites generally had larger surface area than younger sites.

The spatial influence of individual beavers may only encompass a small area in comparison to a catastrophic event. However, the cumulative effect of many ponds over a long period of time results in extensive disturbance (Naiman and Johnston, 1990). Thus, beaver-altered habitat creates a mosaic of diverse habitat types along a stream channel. The degree to which the disturbance influences a basin as a whole, depends on beaver population dynamics, patch longevity, and inherent environmental variables.

Hydrologic and morphologic alterations by beaver result in the ability of riparian systems to resist and recover from disturbances. Modern riparian systems have been largely disturbed by anthropogenic activities and their sensitivity to additional disturbance is attributed to a lack of large stable pools of biomass and short nutrient spirals which are less likely to buffer the system from disturbance. Stream and riparian systems with a high degree of heterogeneity are more resistent to perturbation.

Beaver ponds provide large patch bodies, increase biomass, and lengthen nutrient spirals, resulting in increased resilience of the system to disturbance (Naiman et al., 1986 and 1988; O'Neill et al., 1979).

In summary, it is difficult to directly link hillslope processes, land management and channel processes. This is due in large part to inherent variability between watersheds (making results from paired watershed studies elusive), and the time frame over which changes occur. Yet, the complex interaction of biological, geochemical, hillslope, fluvial and riparian processes provide and maintain a well-functioning and resilient ecosystem.

STUDY AREA

Esmond Creek is a tributary to the Siuslaw River in the Oregon Coast Range. It drains an area of 48.9 square kilometers (km) in a dendritic pattern (Figure 2). The mainstream length of Esmond Creek is approximately 18 km, including a lake in the upper section which is 0.83 km long. Two second-order forks of Esmond Creek enter the lake at an elevation of approximately 210 meters (m). The longer of these forks is 3.5 km long. Leopold Creek is the major tributary, third-order stream, entering Esmond Creek at the lower end of the basin. At this point Esmond Creek changes from a third-order to a fourth-order stream. From the lake to about 0.4 m downstream average channel gradient is 2.7%. From 0.4 to 10 km the average channel gradient is approximately 0.9%.

The dominant rock type of the area is Tyee Sandstone. The soils are described as udic, mesic soils of forested uplands. The Esmond Creek basin is located in the Bohannon-Preacher-Digger soil unit. Bohannon and Digger soils are moderately deep, well drained, derived from sedimentary rock and found on narrow ridgetops and steep sideslopes. On the surface Bohannon soils are dark brown, gravely loam, and subsurface soils are dark-brown and brown, cobbly loam. Digger soils tend to be more gravelly. Soil depth is 51 to 102 centimeters (cm) above weathered bedrock (Lane County Area soil survey).

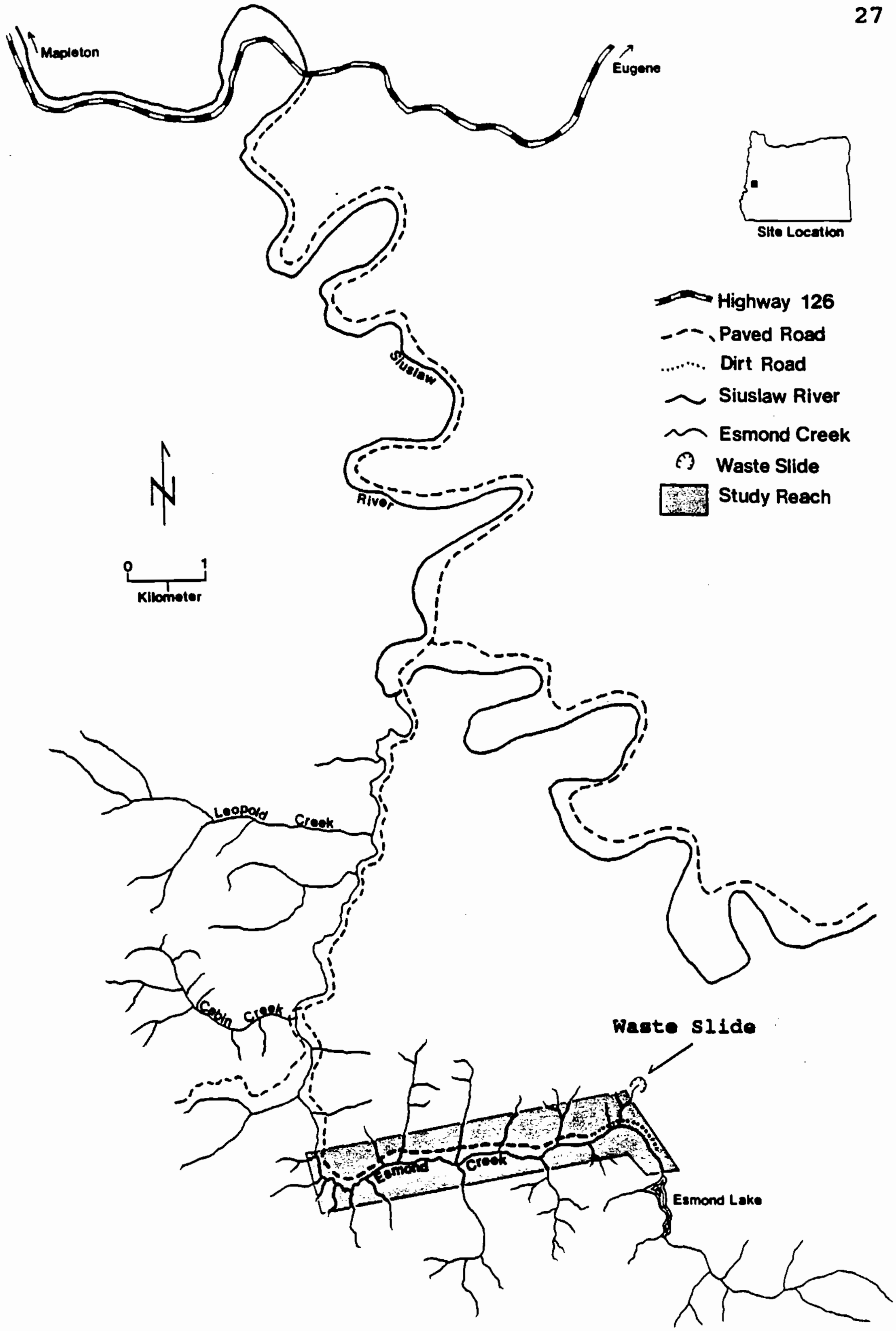


Figure 2. Site location map.

Preacher soils are also derived from sedimentary rock, deep and well drained, and found on the broader ridgetops, in saddles and more stable side slopes. The surface is very dark grayish brown to very dark grey loam. Subsoils and substrate are dark yellowish brown loam. The depth to weathered bedrock varies form 102 to 152 cm (Lane County Area soil survey).

A number of other soil units occur in the Esmond Creek basin. Nekoma silt loam soils are well drained, commonly found on flood plains, and are derived from sandstone. Meda loam soils are well drained and found on fans and terraces. The Blachly soil series is a dark-reddish brown, silty clay loam, derived from sandstone (Lane County Area soil survey).

The vegetation of the basin consists of a predominately Douglas-fir (*Pseudotsuga menzessii*) overstory intermixed with western hemlock (*Tsukga heterophylla*), and western redcedar (*Thuga plicata*). Bigleaf maple (*Acer macrophyllum*), golden chinquapin (*Castanopsis chrysophyla*), red alder (*Almus rubra*), vine maple (*Acer circanatum*), and rhododendron (*Rhododendron macrophyllum*) compose the understory. Red huckleberry, salmonberry, salal, western swordfern, tall Oregon grape, and forbes and grasses are found on the forest floor as well as riparian areas. The dominant riparian overstory fluctuates from a closed canopy of Alder, to a partially open willow (*Salix*) and sedge

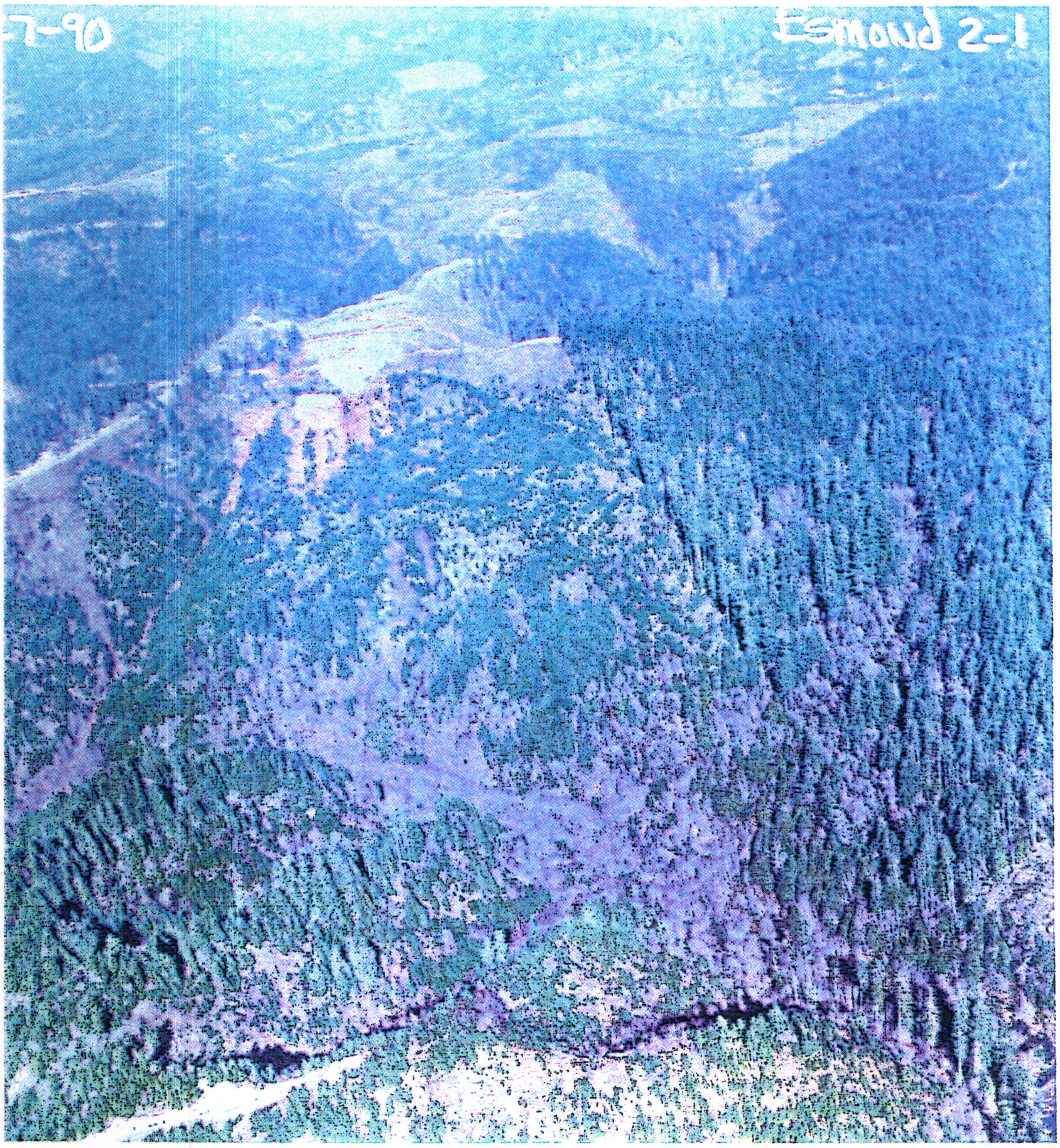
(*Carex*) community. The alders date back to the large flow event in 1978. The willow/sedge vegetation is generally associated with beaver activity. As beaver activity increased, occurrence and size of willow increased.

Landslide History and Description

In January of 1988 a rotational block movement occurred and continues to periodically provide sediment to Esmond Creek via a first-order tributary (Figure 2). The landslide (Figure 3a and 3b), referred to as the Esmond Waste Site Failure, or Waste Slide, is an active landslide, involving approximately 250,000 cubic yards of soil, decomposed rock, and endhaul road waste (personal communication Keith Mills, Oregon Department of Forestry (ODF), 1989). All details about the landslide resulted from an ODF investigation by John Seward, Dave Michael and Keith Mills, published as an ODF memorandum in 1989. To date no further information has been published by ODF.

From 1975 to 1980, roads and an upper and lower landing were constructed above the headwaters of a tributary to Esmond Creek. In 1985, the upper and lower landings were proposed for endhaul waste disposal. The plan was approved in June of 1986 by ODF. Disposal began in July that same year. By 1987, 40,000 cubic yards of material had been deposited at the site. In January of 1988, failure of the lower landing was first noticed.

The slide materials are composed of three soil units



(A)

Figure 3. (A) Oblique of Esmond Waste Slide and (B) an aerial of Esmond Waste Slide.

(B)

Figure 3. (continued)

and two rock units. Soil units either have a developed profile or have been moved by slope forces, while rock units still retain evidence of the original rock formation.

Soil unit A (as identified in the 1989 ODF memorandum) is endhaul waste material consisting of large boulders in a matrix of silty sand. It is light grey to brown in color and low in density. Soil unit B is a red-brown sandy silt occurring on the surface of the slide. It is a low plastic material of medium density and the occurrence of rock particles increases with depth. Soil unit C is a grey organic silt. It is a highly plastic, medium stiff, saturated material, occurring approximately 24 m below the surface. It is an *in situ*, completely decomposed organic mudstone. Unit C is a very weak material, functioning as a barrier to water flow and is the probable failure boundary.

Rock unit A is a completely to partly decomposed sandstone and mudstone and is permeable to water. Rock unit B, below unit A, is a blue-grey fresh sandstone. It is a high density, unfractured unit and impenetrable to water.

Most of the surface material entering Esmond Creek originates from soil unit B and imparts a red-brown signature to sediments derived from the Waste Slide. Characteristic colors of sediment derived from other sources in the basin are white to grey.

Slopes along the ridgetop are low gradient, about 10%, steepening to 30-40% down near the waste storage area. Below this storage location slopes increase to 60-70%. The area surrounding and below the waste site is benchy. Slope failure in this area is described as "calving".

A small tributary approximately 0.83 km long directly transports sediment from the Waste Slide to Esmond Creek. By 1990, debris torrents from the Waste Slide had virtually eliminated the alder riparian corridor along this tributary. In 1991, a significant amount of sediment and woody debris storage occurred in the tributary, with good alder regeneration on these storage sites. The tributary flows over a spur road and a broad alluvial terrace prior to entry to Esmond Creek. There is significant sediment storage on the road (which is currently closed) and the alluvial fan.

Settling ponds were constructed in an attempt to mitigate potential impacts of sediment transportation from the hillslope to the channel. The structures consisted of hay bales and filter fabric, held in place by fence posts and poultry netting. They were located along the fan itself (both longitudinally and down to Esmond Creek), and along approximately 170 m of road. The potential sediment-storage volume of the settling ponds appeared to be at capacity by 1991.

The location of the mouth of the tributary to Esmond

Creek continues to shift across its alluvial fan. It was at different sites in 1990, 1991 and 1992 (before, during and after data collection). This appears to be a response to sediment deposition that has diverted the tributary in an upstream direction (relative to the direction of flow of Esmond Creek).

Hydrologic Records

The nearest stream gage is located on the Siuslaw River near Mapleton. Records extend from October 1967 to the present. Further north is a station near Triangle Lake with records from September 1955 to the present.

METHODS

Aerial Photograph Interpretation

Aerial photographs from 1979 and 1990 were used to assess sediment sources and channel condition in the basin prior and subsequent to the landslide of 1988. The general extent of management activities such as harvesting, and road construction were also noted.

Data Collection

Channel morphology. The initial station was randomly selected, at approximately 60 meters (m) downstream from Esmond Lake. Sampling stations continued every 30 m downstream. At each station thalweg depth, wetted width, bankfull width and bankfull depth were measured with a stadia rod. In addition, thalweg depth was measured every 5 m between each of the 30-m stations. Slope was measured in percent using a clinometer; and habitat type was recorded at each 30-m station. Habitat designations included pool, riffle, glide, cascade, (Bisson et al., 1984) and beaver pond. Landform (e.g. terrace, rock outcrop) when applicable, were recorded at very 30-m station.

Structural Control. Beaver ponds, LWD, and boulders were documented and measured to help assess the influence of structural control on changes in channel morphology associated with the landslide. All beaver dam locations were documented; dam length, width, height and beaver pond length were measured. Channel widths and depth behind the dam were also documented.

Small and large diameters of LWD, length, and percent volume within each zone of influence (Figure 1, page 20) were measured. All wood was measured that had a minimum diameter of 15 cm, a minimum length of 1.5 m, and some percentage of volume within zone 1 or 2. Log jam locations were documented. Height, width, length and percent wood volume in each zone of influence was measured. A diameter tape, Biltmore stick and stadia rod were used for these measurements.

All boulders that were within zone 1 or 2, except if completely submerged, and less than 1/2 m in length along the long axis were counted.

Sediment Sampling. A dual sampling technique was used, consisting of systematic and stratified sampling. Systematic sampling was done at 180-m intervals whereby a sample was collected from each of three locations: the channel bed, the point bar and the floodplain. The channel bed samples were collected from the deepest part of the channel. The point bar sample was taken at the midpoint between the wetted channel and the bankfull width, and the floodplain sample was collected above the high flow mark, yet at the closest proximity to bankfull width. The samples were obtained using a soil auger and stored in plastic bags.

The stratified sampling, focused on instream processes as a function of structural control. Samples were collected upstream from beaver ponds, log jams and fish structures. Ten beaver-dam, log-jam, and fish-structure sites were randomly selected and sediment samples were collected from the channel bed, point bar, and floodplain, as in the systematic portion of the design.

Data Analysis

Landslide influences on Channel Morphology. Two approaches were used to evaluate landslide influences on channel morphology. The first approach involved spatial interpolation, in which the landslide was treated as a point-source of sediment. The portion of the channel upstream from the landslide was considered as a control reach, and upstream channel morphology was compared to downstream channel morphology. There were three problems with this technique:

(1) There was a change in channel morphology 340 m upstream from the landslide. The system changed from a low energy system characterized by pools, riffles and glides, to a high energy system characterized by pools and cascades. Consequently the "control" reach was too short to establish "untreated" trends in channel morphology;

(2) there were a large number of active and abandoned beaver ponds at the toe of the landslide and for

approximately 7 km downstream from the landslide, but there was only one abandoned beaver pond upstream; and (3) the high variability in the data set may have masked the localized depositional characteristics of landslide impacts as they were observed in the field.

The second technique was to compare field data collected in 1984 (four years prior to the landslide), to data collected in 1991. The 1984 data had been collected by the Bureau of Land Management (BLM) to assess fish habitat. Although this comparison was useful, it is important to note limitations to the conclusions that can be drawn, due to differences between the sampling designs of 1984 and 1991.

In 1984 the BLM conducted fish habitat surveys in which they inventoried dimensions of habitat units from Esmond Lake to a location approximately 6.5 km downstream. The 1984 BLM data differs from the 1991 data in two ways. First, in 1984 some of the values were estimated by the BLM, whereas in 1991 all of the features were measured. Secondly, in 1984 sampling sites were dependent upon habitat type (i.e. pool, riffle, glide), versus 1991 in which sampling was conducted systematically (i.e. every 30 m). Therefore changes in channel morphology (or a finding of no significant difference) between 1984 and 1991 comparisons, may be a result of differences in sampling design and technique rather then a true morphological difference.

In 1984, the BLM measured maximum channel depth and width, and estimated average channel width and depth in reaches defined by habitat type. Therefore direct comparisons with the 1991 data at exact locations could not be made. Instead, reaches were defined in which the 1984 and 1991 data were pooled and statistically compared on a reach by reach basis.

Fifteen reaches were defined on the basis of channel slope and beaver influence (Table 1). They ranged in length from 100 to 800 m. Stream distances as measured in 1984 and 1991 did not precisely match in some instances, so tributary locations, old bridges and legal descriptions were utilized in matching the two data sets. The following reach comparisons were made (Note: 1991 "average thalweg depths" based on measurements obtained every 5 m, "average wetted widths" based on measurements obtained every 30 m.):

(1) Depth

(a) 1984 maximum thalweg depth per reach **to** 1991 maximum thalweg depth per reach

(b) 1984 average mean depth **to** 1991 average thalweg depth

(c) 1984 average maximum thalweg depth **to** 1991 average thalweg depth

Table 1. Reach dimensions (starting at Esmond Lake and extending 6.2 km downstream) and general characteristics.

Reach Number	Channel Slope (%)	Reach Length (km)	Characteristics (1991/1984)[a]
1	2.66	0 - 0.42	cascade/cascade
2	1.11	0.42 - 0.76	clear/clear
3	1.0	0.76 - 0.86	slide/clear
4	0.6	0.87 - 0.99	pond/pond
5	0.87	1.0 - 1.5	clear/clear
6	1.0	1.6 - 2.0	clear/clear
7	1.1	2.1 - 2.5	clear/clear
8	1.2	2.6 - 2.9	clear/clear
9	1.29	3.0 - 3.5	clear/clear
10	0.9	3.6 - 4.4	clear/pond
11	0.5	4.3 - 4.8	pond/pond
12	0.5	4.9 - 5.0	mixed/clear
13	0.2	5.1 - 5.5	clear/pond
14	0.1	5.6 - 5.8	pond/pond
15	0.3	5.9 - 6.2	mixed/clear

[a] cascade = higher gradient, no beaver ponds

slide = landslide input

pond = beaver ponds dominate channel control

clear = no beaver ponds present

mixed = beaver ponds present, but not dominant

(d) Above comparisons were made for pools riffles and glides.

(e) 1991 thalweg depths of beaver-pond dominated reaches to upstream reaches not dominated by beaver

(2) Width

(a) 1984 average mean wetted width to average wetted width

(b) 1984 average maximum wetted width to 1991 average wetted widths

(c) 1984 average width/depth ratios to 1991 average width/depth ratios

(d) Above comparisons of width were made for pools riffles and glides.

(e) 1991 wetted widths of beaver-pond dominated reaches to upstream reaches not dominated by beaver

<u>Particle Size Analysis</u>. Sediment samples were oven dried for approximately 24 hours at 105°C. If the samples contained enough fines to cause cohesion of particles, then the oven dry sample was weighed, washed through a #200 (0.075 mm) sieve, then oven dried again for 24 hours. The oven dried residue was then weighed again, and sieved for 10 to 15 minutes through a stack of five sieves; a #2.5 (12.5 mm), #5 (4.0 mm), #10 (1.65 mm), #20 (0.85 mm), #200 (0.075 mm) and a pan. Each sieve was weighed and the

percent of sample retained and the percent of sample finer were calculated. If the sample did not exhibit cohesion, it was weighed, sieved through the stack of sieves, and each sieve weighed to calculate the percent of sample retained and percent of sample finer. (A detailed procedural description and sieve numbers, mesh size and particle characteristics are given in Appendix A).

The sieve results for each individual sample were plotted on semi-log graphs showing percent finer against grain size. While the line describing particle distributions is typically drawn curvilinear and by hand, a straight-line procedure for connecting data points was used in this analysis. The results are somewhat different than those of a curvilinear relationship. Since all sample distributions were treated in this manner, the ultimate result is a relative index of the actual distribution.

An important aspect to note about these distributions are the upper and lower limit of the particle diameters (Figure 4a and 4b). Any particles which passed the #200 sieve were caught in the pan. Thus the lower limit of the distribution had to be estimated. The lower limit was designated as 0.01 mm based on the relationship between characteristic grain size and settling velocity (Figure 5).

In some instances 20 to 50% (Figure 4b) of the sample did not pass through the largest sieve (#2.5; 12.5 mm). In this case the grain size of the upper limit of the

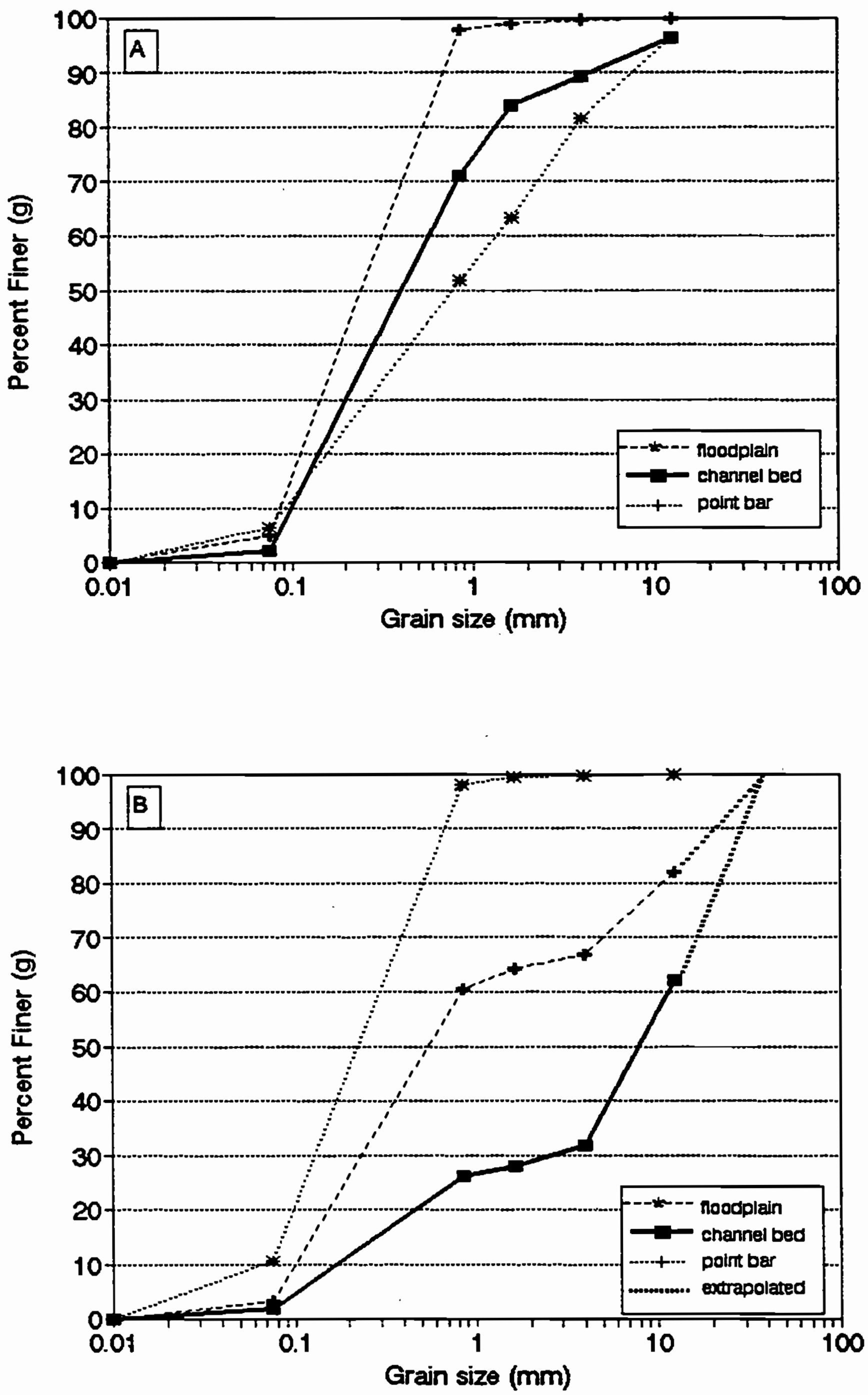


Figure 4. Particle size distribution of samples collected (A) upstream from a log jam and (B) at station 4290.

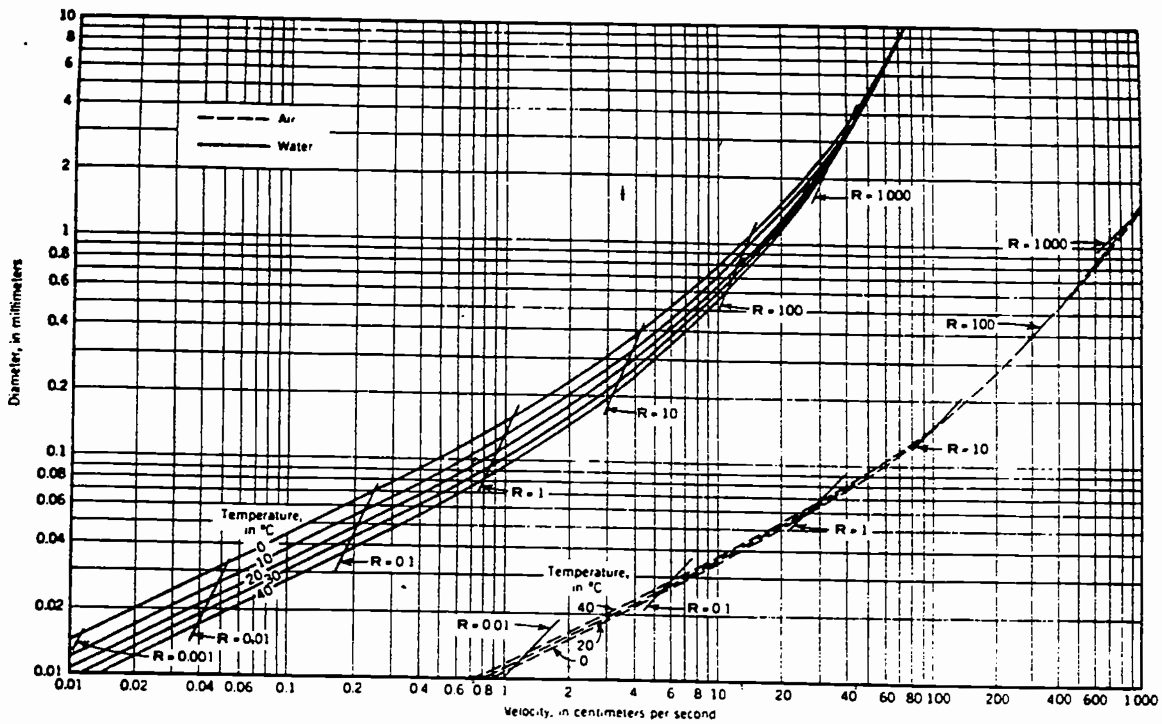


Figure 5. Grain size versus settling velocity (Vononi, 1977).

distribution had to be estimated. This was determined to be 40 mm, based on the diameter of the largest particles from all the samples, and the distribution was extrapolated to that point.

The median particle diameter (D_{50}), geometric mean (D_g), standard deviation of the geometric mean (SD_g) were derived form these distributions. The median particle diameter is the grain size at which 50% of the particles (by weight) are finer and was read off the graph for each sample, as were the D_{16} and D_{84}. The geometric mean and the standard deviation of the geometric mean were calculated using:

$$D_g = (D_{84} * D_{16})^{1/2}$$

$$SD_g = (D_{84} / D_{16})^{1/2}$$

While these estimates of D_g and SD_g are only considered accurate if the particle distributions are log-normal, the practice is to determine D_g and SD_g using these equations even when the assumption of log-normality is not entirely met (Vanoni, 1977). Once again a relative index is achieved.

The results of the particle size analyses were regressed versus distance downstream to investigate spatial trends and longitudinal distribution of landslide-delivered sediment. Influences of instream processes associated with beaver dams and log jams, were also investigated using linear regression. The standard deviation of the geometric mean diameters were regressed on the geometric mean diameters from particle distributions. T-tests and non-parametric statistical techniques were also utilized for comparative purposes.

RESULTS AND DISCUSSION

Aerial Photograph Interpretation

General zones of sediment yield and deposition were evaluated from 1979 and 1990 aerial photographs. The spatial boundaries of this analysis were from Esmond Lake to the mouth of Esmond Creek. The objectives were to identify locations of sediment sources and storage, and channel reaches in which depositional characteristics changed over time. The following description of these sites are categorized by reach.

Esmond Lake to the Waste Slide (0.8 km). In 1979 there was a debris slide in the first order tributary just downstream from Esmond Lake, on the south side of Esmond Creek (Figure 6). Subsequent sediment deposition was visible on a high terrace which occurs for about 510 meters along the higher gradient reach of Esmond Creek below the lake. By 1990 the hillslope from which the slide had occurred was completely revegetated (combination of overstory and shrub recovery) and the terrace and tributary had a riparian canopy closure of 100%.

Most of Esmond Creek between the lake and the slide had a riparian canopy closure of 100% in both 1979 and 1990, so the channel could not be observed. However, from approximately 30 m upstream of the Waste Slide to approximately 200 m downstream, the vegetative cover was sufficiently open in both years to reveal the channel.

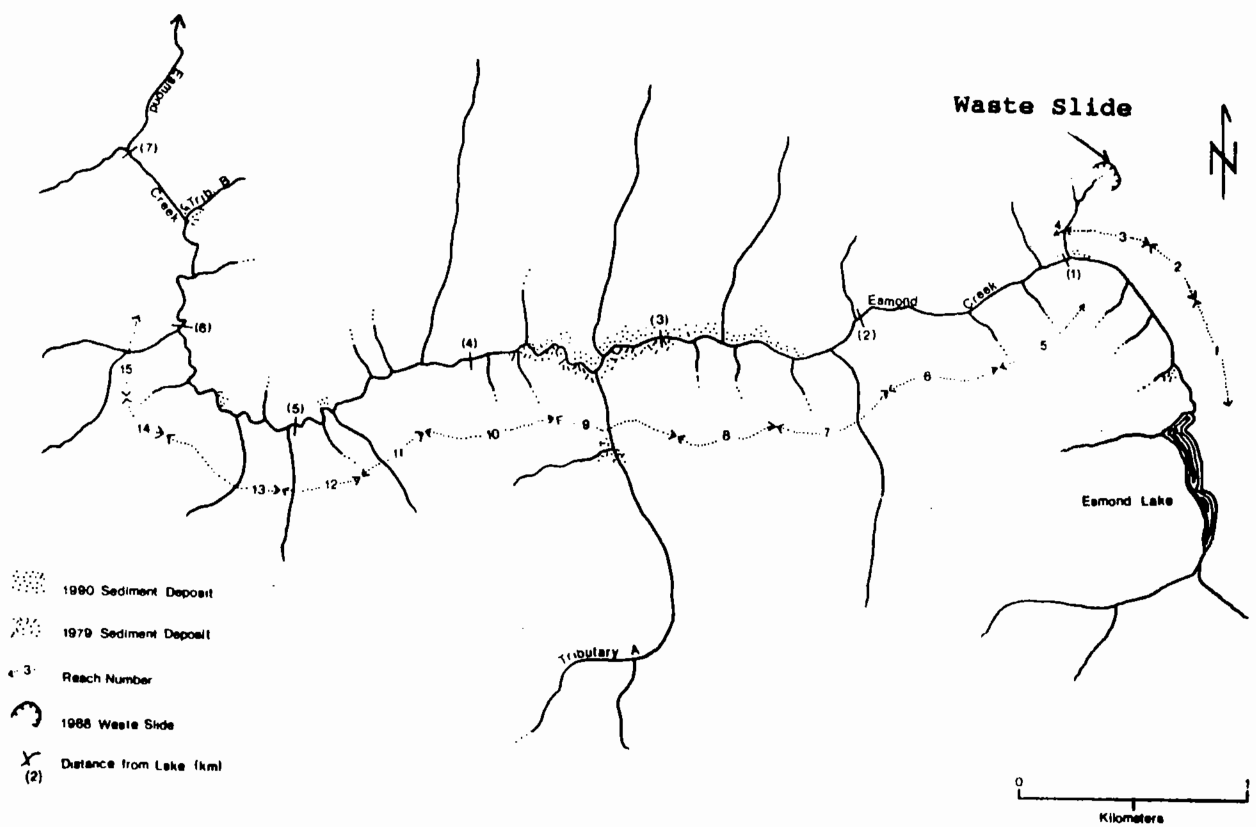


Figure 6. Aerial photograph identification of historic sediment storage sites within the study reach, and Reach designation utilized in data analysis.

There was an obvious increase in sediment deposition in 1990, whereby the red characteristic color of the landslide sediment was visible in the channel (Figure 6). Changes in channel width were not detectable at the scale of the aerial photographs.

Roads are considered a long-term source of sediment with those nearest the creek affording the highest potential for delivery to the channel and subsequent negative impacts. Studies show that maximum sediment yield often occurs immediately following construction and declines over a period of years (Beschta, 1978; Harr and Fredriksen, 1988). Although a paved road extends much the length of Esmond Creek, the surface changes to dirt approximately 0.5 km downstream from the Waste Slide. Historically the road crossed Esmond Creek a number of times, but these crossing have been removed. In 1979 the Esmond Creek road extended 0.81 km upstream from the landslide. By 1990, the road was closed and heavily revegetated with herbs, forbes and Alder. Ridgetop roads totaled 4 km in this portion of the watershed.

<u>Waste Slide (0.8 km) to Tributary A (3.3 km)</u>. In 1979 two zero- to first-order basins, located on the south side of Esmond Creek upstream from Tributary A, were intensively logged, with a narrow buffer strip left along Esmond Creek. In 1979 riparian vegetation was open and sediment deposition was apparent in Esmond Creek from these

tributaries to about 3.5 km beyond Tributary A. These basins were mostly revegetated (65%) by 1990.

From the tributary at 2.2 km to about 3.5 km, sediment deposition, red in color, was visible in the 1990 aerial photographs (Figure 6). It is along this reach that the Waste Slide deposition was most obvious. In addition, 1991 field notes indicate that this reach represented the longitudinal extent at which sediment from the landslide, identifiable by the red color, could be discriminated from other-source sediments. Roads along this reach total 4.2 km of stream-side road, and 9.2 km of ridgetop and midslope roads.

Tributary A (3.3 km) to tributary at 7 km. Tributary A had been intensively logged by 1979. A water impoundment on this tributary appeared to have been caused by sediment delivery from management-related debris slides (Figure 6). In 1990 the riparian vegetation along the tributary had recovered significantly and the impoundment was barely visible.

The occurrence of large openings in the riparian cover along this reach of Esmond Creek in 1979 and 1990, may have been associated with beaver activity. Sediment deposition was visible from Tributary A to approximately 3.5-3.7 km in both years, and in isolated locations in 1990.

By 1979, a small tributary on the east side of Esmond Creek, Tributary B, had been intensively logged (Figure 6).

A failure at the lower end of the basin most likely supplied sediment to Esmond Creek. In 1990, the basin was about 60% revegetated and sediment supply from the basin was not evident. Excessive sediment deposition along Esmond Creek was not evident in 1979 or 1990 downstream from the northward bend in Esmond Creek. There were 2.1 km of stream-side roads and 6.2 km of ridgetop and midslope roads along this reach of Esmond Creek.

Tributary at 7 km to Cabin Creek (8.5 km). The riparian closure along Esmond Creek was 100% in 1990. In 1979 there were a few openings, and no extraordinary sediment storage was observed. In 1979 Cabin Creek had been intensively logged and a debris jam in Cabin Creek was impounding water. In 1990 the basin was 90% revegetated, but the impoundment was still evident. The tributary on the east side of Esmond Creek, upstream from Cabin Creek, was intensively logged by 1979, and about 70% revegetated by 1990. There were 2.1 km of stream-side roads and 1.6 km of ridgetop and midslope roads.

Cabin Creek (8.5 km) to Kline Creek (11.2 km). In 1979 the Kline Creek drainage had been intensively logged and the riparian vegetation was denuded. By 1990, the hillslopes were 80-90% revegetated. Esmond Creek riparian canopy closure was mostly 100% and openings revealed no changes between 1979 and 1990. There were 2.5 km of stream-side road and 10 km of ridgetop and midslope roads.

Kline Creek (11.2 km) to the Mouth (18 km). Both Kline Creek and Leopold Creek basins had been intensively logged by 1979. By 1990, vegetative recovery in both basins was approximately 90%. However, the vegetative recovery in Leopold Basin lacked overstory vegetation.

Esmond Creek appears relatively wide wherever visible through the riparian canopy along this reach, but the most astounding changes occurred at its junction with the Siuslaw River. Although there was a definite sediment bar in 1979, by 1990 the point bar had increased substantially and jutted well into the Siuslaw. In addition, sediment deposition had increased along the channel for about 130-170 m upstream from the mouth. There were 6 km of stream-side roads and 13.3 km of ridgetop and midslope roads from Kline Creek to the mouth of Esmond Creek.

Summary. Two sources of sediment other than the Waste Slide were identified through analysis of the 1979 and 1990 aerial photographs: (1) upland sites from which sediment was transported to Esmond Creek via tributaries, and (2) road surfaces. The effects of harvesting on sediment yield have not been well established, but studies generally indicate that road-associated and naturally-occurring mass failures have a greater effect on the sediment budget than harvesting itself. However, logging practices which provided little protection to tributary riparian zones, combined with the high flow event of 1978, most likely resulted in increased sediment yield with consequent aggradation of the tributaries and Esmond Creek by 1979.

By 1979 the main upland sources of sediment were from Tributaries A and B (Figure 6), Cabin, Kline, and Leopold Creeks. All of these tributaries were considerably revegetated by 1990, with little evidence of recent sediment input.

The 1991 field survey terminated upstream from Kline Creek (11.2 km). The 1984 to 1991 comparisons terminated upstream from Cabin Creek (8.5 km) at approximately 6 km. Tributary A (3.3 km) may have been an ongoing source of sediment input through 1991 that could have affected the results of this study. However it is likely that any fine sediment supplied from this tributary had been largely transported out of the study area by 1991. While it appears that the Waste Slide of 1988 is the dominate source of upland sediment in recent years, the potential for chronic input from other historic sites still exists. In addition, it is possible that Esmond Creek experienced widespread aggradation from land management impacts prior to 1979.

The stream-side roads also represent potential sources of chronic and episodic sediment to the stream channel. It should be noted that several portions of stream-side roads had been abandoned prior to 1990. These general sediment sources in the Esmond Creek drainage are summarized in Table 2.

Spatial Interpolation

Landslide influences on channel morphology, were initially analyzed by considering the Waste Slide as a point-source of sediment. Channel cross-sectional area and width/depth ratios plotted versus distance downstream (Figure 7a and 7b, respectively) reveal the high variability of the data set. The high variability and relatively small data set upstream from the landslide indicate that it was not appropriate to assess landslide influences on channel morphology using spatial interpolation. However a few observations based on these figures are useful.

Field observations from 1991 indicated that localized channel aggradation was evident from 0.84 to approximately 5 km. However, at approximately 3.5 kilometers the characteristic red sediment generated from the waste slide become indistinguishable from sediment derived from other sources in the basin. Figures 7a and 7b, appear to confirm these observations in that the wetted cross-sectional areas decrease and width/depth ratios increase from 1-2.7 km and again from 3-4.5 km. However from 2.7-3 km and 4.5-7.4 km, Esmond Creek is predominately influenced by beaver ponds. Thus, the apparent "decrease" in area and "increase" in W/D ratios is most likely a function of a lack of beaver from

Table 2. Upland and road-related sources of sediment to Esmond Creek.

Source (distance)	1979 Condition	1990 Condition
Waste Slide (0.8 km)	Non-existent	Transitional-block slide involving 250,000 cubic yards of material
Tributary A (3.3 km)	Intensively logged and failure-related water impoundment	basin slopes 60% revegetated, impoundment still visible
Two 1st order Tributaries (2.25 & 2.75 km)	Intensively logged, a buffer was left along Esmond Creek	basin slopes 60% revegetated
Tributary B (6.5 km)	Intensively logged, failure at low end of basin	Mostly recovered and basin slopes 60% revegetated
Cabin Creek (8.5 km)	Intensively logged, debris slides and tributaries void of riparian vegetation, debris jam caused water impoundment	basin slopes 90% revegetated, impoundment still present
Kline Creek (11.2 km)	Intensively logged down to channel	Riparian vegetation recovered, basin slopes 90% revegetated
Leopold Creek (11.8)	Intensively logged down to channel	Poor regeneration of overstory on slopes, app. 40%
Creek-side Roads	**	17.7 km
Ridgetop Roads	**	44.5 km

** Distance of roads was measured from a BLM map and included all roads up to 1990. The condition of roads (i.e. abandoned, revegetated...) was not considered.

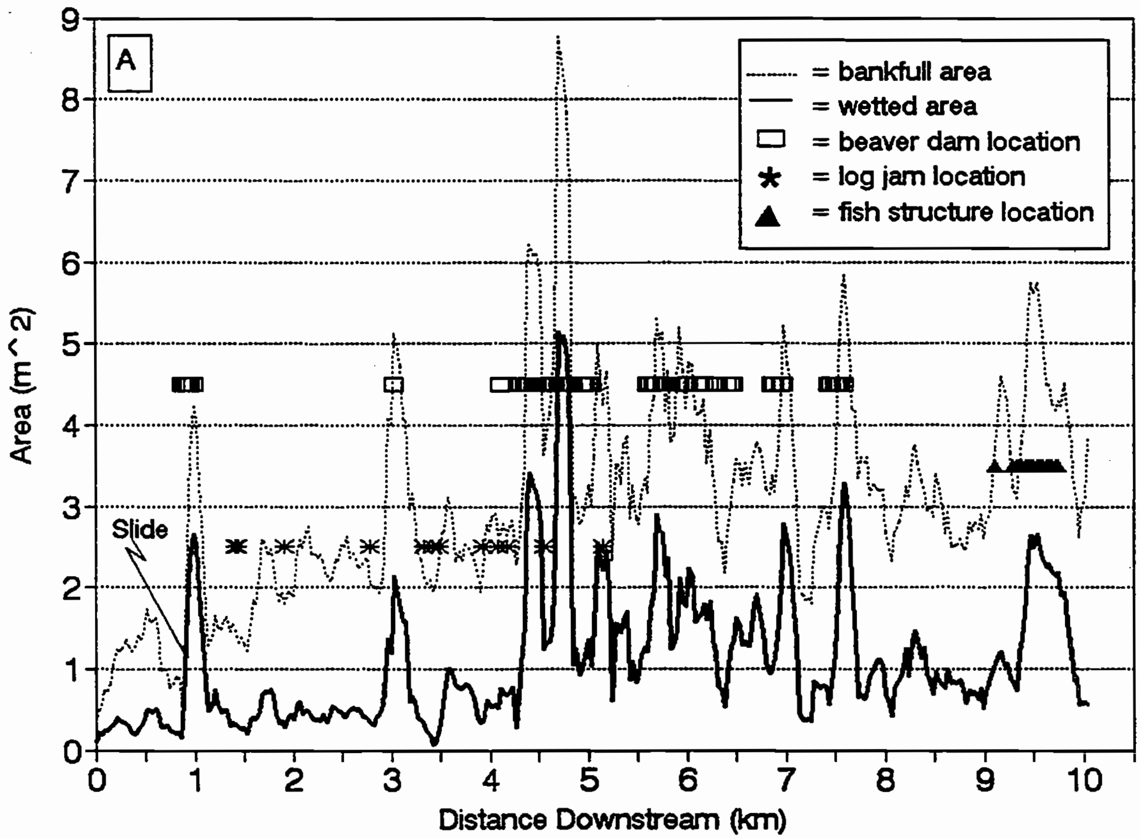


Figure 7. Moving average of (A) cross-sectional area and (B) width/depth ratio versus distance downstream.

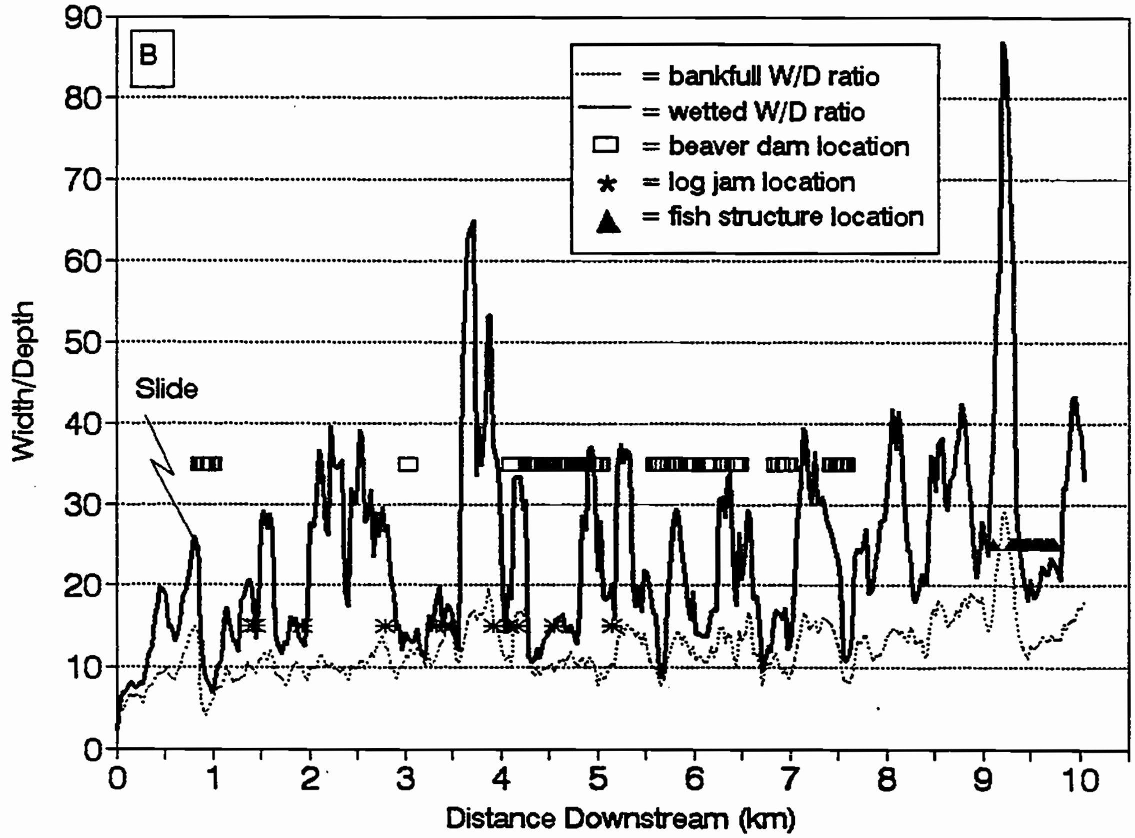


Figure 7. (continued)

1-2.7 km and 3-4.5 km, rather than a result of sediment deposition due to the landslide. In addition the wetted cross-sectional area does not appear to be greatly different from reaches upstream of the landslide.

The important influence of beaver on the stream system is further demonstrated in Figures 8a and 8b. Wetted thalweg depths and wetted widths associated with beaver ponds largely tend to fall above the regression lines of depth and width versus distance downstream. In contrast, channel morphology associated with log jams in close proximity to the slide, tend to be narrower and shallower (Figures 7a and 7b) than other portions of Esmond Creek downstream from the Waste Slide. Because log jams generally attenuate sediment transport, they may be partially responsible for the deposition of sediment between 0.84 and 3.5 km that was most notable form 1991 field observations.

Although data on reaches with fish structures was collected, the influence of fish structures on channel morphology was beyond the scope of this study. In addition, the structures were located in those reaches farthest from the Waste Slide (9-9.8 km) where their interaction with the slide would be limited.

1984 and 1991 Widths and Depths

Differences between widths and depths from 1984 to 1991 may be attributable to differences in flows. Stream

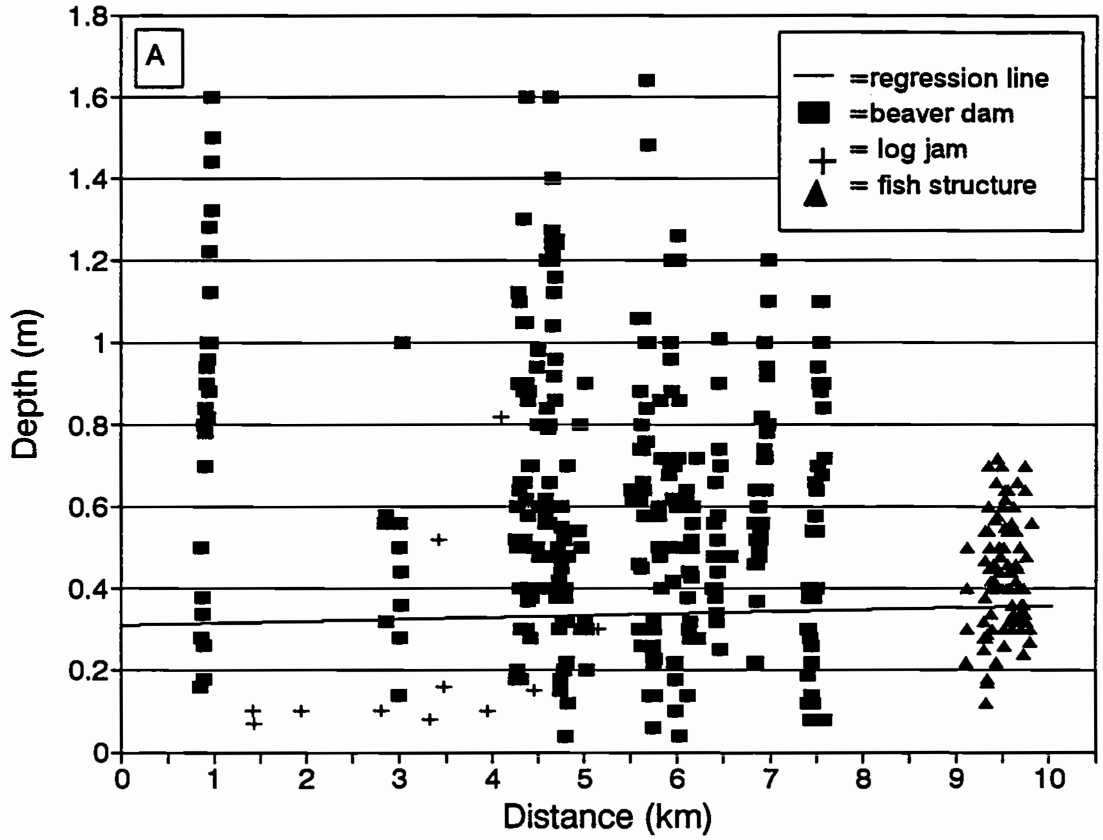


Figure 8. (A) Wetted thalweg depth and (B) wetted width versus distance downstream and depths and widths associated with beaver ponds, log jams and fish structures.

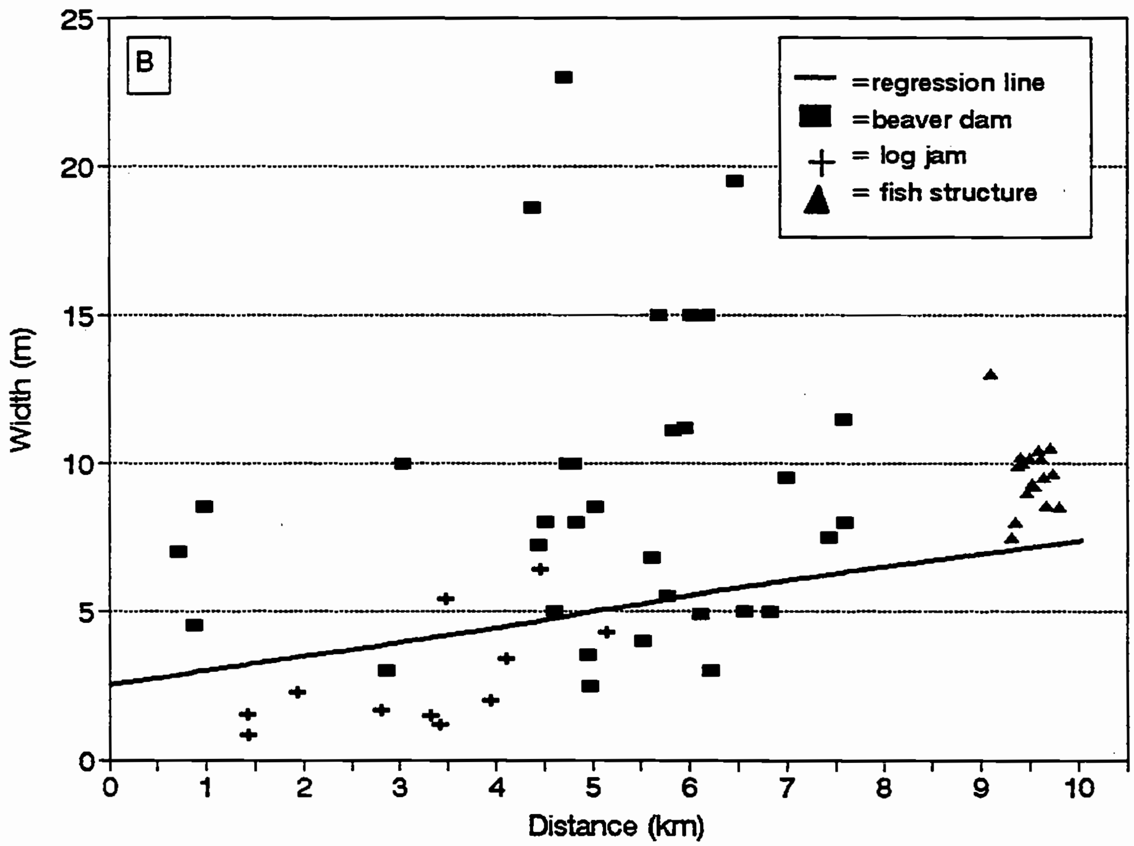


Figure 8. (continued)

gage data from the Mapleton Station on the Siuslaw River reveal that average daily discharge during the months of July and August was 28% lower in 1991 than in 1984 (Appendix B). However, adjusting the data by 28% was considered inappropriate for three reasons:

(1) The adjustment would be based on an assumption that the difference in flows on Esmond Creek between 1984 and 1991 was of the same magnitude (28%) as that of the Siuslaw River. Esmond Creek is a 2nd-3rd-order drainage that most likely does not have the same hydrologic response as a larger river;

(2) A 28% change in flows may correspond to smaller changes in widths and depths based on hydraulic geometry relationships (Richards, 1982):

$$w = aQ^b$$

$$d = cQ^f$$

An exponent of 0.05 for b and 0.45 for f is applicable to stable, cohesive, silty-bank sediments in which a trapezoidal cross-section is maintained. Thus, a 28% difference in flows may correspond to a 1% and 15% adjustment in widths and depths, respectively. An exponent of 0.33 for b and f is applicable to cohesionless, homogeneous sands in which a broad parabolic cross-section occurs. In this later case a 28% difference in flow corresponds to a 10% adjustment of widths and depths;

(3) Other sources of error (e.g. differences in measuring techniques between 1984 and 1991, changes in the spatial distribution of beaver ponds) may exceed the magnitude of adjustments attributable to flow differences.

Thus, the data were not adjusted in an attempt to account for flow-related changes in widths and depths. The following analyses were applied using the original 1984 and 1991 data.

The single maximum thalweg depth for each reach in 1984 (pre-slide) was compared to the single maximum thalweg depth for each reach in 1991 (post-slide) (Figure 9). While statistical analysis is not applicable, this comparison is useful for two reasons. First, it is the most viable comparison, in that the difference in sampling design between 1984 and 1991 should not influence the results. Secondly, this comparison may be useful in interpreting the statistical results of following comparisons, in which sampling design differences may influence the results. The only reaches in which channel depth increased since 1984, were those in which beavers were present during both years (Figure 9), with the exception of Reach 2 (upstream from the landslide). Furthermore, the only reaches in which the depths decreased were those absent of beaver ponds, with the exception of Reach 1 (also upstream from the landslide).

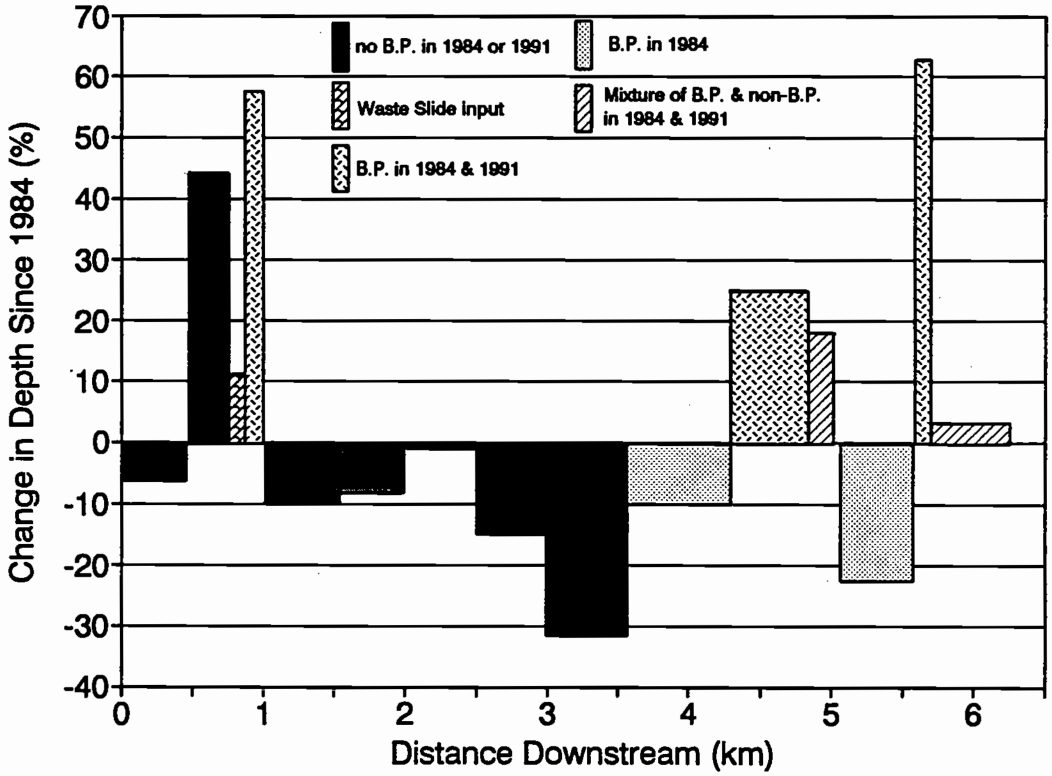


Figure 9. Percent change in maximum thalweg depths per reach from 1984 to 1991. B.P. = beaver pond.

It is also apparent from Figure 9 that an upstream/downstream comparison is an inappropriate analysis for deciphering the effects of the Waste Slide. The two reaches upstream from the landslide, and Reach 3 in which the landslide enters Esmond Creek, do not provide adequate control reaches since rather large changes in depth have occurred since 1984. The changes which occur upstream from the landslide may be used to define a margin of error. In Reach 2, immediately upstream of the Waste Slide, 1991 depths were 44% greater than 1984 depths. Therefore if a change in channel morphology has occurred due to the landslide, and the margin of error is accounted for, then that change should be greater than 44%. The only reaches in which a change of this magnitude has occurred are 4 and 14, however, these changes correspond to beaver activity rather than landslide impacts. Both of these reaches were dominated by beaver activity in 1984 and 1991, but the number of beaver dams increased over the 8 year period. It is possible that beaver respond to aggradation, by increasing dam height, thus "drowning out" the measurable impacts of the landslide. A more detailed analysis follows, including statistical testing, which investigates the influence of beaver dams on changes in widths and depths.

Summary statistics and statistical results from reach by reach comparisons can be found in Appendices B-E. While t-tests and Wilcoxon tests are useful in determining statistically significant differences in means, it is vital to recognize the limitations of such tests. First, as previously discussed, the differences in sampling design may affect the results. Second, in some cases there were sufficiently large differences in sample sizes and variances such that t-test assumptions were not met, even though t-tests are considered robust in terms of unequal sample sizes. The point at which robustness is considered inadequate, is when sample size (n_1) is greater than two times that of the other (n_2) and the ratio of variances (S^2_1/S^2_2) is greater than two (Ramsey and Schaefer, 1991). Unequal variances were often corrected by transforming the data using logarithm and square-root functions. If this did not accomplish the acceptable ratio of variances, then the Wilcoxon test, a "distribution-free" test, was utilized. In light of these limitations to the statistical analysis, it would be inappropriate to make unequivocal conclusions on the basis of statistical results alone. The aggregate of information, combined with field observations was used to determine if and how the landslide affected channel morphology.

There are two sets of measurements available from each year. In 1984, for every habitat identified (1) mean width and depth were estimated and (2) maximum width and depth were measured. In 1991, (1) width was measured every 30 m, and (2) thalweg depth was measured every 5 m.

A direct comparison of average 1984 mean depths to average 1991 thalweg depths is inappropriate since the 1984 mean depth represents the entire habitat (cross-sectionally and longitudinally), while the 1991 thalweg depth represents only the deepest portion of the channel. A direct comparison of 1984 thalweg depths to 1991 thalweg depths is also inappropriate since for a given reach in 1984 there may only be one measurement of thalweg depth while in 1991 that same reach may be represented by 10 thalweg depth measurements. Thus, rather than rely on one set of parameters (i.e. mean measurements, or maximum measurements), both mean and maximum measurements from 1984 were utilized to provide an evaluation criterion to determine if changes in channel morphology took place due to the landslide.

The null hypothesis was no detectable change in depth and width. The null hypothesis was not rejected if the average 1991 measurements fell between the 1984 mean and maximum measurements (1.e., 1984 mean $\leq$ 1991 $<$ 1984 maximum). Thus, the only circumstances under which the null hypothesis was rejected ($\alpha = 0.01$, $\alpha = 0.05$) and a change in depth or width was accepted included the following:

(1) average 1984 mean depth $>$ average 1991 thalweg depths

or,

(2) average 1984 thalweg depth $\leq$ average 1991 thalweg depths

Similarly, circumstances under which a change in width was accepted (α = 0.01, α = 0.05) included:

(3) average 1984 mean width $>$ average 1991 width

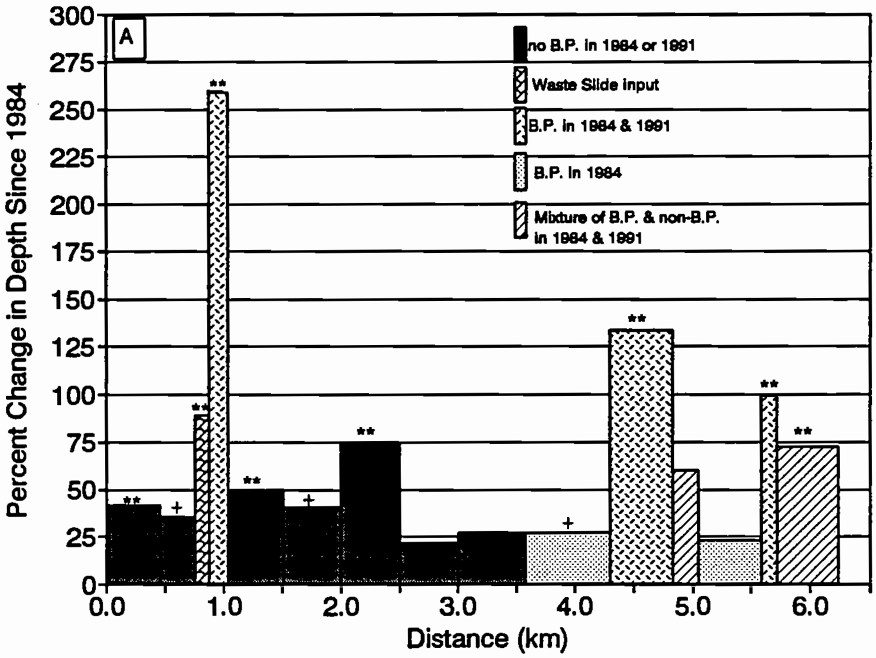
or,

(4) average 1984 maximum width $\leq$ average 1991 width

Rejection of the null hypothesis would indicate that in 1991 the reach was shallower under evaluation criterion (1) and deeper (2), narrower under (3) and wider under (4).

The percent change in width and depth since 1984, with respect to the mean 1984 measurements and the maximum 1984 measurements, was computed for all 15 reaches and graphed in Figures 10a, 10b, 11a, and 11b. Statistical results (α = 0.01, α = 0.05) from t-tests and wilcoxon analysis are also indicated.

Reaches 1 and 2 are above the landslide. When the 1984 mean depth measurements were compared with the 1991 thalweg depth measurements (Figure 10a), t-test results indicate that average 1991 channel depths for Reaches 1 and 2 were 41% and 36% greater (respectively) than the average 1984 mean depths. There were no statistical differences between average 1984 maximum thalweg depths, and average



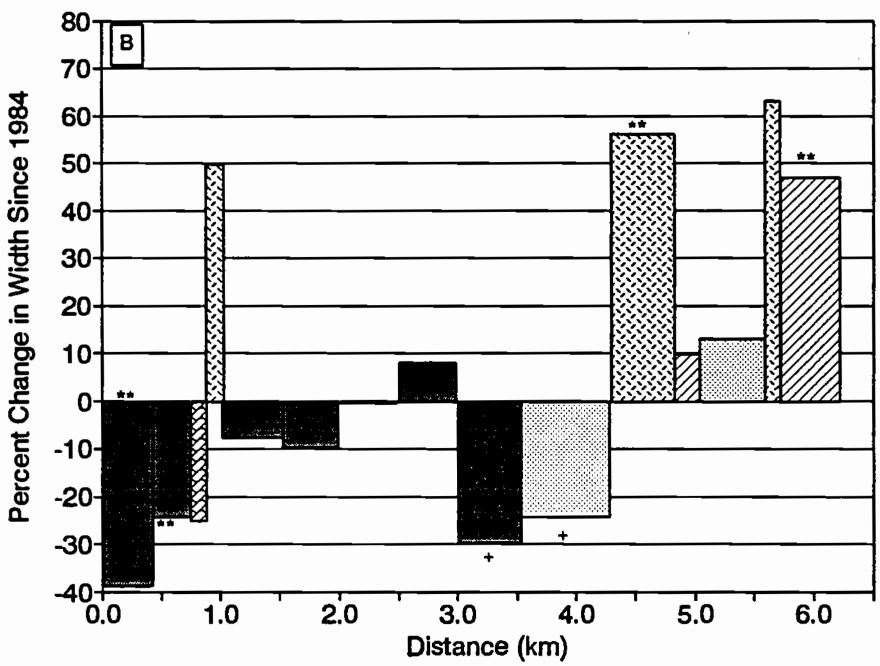
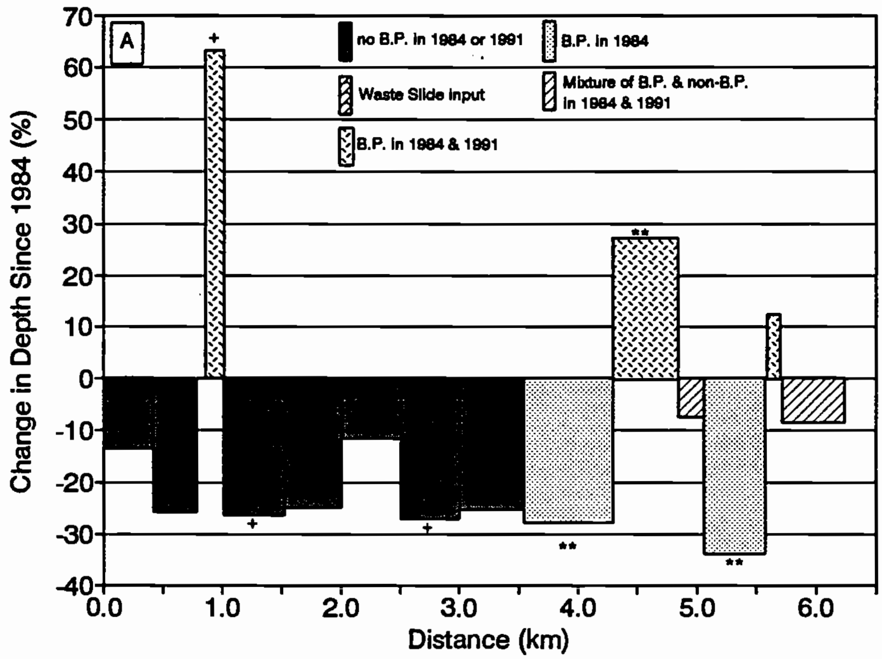


Figure 10. Percent change in (A) reach depth based on 1984 mean depths and (B) reach width based on 1984 mean widths. Significant changes at $\alpha = 0.01$ indicated by (**) and $\alpha = 0.05$ by (+). B.P. = beaver pond.



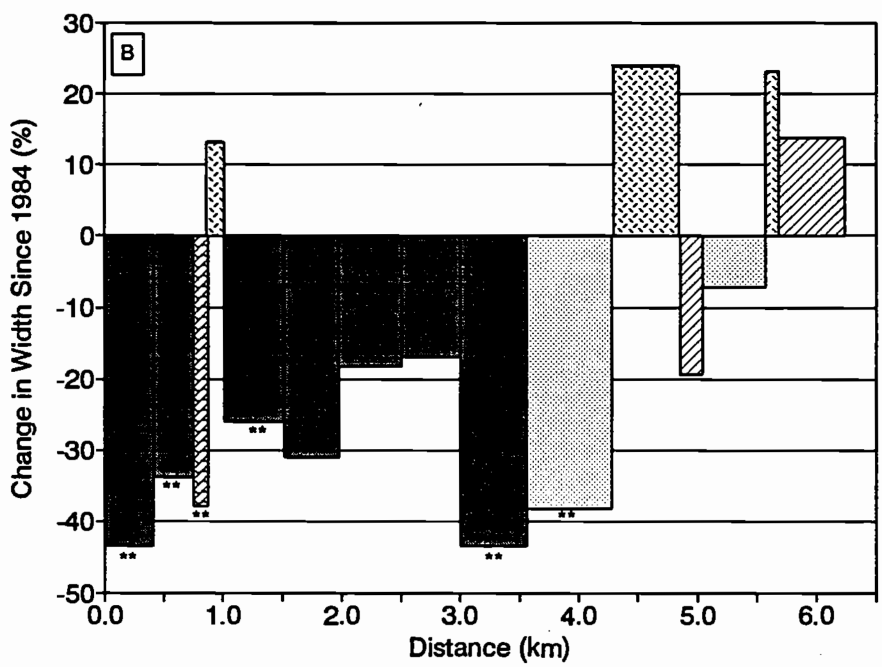


Figure 11. Percent change in (A) reach depth based on 1984 maximum depths and (B) reach width based on 1984 maximum widths. Significant changes at $\alpha = 0.01$ indicated by (**) and $\alpha = 0.05$ by (+). B.P. = beaver pond.

1991 thalweg depths (Figure 11a). Based on the evaluation criterion established above, these results suggest that the portion of Esmond Creek upstream from the landslide was deeper in 1991 than in 1984. Average 1991 channel widths were 39% and 24% less than the average of the mean 1984 channel widths for Reaches 1 and 2 (Figure 10b). This is strong evidence to support a decrease in width since 1984.

In total the results indicate that the portion of channel upstream from the Waste Slide was wider and shallower in 1984 than in 1991. The cause of this change could be due to differences in measurement techniques, flows, or some other factor. These results confirm the earlier conclusion that the upstream channel morphology should not be considered as a control reach.

The 1991 average reach depths were consistently greater than the averaged mean depths of 1984 for all 15 reaches (Figure 10a). However, Reaches 4, 11 and 14 increased in depth over 1984 averaged mean depths by at least 100%. In addition, Reaches 4 and 11 were 63% and 27% greater in depth over the 1984 averaged maximum depths (Figure 11a). For Reach 14, there was no statistical difference between average 1984 maximum thalweg depths and 1991 average thalweg depths. These results indicate a general increase in depths Reaches 4, 11, and 14.

Reaches 4, 11, and 14 also increased in width by 50%, 56% and 63%, respectively, over the averaged mean widths of

1984, but only Reach 11 showed a statistically significant difference (Figure 10b). There were no statistical differences between 1984 maximum wetted widths and 1991 wetted widths (Figure 11b) for Reaches 4, 11 and 14.

In 1991, average depths and widths of Reach 15 were 72% and 47% greater than the average 1984 mean depth and mean width (Figures 10a and 10b). There were no statistical differences between the 1984 maximum measurements of depth and width and the 1991 measurements (Figures 11a and 11b). These results indicate that Reach 15 was deeper and wider in 1991 than in 1984.

Beaver activity represents a common denominator between Reaches 4, 11, 14 and 15. In both 1984 and 1991 Reaches 4, 11, and 14 were dominated by beaver ponds, and Reach 15 had a mixture of beaver-pond and non-beaver-pond influenced channel. However, over the 8-ear period, there was an increase in the number of beaver dams on these reaches. Therefore, the wider and deeper channel in 1991 is most likely a response to increased beaver activity rather than a relationship associated with the Waste Slide.

Reaches 9 and 10 are the only other reaches which have changed substantially. The 1991 widths decreased by 40% and 24% respectively below the 1984 averaged mean widths (Figure 10b). Similarly, decreases in maximum widths of 44% and 38% for Reaches 9 and 10, respectively, are shown in Figure 11b. The statistical evidence tends to support a conclusion that channel depths remained unchanged.

Field notes for Reaches 9 and 10 indicate heavy deposits of sediment along the perimeter of pools, but deposits attributable to the Waste Slide, identifiable by the red-brown signature, became less distinguishable beyond 3.5 km, or beyond Reach 9. If the statistical evidence is reflecting a landslide influence, it is possible that Reach 9 was sufficiently influenced by sediment such that the channel capacity has decreased along with a concurrent decrease in wetted area. However, for reaches upstream from the landslide in 1991 widths were also 25-40% less than 1984 widths (Figure 10b and 11b).

Reach 10 was dominated by beaver ponds in 1984, whereas in 1991 there were no beaver ponds. A loss of beaver ponds is the most likely cause of decrease in width along Reach 10.

The presence of beaver has significantly altered the channel morphology of Esmond Creek since 1984. Increases in channel widths and depths generally correspond with increased number of beaver dams. Although, beaver related changes were detectable by comparing the 1984 and 1991 data, changes attributed directly to the Waste Slide were not conclusive.

The beaver ponds located directly below the toe of the landslide (Reach 4) undoubtedly increased the sediment storage capability of Esmond Creek by increasing width and depth, and creating a depositional environment. Anticipated changes in channel morphology (i.e. increased width/depth ratios) that might have occurred due to increased sediment input, may have been mitigated by beaver activity.

Width/Depth Ratios

Habitat surveys from 1984 provide two measurements of width/depth ratios; mean width divided by mean depth, and maximum width divided by maximum depth. The ratio of maximums was utilized in the comparisons between 1984 and 1991, since the 1984 measurements of maximum width and depth taken in 1984 were likely to be more accurate than the estimates of average width and depth.

Landslide related changes in width/depth ratios were not detectable. Increased width/depth ratios are an expected result of increased sediment supply. There were no statistically significant differences on a reach by reach basis between 1984 and 1991 width/depth ratios, except along Reaches 1 and 13 (Figure 12). Average W/D ratios for Reach 1 were 36% lower in 1991 than in 1984. For Reach 13, the mean 1991 width/depth ratio was 58% greater than in 1984. The change in morphology along Reach 13 is likely attributable to a loss of beaver activity rather than increased sediment deposition. The basis for this conclusion are three-fold: (1) Reaches 13 and 10 are

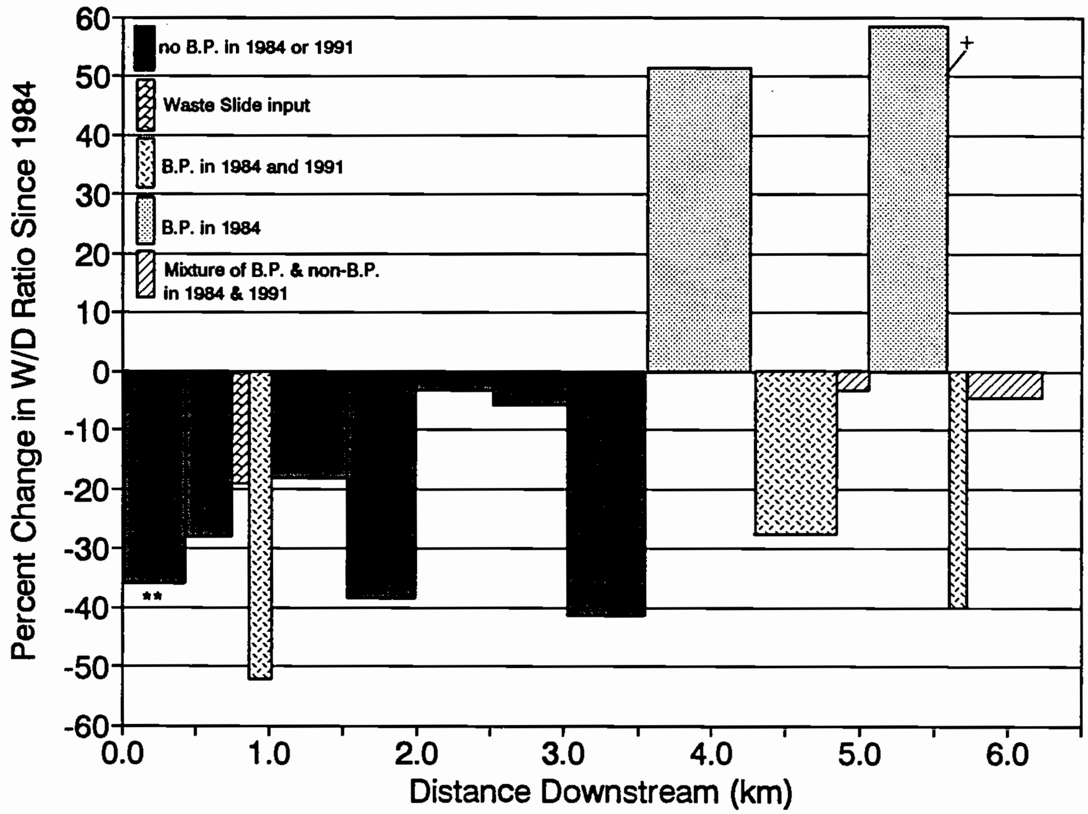


Figure 12. Percent change in reach W/D ratios based on the maximum width and depth measurements from 1984. Significant changes at $\alpha = 0.01$ indicated by (**) and $\alpha = 0.05$ by (+). B.P. = beaver pond.

the only reaches in which beaver activity were present in 1984 and not in 1991. Although not statistically significant, Reach 10 was the only other reach in which W/D reaches increased; (2) field observations indicated that Waste Slide influences, recognizable by red-brown silt deposition, diminished approximately 1.5 km prior to Reach 13; and (3) as described in the previous section, beaver activity appears to increase both channel width and depth. Therefore a loss of beaver activity appears to have resulted in a greater decrease in depth than in width, thus increasing width/depth ratios.

The remaining reaches all showed a decrease in width/depth ratios with only one greater than 50%, Reach 4. Again, this reach is the first reach downstream from the landslide, and it was dominated by beaver in 1984 and 1991. The reaches upstream from the landslide also showed a decrease in width to depth ratios, 36% and 28% for Reaches 1 and 2 respectively. Changes along Reach 2 were not statistically significant.

Decreased width/depth ratios are contrary to the expected landslide influence, therefore there is little evidence to support landslide-related changes in channel morphology using width/depth ratios.

Morphological Comparisons on the Basis of Habitat Type

Pools. Habitat comparisons based on the initial 15 reaches were not possible due to small sample sizes.

Therefore reaches were combined to form a total of 5 habitat reaches (Table 3). The differences in sample sizes between 1984 and 1991 are a result of the differences in sampling designs (i.e. measurements on the basis of habitat unit in 1984 versus systematic measurements in 1991). Pool depths and widths were compared with and without beaver ponds (statistical summary and results are reported in Appendix C).

A comparison of widths of pools without beaver ponds, from 1984 to 1991, reveals no significant difference in pool widths in any of the reaches. However, analysis of habitat reaches with beaver ponds, reveals that the 1991 widths were significantly ($\alpha \leq 0.05$) greater than 1984 widths along Reach 5.

Comparisons of pool depths in 1991 compared to 1984 without beaver ponds, indicated that 1991 pool depths along habitat Reaches 1, 3, 4, and 5 were "bracketed" by the average and maximum depths from 1984 (1984 means < 1991< 1984 maximums), indicating no perceptible change since the landslide. Pools along Reach 2 may have been deeper in 1991 than they were in 1984 since there was no significant difference between the averaged 1984 maximum thalweg depths and the 1991 average thalweg depths. All pools along Reach 2 were attributable to beaver ponds.

These results support previous indications that increases in depth were likely due to beaver dams. They

Table 3. Habitat reaches and the associated number of pools, riffles and glides in 1984 and 1991.

	Habitat Reach Number [a]				
	1	2[b]	3	4	5
1984 Pools	10	—	48	68	49
1991 Pools	8	—	21	17	18
1984 Riffles	24	1	78	50	27
1991 Riffles	6	—	12	14	6
1984 Glides	22	2	57	51	16
1991 Glides	13	—	32	14	6

[a] Habitat Reach (HR) 1 includes Reaches 1-3, HR 2 includes Reach 4, HR 3 includes Reaches 5-8, HR 4 includes Reaches 9-11, HR 5 includes Reaches 12-15.

[b] HR 2 consisted of a combination of beaver ponds, glides and riffles in 1984 and 2 beaver ponds in 1991.

further support the conclusion that landslide-related changes in channel morphology were not detectable from these comparisons. Although zones of heavy sediment deposition were most commonly observed in pools, statistically significant differences in channel morphology were not evident.

Riffles and Glides. Reach comparisons of riffle morphology over the sampling period revealed increased depth and decreased width for Reach 1. Reach 3 increased in depth and Reaches 4 and 5 showed no significant differences in width or depth.

Glide widths also decreased along Reaches 1 and 4, with no significant differences for Reaches 3 and 5. No significant differences in depths were apparent in any of the reaches.

Previous analysis indicated that reaches upstream from the landslide had narrowed and deepened. It appears those changes occurred in glides and riffles. Changes in riffle and glide dimensions were unexpected, considering the lack of sufficient winter storms that might produce sufficient bedload transport to modify these stable bedforms. However, 350 m of the 740 m upstream from the landslide is relatively high gradient (avg. slope = 2.7%). In addition, Reach 1 begins 60 m downstream from Esmond Lake. Thus, relatively low sediment-laden discharge from the lake may have a greater capability to transport sediment immediately downstream from the lake than farther down in the stream, resulting in higher bedload transport and changes in otherwise stable bedforms.

Beaver Influences

As the 1991 field season unfolded, it became apparent that beaver activity in the Esmond Creek drainage could not be ignored. During the 1991 field season there were 33 beaver dams in 10 km of surveyed stream length (Table 4a). The first one was located immediately downstream of the toe of the slide. The dam was 1.7 meters high, spanned 8.5 meters across the channel and ponded water for 100 m, the largest pond on Esmond Creek. In Table 4, summary statistics of beaver ponds are presented for small, medium and large dams, defined on the basis of the dam length spanning the channel. The largest dam was 23 m in length and ponded water for 72 m.

The 6.2 km of Esmond Creek utilized in the 1984/1991 comparisons, included 16 beaver dams in 1984 compared to 26 in 1991. In 1984, 0.55 km, or 8.8% of total inventoried stream distance, was comprised of beaver ponds (Table 4b). During 1991, 1.1 km, or 17.5% of total inventoried stream distance, was comprised of beaver ponds.

The influences of beaver on Esmond Creek channel morphology were analyzed in two ways. First, the previous comparisons were made between reaches defined on the basis of the presence of beaver, providing an inherent means of

Table 4a. Beaver dam and pond statistics for 10 km of stream in 1991.

Characteristic	Size Class [a] Small	Medium	Large	All Ponds
Number of dams	10	11	12	33
Average length of dam spanning the channel. (m)	4.1	7.7	14.2	8.9
Minimum length (m)	2.5	5.5	10.0	2.5
Maximum length (m)	5.0	9.5	23.0	23.0
Standard deviation (m)	1.0	1.1	4.3	5.1
Average pool length	15.8	49.3	62.6	42.1

[a] Classification criterion for size class designation is based on the length of the dam spanning the channel: small dams $\leq$ 5 m, 5 m < medium dams < 10 m, and a large dam $\geq$ 10m.

Table 4b. Beaver pond influence on 6.2 km of stream inventory from 1984 and 1991.

Year	Number of Ponds	Distance [a] (km)	% of Reach
1984	16	0.55	8.8
1991	26	1.1	17.5

[a] Channel length affected by beaver ponds.

assessing the influence of beaver over time and in relation to the landslide. The second approach was to look at the influence of beaver ponds during each individual year, 1991 and 1984. This latter approach entailed comparing upstream and downstream channel morphology of reaches not influenced by beaver, with that of reaches that are dominated by beaver. The same 15 reaches that were defined initially were used for this comparison (statistical results are reported in Appendix E).

The upper-most, beaver-dominated reach is Reach 4. Reach 4 was 747% deeper and 112% wider than the upstream Reach 3, which had no beaver activity (Figure 13). Reach 4 was also 324% deeper and 78% wider than the downstream Reach 5 (no beaver activity). Reaches 11 and 14 were the lower-most beaver dominated reaches separated by a reach with no beaver dams and a reach with a mixture of beaver and non-beaver activity. Reach 11 (beaver dominated) was 151% deeper and 64% wider than Reach 10 (no beaver activity), and Reach 14 (beaver dominated) was 86% deeper and 33% wider than Reach 13 (no beaver activity).

Similar comparison were made between intermediate reaches (i.e. 5-6, 6-7, etc.) even though none were dominated by beaver activity (Figure 13). Statistical results indicate no significant difference in width and depth between non-beaver reaches, except Reach 6 and 7. Reach 7 is approximately 23% deeper than Reach 6. These

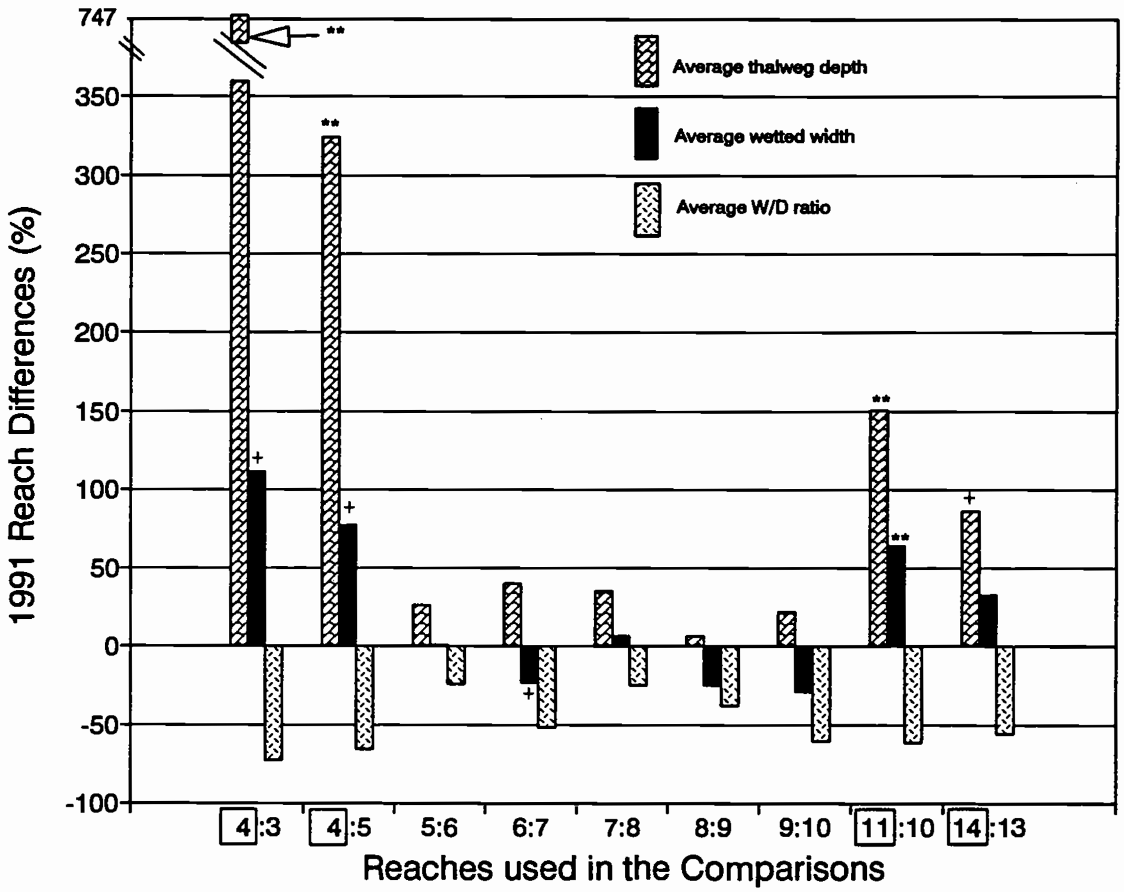


Figure 13. Comparisons of beaver-pond dominated reaches to non-beaver dominated reaches. Boxed numbers represent a beaver-pond reach. Intermediate reaches (i.e. reaches 5-10) don't have beaver ponds. Significance levels are indicated by (**) α = 0.01 and (+) α = 0.05.

results demonstrate the profound effect of beaver on wetted channel characteristics.

In 1984, beaver ponds were prevalent along Reaches 4, 10, 11, and 13. Maximum depths along Reach 4 were 161% and 86% deeper than Reaches 3 and 5, respectively. However, mean depths along Reach 4 were not significantly deeper than Reach 3, but they were 66% deeper than Reach 5. There were no significant differences in width. Reach 10 (beaver dominated) was 29% greater in width than 9. There were no statistical differences between Reaches 11 and 12 or Reaches 13 and 12.

Intermediate reaches were not significantly different from each other except Reaches 8 and 7. Mean depths along Reach 8 were 58% deeper than mean depths along Reach 7.

These results indicate that in 1991, channel reaches with a large number of beaver ponds were significantly deeper and wider than those without beaver. The beaver dominated reach which had the greatest difference in width and depth in relation to upstream and downstream reaches, was located immediately downstream from the toe of the Waste Slide (Reach 4). Reach 4 was 747% greater in depth than Reach 3 in 1991, as apposed to 161% in 1984.

Aggradation of Reach 3 (located along the alluvial fan of the Waste Slide) may be increasing the relatively large morphologic differences between Reach 4 and 3. Even so, depths were over 300% greater in Reach 4 than in the downstream Reach 5. Field observations indicate localized zones of heavy sediment deposition from Reach 5 to the end of Reach 9. Although aggradation in Reach 5 may be contributing to the differences in channel morphology, the increase in differences, from 66% in 1984 to 300% in 1991, between Reaches 4 and 5, may be primarily a result of increased size of dams since 1984. Unfortunately the sizes of beaver dams were not recorded in 1984.

Overall morphological difference between beaver pond reaches and upstream and downstream reaches was not as profound in 1984 as in 1991. This may be a function of aggradation from the landslide, or increased beaver activity and dam sizes on Esmond Creek since the 1984 surveys were completed.

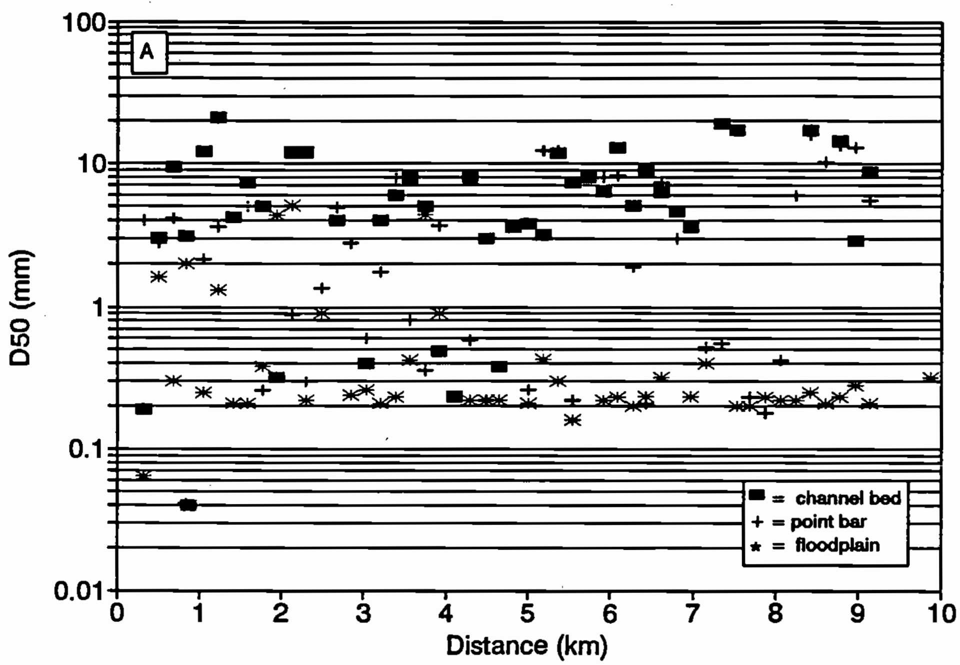
The 1991 comparisons of stream reaches without beaver activity to each other reinforces the conclusion that beaver activity is the cause of a wider and deeper channel. In addition, the lack of variation between reaches not dominated by beaver, and in close proximity to the landslide suggests an inability to detect landslide influences upon channel morphology (unless all reaches were equally impacted). Although the Waste Slide influenced approximately 40% (according to field observations and aerial photograph analysis) of the inventoried stream channel, beaver ponds which influenced 17.5% had a greater influence on channel morphology.

Particle Size Analysis Results

Characteristic diameters were calculated from the particle size distribution for each sample. These included: median diameter (D_{50}), geometric mean (D_g), and the standard deviation of the geometric mean (SD_g). These values were analyzed with respect to distance downstream, channel location (channel bed, floodplain and point bar), and trends associated with structural control.

Graphs of D_{50} and D_g versus distance downstream were constructed to investigate possible landslide effects. The expected trend in sediment size versus distance from the headwaters, is a decrease in particle size in a downstream direction. Figures 14a and 14b depict the D_{50} and the D_g, respectively.

Four observations can be derived from Figures 14a and 14b: (1) There is a divergence of the channel bed and floodplain geometric means in a downstream direction; (2) geometric means of the point bar samples are highly variable, and tend to fall between those of the floodplain and channel bed samples; (3) floodplain samples demonstrate decreasing particle size in a downstream direction, but the channel bed samples tend to increase, by virtue of a decrease in variability; and (4) from 0.2-5 km there are a number of channel bed samples in which the median grain diameter is less the 1 mm. The smallest D_{50} is 0.05 mm and



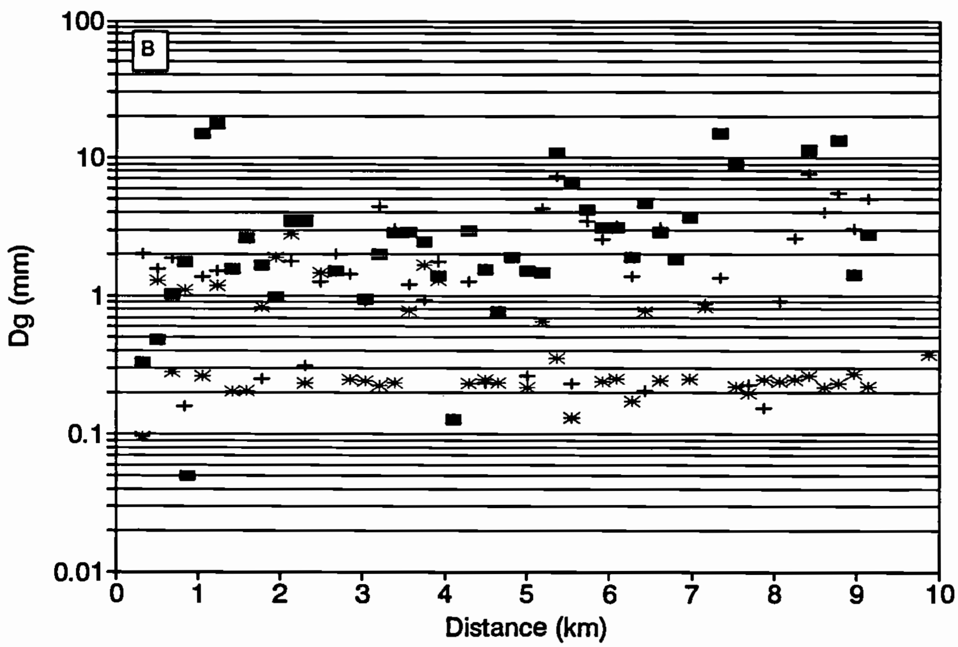


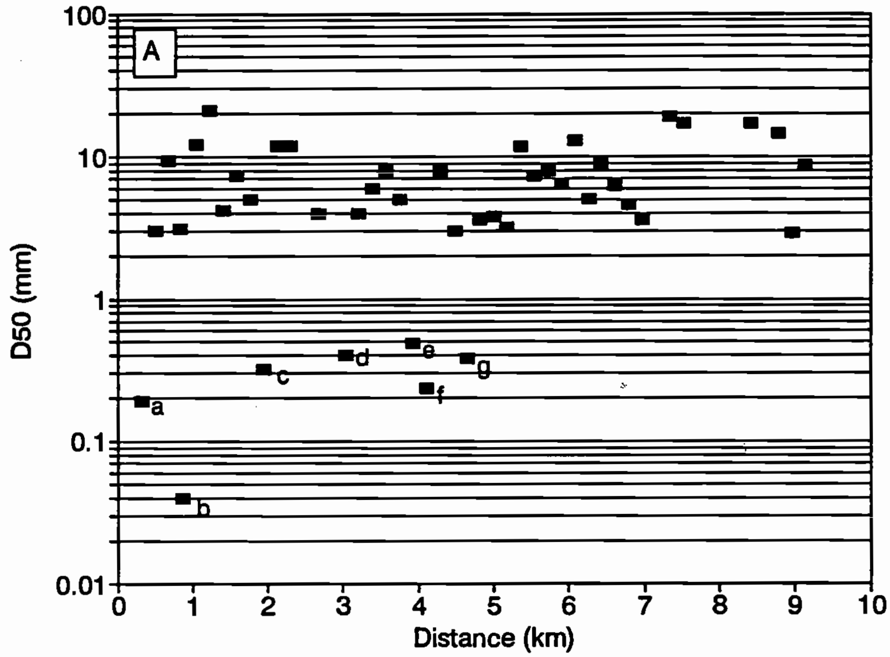
Figure 14. (A) D_{50} and (B) D_g versus distance downstream for channel bed, floodplain and point bar samples.

represents the channel bed at the base of the alluvial fan associated with the Waste Slide.

The next analysis evaluated sediment characteristics associated with channel bed, floodplain and point bar samples, Figures 15a, 15b and 15c, respectively. When the D_{50} of the channel bed is plotted against distance, most notable features are the 7 values less than 1 mm in size (denoted by lower case letters in Figures 15a). The stations from which these samples came include 330, 870, 1950, 3030, 3930, 4110, 4650.

Station 330 [a] was a unique site, upstream from the landslide, in which the channel bed was composed of highly compressed fines. This was a localized phenomenon totaling 7.3 m of channel bed, that was sampled as a part of the systematic sampling phase. The degree of consolidation and cohesion suggests formation took place many years ago. The time of deposition, combined with the high resistance due to cohesive forces, effectively reduces the possibility that this site functioned as a source of fine sediment to downstream locations, during the 1984 to 1991 sampling period.

The rest of the stations are located at the base of and downstream of the alluvial fan. Station 870 [b], has the smallest D_{50}, and is associated with the Waste Slide fan. Station 1950 [c] was a log jam, stations 3030 [d], 4110 [f] and 4650 [g] are all beaver ponds, and station



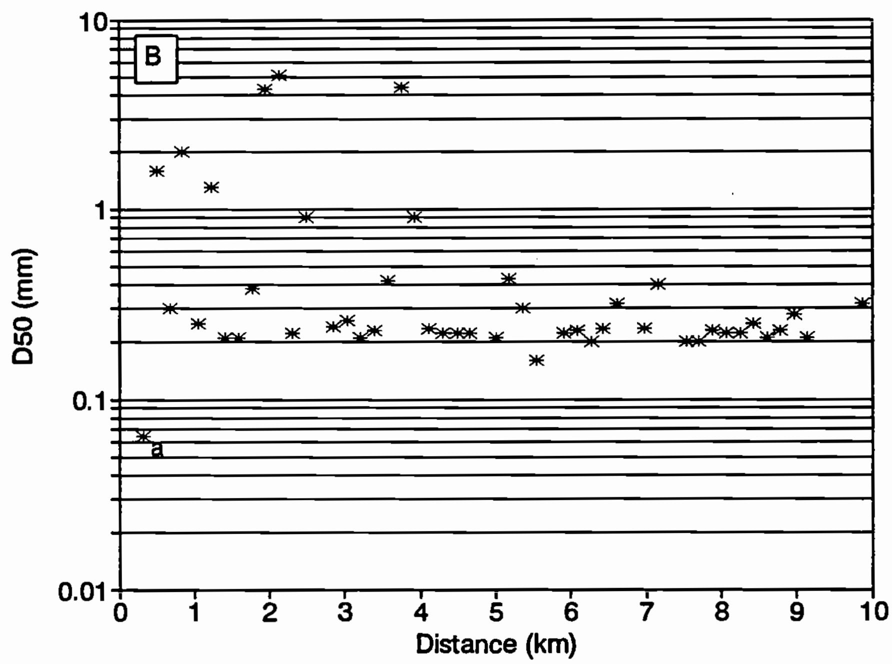


Figure 15. D_{50} versus distance downstream for (A) channel bed, (B) floodplain and (C) point bar samples. Lettered points are discussed in text.

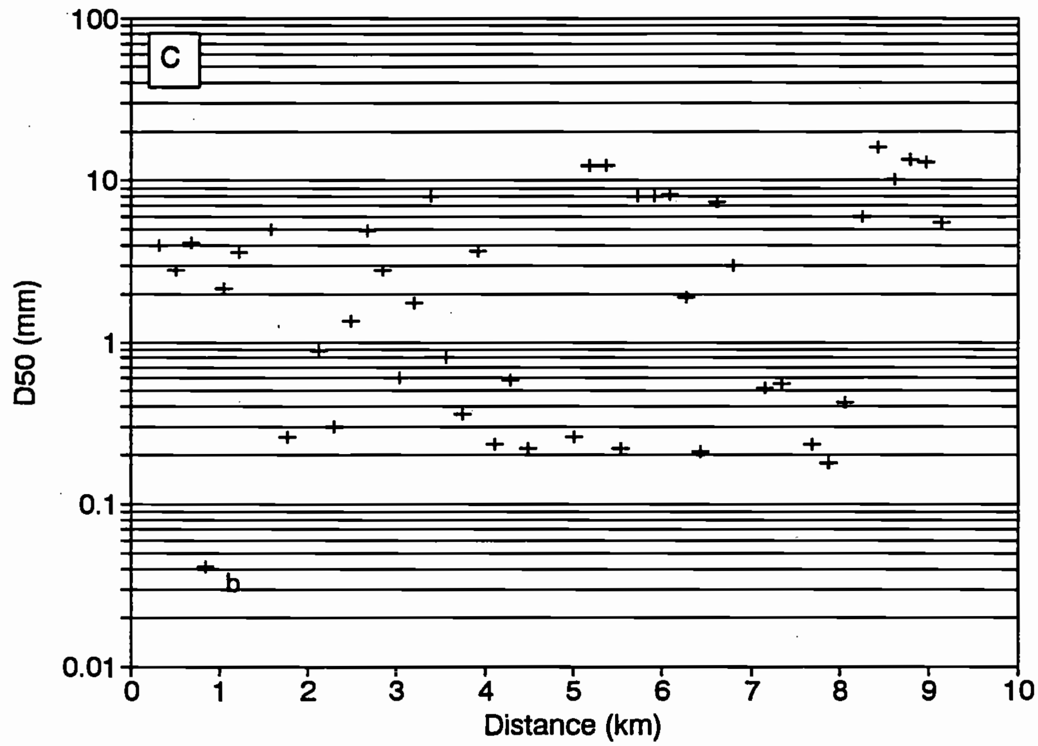


Figure 15. (continued)

3930 [e] was a pool. Thus, the channel bed locations, in which the finest sediment deposition took place were associated with the landslide input and quiet water environments. The relationship between beaver ponds, log jams and percent fines will be discussed later.

A plot of D_{50} versus distance for floodplain locations (Figure 15b) revealed a slight decreasing trend in D_{50}. In addition the variability is greater for the first 4 km than lower in the basin. A similar plot of D_{50} versus distance (Figure 15c) revealed high variability throughout the 10 km for the point bar samples. The smallest floodplain D_{50} [a] was associated with station 330, and the smallest point bar D_{50} [b] with the landslide input.

The relationship between SD_g and D_g is useful in the comparison of different settling environments (i.e. beaver ponds, log jams, channel bed and floodplain). Figures 16a and 16b are regressions of SD_g versus D_g for the channel bed and floodplain samples. In each case bedrock cross-sections, beaver pond and log jam influenced cross-sections were removed from the data set. The negative relationship between SD_g and D_g of the channel bed is very strong, ($r^2 = 0.75$, $p < 0.01$), while the floodplain relationship is positive ($r^2 = 0.64$, $p < 0.01$). A similar relationship with respect to the point bar does not exist.

The channel bed is a zone of transportation where fine particles are transported as suspended load and typically

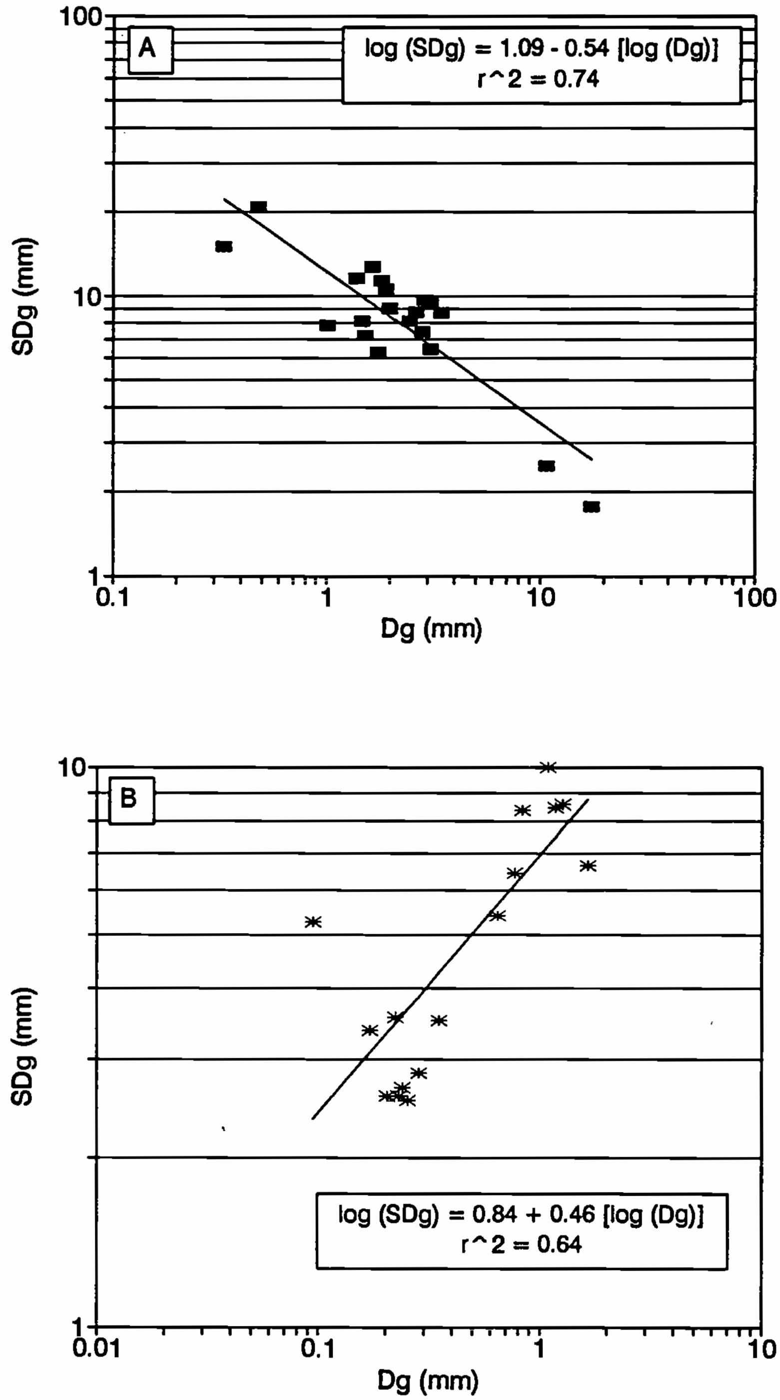


Figure 16. SD_g versus D_g for (A) channel bed and (B) floodplain locations.

do not deposit in the channel bed. Therefore the bed material consists mostly of larger particles. Subsequently, as fines are introduced into channel bed deposits, the standard deviation of the geometric mean may increase. Thus there is a negative relationship between SD_g and D_g (Figure 16a).

The opposite would be true for the floodplain. A properly functioning floodplain is predominantly a zone of deposition of fine particles which are transported as suspended load during higher flow events. As such the SD_g should be greater for samples in which larger particles occur. Thus there is a positive relationship between SD_g and D_g (Figure 16b).

Trends in sediment distribution with respect to habitat type were similarly analyzed (Figures 17a, 17b, 17c). The relationship between SD_g and D_g for channel bed samples associated with pools ($r^2 = 0.89$, $p < 0.01$), riffles ($r^2 = 0.77$, $p = 0.05$) and glides ($r^2 = 0.86$, $p < 0.01$) was negative, as was the case for the entire data set (Figure 17a).

An analysis of floodplain particle size distribution with respect to habitat type, revealed a positive relationship for pools, riffles and glides ($p < 0.01$), as was true with the entire data set (Figure 17b). As D_g increased so did SD_g for pools ($r^2 = 0.75$), riffles ($r^2 =$

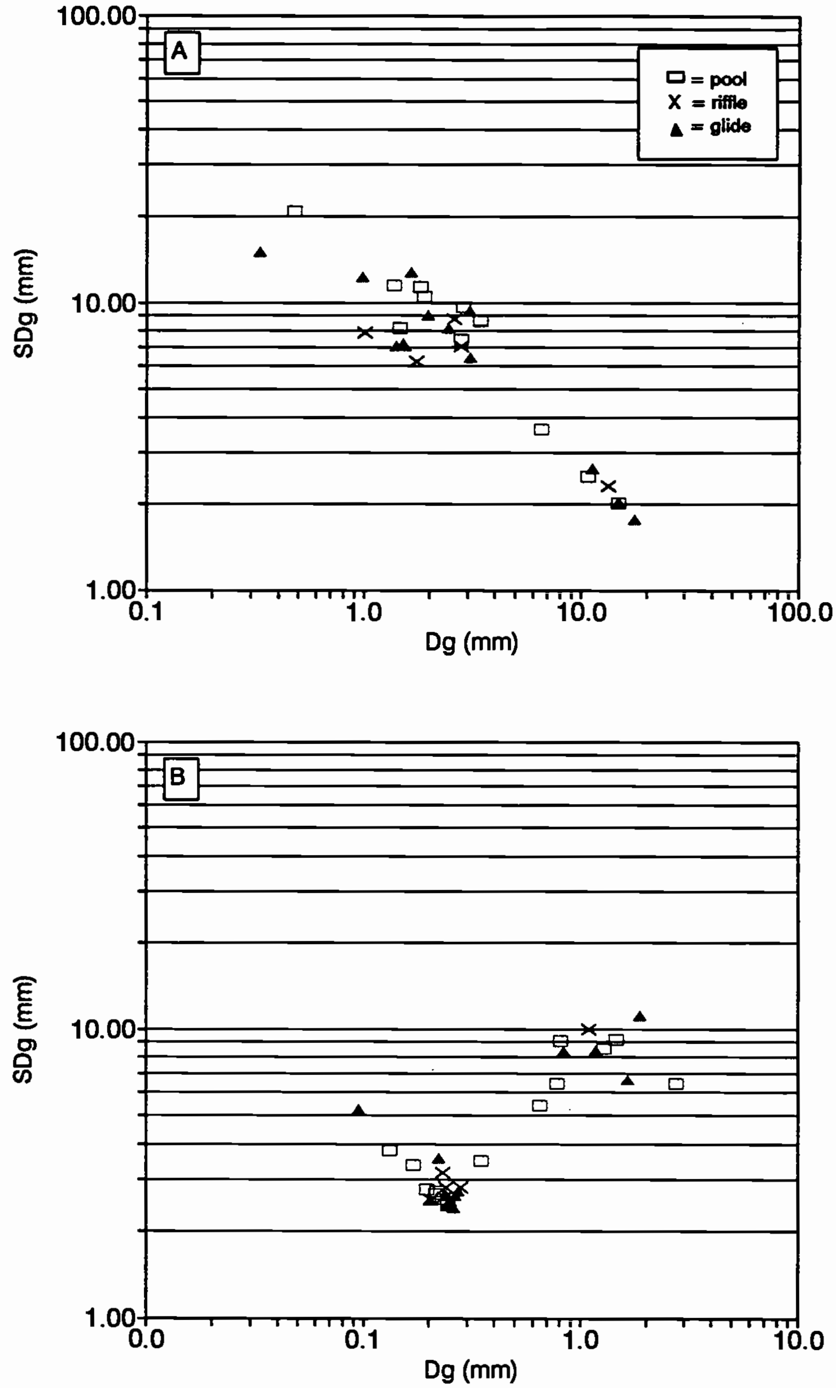


Figure 17. SD_g versus D_g for (A) channel bed, (B) floodplain, and (C) point bar locations. Symbols indicate habitat type.

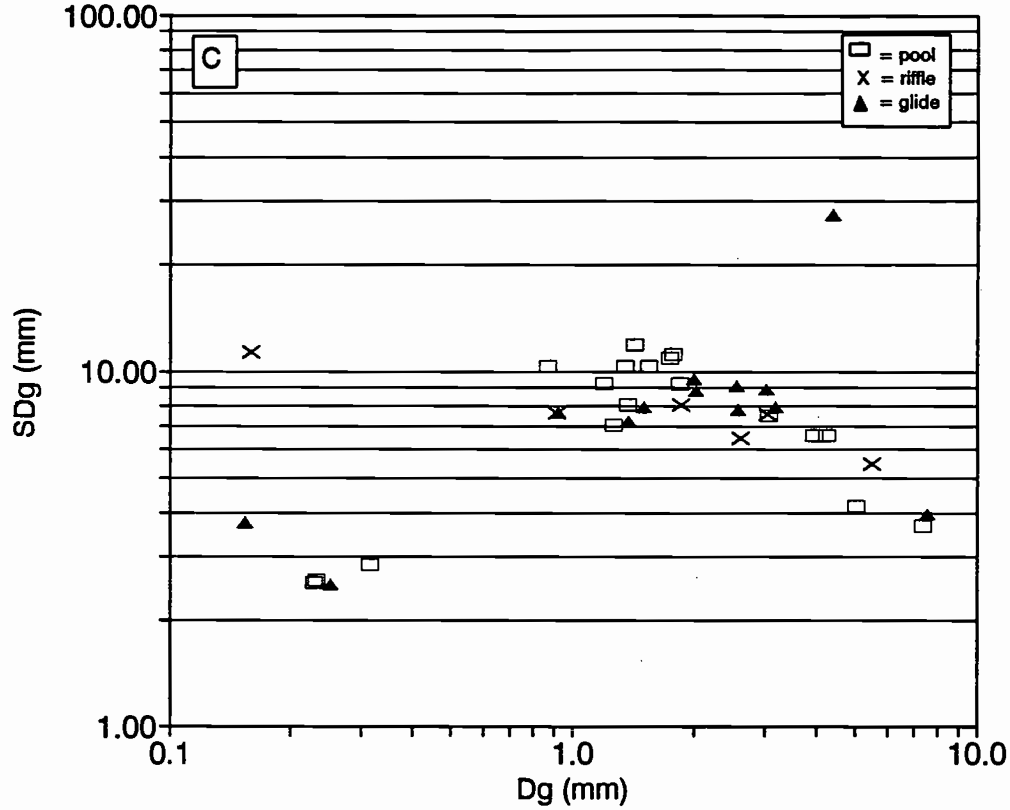


Figure 17. (continued)

0.97) and glides ($r^2 = 0.59$), with glides displaying a relatively poor correlation.

Finally, the same analysis performed with respect to point bars substantiated the earlier conclusion that the point bar is a zone of highly variable particle sizes (Figure 17c). The correlation between SD_g and D_g continued to be poor, with p-values > 0.05 for the those samples associated with pools and glides ($r^2 = 0.14$ and 0.34, respectively). Point bars associated with riffles displayed a negative relationship between SD_g and D_g ($r^2 = 0.85$, $p < 0.01$), in keeping with trends associated with pools. However, the sample size was only 6.

The question still remains, "What evidence is there of a landslide impact in the particle size distribution?". The only potential change in particle size distribution that could be detected was from Figure 15a, displaying D_{50} of the channel bed versus distance downstream. Seven sites were noted in which the median particle size was less than 1 mm. If the upper most site (station 330) is treated as an anomalous outlier, the only other upstream site was the landslide source. Therefore it is likely that one effect of the landslide is a decrease in mean particle diameter in certain depositional environments. Of the six other sites, one was at the toe of the Waste Slide, three were beaver ponds, one was a log jam, and one was a pool.

How then does the particle size distribution of beaver ponds and log jams compare with that of the rest of the system? Furthermore, is there an indication of interaction between the input of fines from the slide, and these structural control elements?

In an attempt to answer the first question, SD_g was plotted against D_g of channel bed samples located upstream of beaver dams and log jams (Figure 18a, 18b, and 18c). There is a positive correlation between SD_g and D_g for beaver ponds, with the exception of one data point [a] (Figure 18a). Point [a] came from the farthest downstream beaver pond. Sorting of particles in a downstream direction, and a change in the dominant sediment source, may account for this anomaly. If this point is treated as an outlier the explanation of variance in SD_g is $r^2 = 0.98$ ($p < 0.01$) for beaver ponds and 0.64 ($p = 0.01$) for log jams (Figure 18b), a positive relationship in both cases.

The positive relationships between SD_g and D_g displayed for the beaver-pond and log-jam channel bed samples are opposite of the relationship from the other channel bed locations. Pools, non-beaver pond and non-log jam cross-sections of the system displayed a negative relationship between SD_g and D_g. In addition, the channel bed relationships associated with beaver ponds and log jams, mimic those of the floodplain. This indicates that the depositional environment of beaver ponds induces fine sediment deposition along the channel bed (as does the

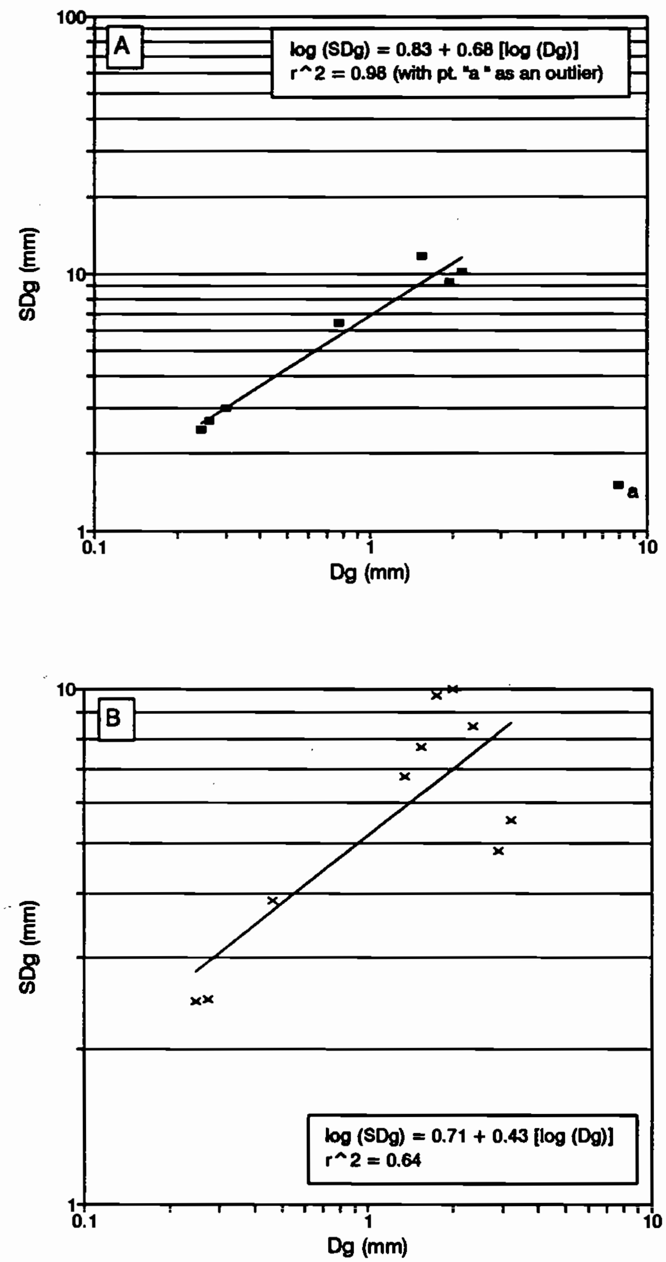


Figure 18. SD_g versus D_g for (A) beaver pond, (B) log jam and (C) an aggregate of beaver pond and log jam locations.

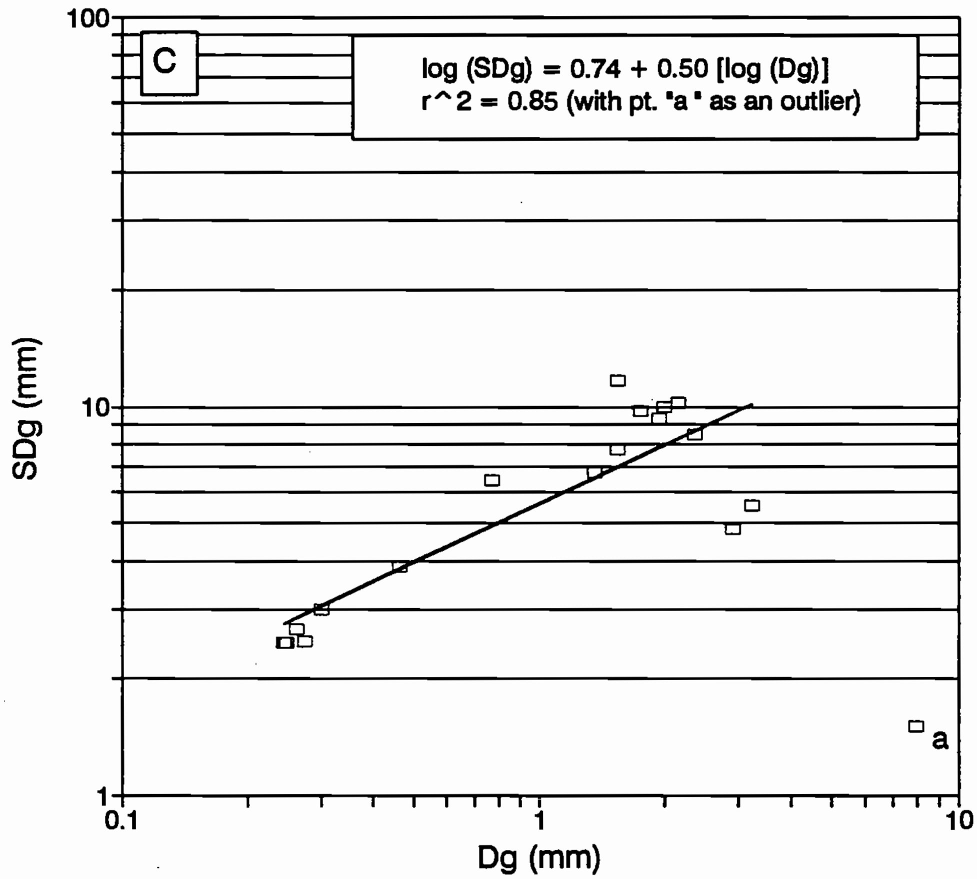


Figure 18. (continued)

floodplain), modifying sediment transportation of the stream channel.

Assuming the processes involved in sediment deposition for beaver ponds are similar to those of log jams it is reasonable to graph the two data sets together (Figure 18c). Assuming point (a) is an outlier, the result is an $r^2 = 0.85$ ($p < 0.01$).

No relationship was evident between the SD_g and D_g of the floodplain with respect to beaver ponds. This result directly conflicts with the results involving the entire data set, in which there was a positive correlation between SD_g and D_g. This may be attributable to the wetted channel, rather than the floodplain, functioning as the primary zone of sediment deposition in beaver ponds. In addition, the floodplain associated with beaver ponds tended to be a zone of greater soil development than along other reaches of stream channel. Soil development may have altered sieve results in two ways: (1) increased organic matter while relatively light may have altered weight retained on each sieve, and (2) soil aggregates would not have broken up as easily into smaller particles.

A positive relationship between SD_g and D_g was maintained in the case of floodplain samples associated with log jams ($r^2 = 0.73$, $p < 0.01$). There was a weak positive relationship between SD_g and D_g for point bar samples associated with log jams ($r^2 = 0.44$, $p = 0.05$).

This result differs from that of the entire data set in which there was no relationship, and from the relationship associated with riffles in which there was a negative slope.

To investigate sorting of particles in a downstream direction, D_g was regressed versus distance downstream for channel bed samples associated with beaver ponds. The model was not statistically significant.

Particle size analysis revealed locations in which geometric mean diameters of the channel bed were uncharacteristically low, potentially a result of sediment deposition related to the Waste Slide. However, three out of seven of these were associated with beaver ponds. Further analysis revealed that beaver ponds may be trapping fine sediment possibly mitigating longitudinal extent of the Waste Slide effects. However, similar results may have been obtained even if the Waste Slide had not occurred. That is, beaver ponds tend to trap fine particles, so the D_g of particles deposited in channel beds associated with beaver ponds are expected to be relatively low.

SUMMARY AND CONCLUSIONS

Field observations in 1991 indicated that sediment deposition occurred along Esmond Creek in response to the Waste Slide of 1988. The longitudinal extent of observed sediment deposition was approximately 2.5 km downstream of the slide input. These field observations concurred with aerial photograph analysis.

Aerial photographs from 1979 (prior to the Waste Slide) indicated sediment was delivered to Esmond Creek by means of tributary channels from upland sources. The portion of Esmond Creek most heavily affected by the Waste Slide of 1988, appeared to have aggraded by 1979 as a result of sediment deposition from previous landslides. Although, revegetation and reduced sediment yield from these sources had occurred by 1990, sediment deposition at the mouth of Esmond Creek where it enters the Siuslaw River had increased from 1979 to 1991.

The results of this study were inconclusive in determining to what extent the channel morphology of Esmond Creek has been altered as a result of sediment delivery from the Waste Slide. Part of the problem in analytically establishing cause-and-effect changes in channel morphology was that Esmond Creek may have been continuing to aggrade in response to pre-1988 sediment yields.

The presence of beaver on Esmond Creek has further confused potential sedimentation effects from the 1988 slide. Beaver dams have dramatically altered typical channel morphology by creating wide and deep channels. Reaches in which major changes in channel width and depth have occurred since 1984 were those in which beaver activity had either increased of decreased since 1984.

Channel morphology measurements and analysis using 1984 and 1991 data did not prove effective in defining where sediment deposition took place. Field observations indicate the heaviest deposition was observed on the periphery of pools and at the bottom of pools. A comparison on the basis of habitat type revealed no significant differences in pool characteristics, with the exception of pools associated with beaver dams. Changes in channel widths and depths due to the Waste Slide were not found, although this result may be due in part to differences in sampling design.

Heavy sediment deposition was observed in beaver ponds. These ponds most likely altered the capacity of the channel to store sediment. Since 1984, the number of beaver ponds has increased from 16 to 26 along a 6.2 km portion of Esmond Creek.

Particle size distribution analysis revealed only seven sites in which the channel-bed median particle diameter was uncharacteristically low (< 1 mm); three of these were associated with beaver ponds. The variability of mean diameters was such that conclusive landslide effects were not obvious.

Instream processes involving sediment transport are modified by beaver dams and log jams. A regression of SD_g versus D_g revealed positive relationships for channel-bed samples associated with beaver ponds and log jams. In contrast, there was a negative relationship for non-beaver pond, non-log-jam, channel-bed samples. In addition the positive relationship for channel-bed samples associated with beaver ponds and log jams was evident for flood plain samples. Consequently, the channel bed which typically functions as zone of sediment transportation had been altered by beaver and large woody debris to function as a zone of deposition or a sink of sediment upstream of these structures.

Management Implications

This study revealed that the influence of beaver on stream morphology and sediment deposition, was greater than the influences of the Waste Slide. The influence of beaver on Esmond Creek may have increased the ability of the stream to mitigate anticipated effects of increased sediment input from the Waste Slide. Beaver activities which may be considered desirable on an ecosystem level are often considered problematic when human activity and beaver activity overlap. However, beaver are a significant and essential component of many stream ecosystems and should be included in watershed management plans.

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APPENDICES

APPENDIX A

PARTICLE SIZE ANALYSIS: A MECHANICAL METHOD

The following procedure for particle size analysis was obtained from Engineering Properties of Soils and Their Measurements, (Bowles, 1978). The analysis was undertaken to determine relative proportions of different grain sizes in a sample. This is achieved by passing an oven-dried sample through a set of stacked sieves ranging in size of mesh. The quantity, or in this case weight, of material that passes a given sieve opening but is retained on a sieve of smaller mesh opening is related to the weight of the entire sample.

The sieves used in analyzing the Esmond Creek samples are listed below in Table A1. Table A2 gives a list of Tyler Standard Screen Scale, and U.S. Series sieve diameters and numbers.

Table A1. Sieves used in analysis of Esmond Creek samples.

Sieve Numbers		Diameter (mm)
Tyler Mesh	U.S. Standard	
2.5	—	12.5
—	5	4.00
—	10	1.65
—	20	0.850
—	200	0.075
—	Pan	< 0.075

Table A2. Grain size classification, standard sieve diameters and sieve numbers, for Tyler and U.S. Standard sieves.

Class name (1)	Size Range: Millimeters (2)	Size Range: Millimeters (3)	Size Range: Microns (4)	Size Range: Inches (5)	Approximate Sieve Mesh Openings per inch: Tyler (6)	Approximate Sieve Mesh Openings per inch: United States standard (7)
Very large boulders		4,096-2,048		160-80		
Large boulders		2,048-1,024		80-40		
Medium boulders		1,024-512		40-20		
Small boulders		512-256		20-10		
Large cobbles		256-128		10-5		
Small cobbles		128-64		5-2.5		
Very coarse gravel		64-32		2.5-1.3		
Coarse gravel		32-16		1.3-0.6		
Medium gravel		16-8		0.6-0.3	2-1/2	
Fine gravel		8-4		0.3-0.16	5	5
Very fine gravel		4-2		0.16-0.08	9	10
Very coarse sand	2-1	2.000-1.000	2,000-1,000		16	18
Coarse sand	1-1/2	1.000-0.500	1,000-500		32	35
Medium sand	1/2-1/4	0.500-0.250	500-250		60	60
Fine sand	1/4-1/8	0.250-0.125	250-125		115	120
Very fine sand	1/8-1/16	0.125-0.062	125-62		250	230
Coarse silt	1/16-1/32	0.062-0.031	62-31			
Medium silt	1/32-1/64	0.031-0.016	31-16			
Fine silt	1/64-1/128	0.016-0.008	16-8			
Very fine silt	1/128-1/256	0.008-0.004	8-4			
Coarse clay	1/256-1/512	0.004-0.0020	4-2			
Medium clay	1/512-1/1,024	0.0020-0.0010	2-1			
Fine clay	1/1,024-1/2,048	0.0010-0.0005	1-0.5			
Very fine clay	1/2,048-1/4,096	0.0005-0.00024	0.5-0.24			

(Source: ASCE, Sedimentation Engineering, Vanoni editor, 1975)

Procedure

1) Place sample in clean pre-weighed pan and oven dry at 105 °C for 24 hours.

2) Weigh oven dry sample. If the sample displays cohesion then go to step 6.

3) Place sample on the stacked sieves with lid, and place in a mechanical sieve shaker. Sieve time was approximately fifteen minutes.

4) Weigh material retained on each sieve

5) Calculate percent finer (Figure A1).

6) Place sample on the No. 200 sieve. Carefully wash the material through with tap water until water passes clear of sediment. Poor residue into a pre-weighed dish. Poor off water after a brief settling period. Repeat steps 1-5, omitting step 2.

The results of the mechanical sieving process are commonly presented in the form of a particle size distribution curve. Percent passing, or percent finer, is plotted versus particle size on a logarithmic scale. The particle size coordinates correspond with the size of the sieve opening. From these distribution curves characteristic particle sizes such as median diameter (D_{50}), geometric mean (D_g), and standard deviation of geometric mean(SD_g), can be obtained.

Sample #: <u>(station #)</u> Date:________
Location: <u>(Point bar, Channel Bed, or Flood Plain)</u>
<u>Before Washing</u>:
1.) weight of tray + sed. ....
2.) weight of tray ....
3.) weight of sed. = (#1 - #2).............________
<u>After Washing</u>:
4.) weight of tray + dried sed. ....
5.) weight of tray.........................
6.) weight of dried sed. ....
7.) Weight of sed < No. 200 sieve
= (#3 - #6)...........________

Sieve No.	Wt. Retained	Percent Retained	Cumulative Percent Passing
2.5		**	*
5			
10			
20			
200			
pan			

**Percent Retained = $\frac{\text{Weight ret. on each sieve}}{\text{Total Weight of Original Sample}}$

*Cum. % Passing = 100% - cumulative percent retained

Sum of Weight on each sieve = Weight of original sample
if more then 2% is lost, repeat procedure.

Figure A. Example data and calculation sheet, for use in the particle size analysis.

APPENDIX B

SUMMARY STATISTICS OF 1984 AND 1991 DAILY DISCHARGE AND REACH DIMENSIONS

Table B1. 1984 and 1991 mean daily discharge at the Siuslaw River near Mapleton.

Date (mo/day)	1984 (cfs)	1991 (cfs)	Difference (%)
7/24	317	235	-25.9
7/25	343	236	-31.2
7/26	349	236	-32.4
7/27	327	231	-29.4
7/28	316	221	-30.1
7/29	308	213	-30.8
7/30	301	206	-31.6
7/31	293	200	-31.7
8/1	281	193	-31.3
8/2	273	188	-31.1
8/3	273	187	-31.5
8/4	270	182	-32.6
8/5	262	179	-31.7
8/6	261	178	-31.8
8/7	259	181	-20.1
8/8	251	186	-25.9
8/9	241	190	-21.2
8/10	235	188	-20.0
8/11	229	177	-22.7
8/12	225	169	-24.9
8/13	225	165	-26.7
8/14	224	161	-28.1
8/15	219	160	-26.9
8/16	215	158	-26.5
8/17	210	157	-25.2
8/18	208	156	-25.0
8/19	204	153	-25.0
8/20	198	153	-22.7
8/21	195	148	-24.1
8/22	192	143	-25.5
8/23	192	140	-27.1
8/24	192	138	-28.1
8/25	190	138	-27.4
8/26	186	134	-28.0
8/27	182	142	-22.0
Avg. for sampling period........	247	178	-28.0

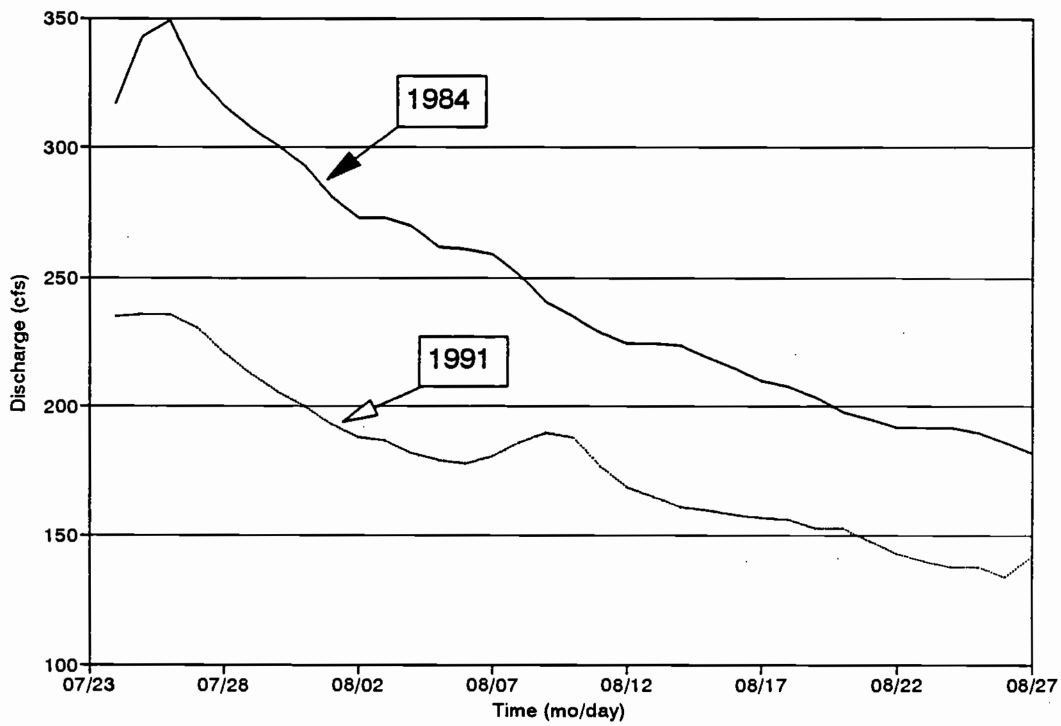

Figure B. Mean 1984 and 1991 daily discharge versus time.

Table B2. Summary statistics of 1984 and 1991 reach data.

	1984 Maximum Widths				1984 Mean Widths			
Reach Number	Average (m)	Max. (m)	Min. (m)	STD (m)	Average (m)	Max. (m)	Min. (m)	STD (m)
1	4.1	6.1	1.8	1.1	3.8	5.2	1.8	0.9
2	5.0	7.6	3.7	1.1	4.4	6.1	1.8	1.0
3	3.7	4.9	2.1	1.0	3.1	4.3	1.8	0.9
4	5.1	7.3	1.8	1.9	3.9	5.5	0.9	1.7
5	4.4	9.1	1.8	1.7	3.5	7.6	1.2	1.5
6	4.8	15.2	1.8	2.9	3.7	7.6	0.6	1.8
7	5.3	10.7	1.5	2.2	4.3	9.1	1.2	2.2
8	5.5	18.3	1.2	3.2	4.3	9.1	1.2	2.3
9	6.2	15.2	1.5	3.7	5.0	9.1	0.9	2.6
10	7.9	17.1	1.8	3.8	6.4	13.7	1.8	3.1
11	6.5	18.3	1.8	3.4	5.1	12.2	1.2	2.6
12	7.7	15.2	3.7	3.6	5.7	10.7	2.4	2.8
13	6.5	13.7	2.1	3.5	5.4	12.2	1.2	3.0
14	6.5	10.4	2.4	2.6	4.9	8.5	1.5	2.2
15	5.8	12.2	1.8	2.7	4.5	9.1	1.5	2.0

	1984 Maximum Depths				1984 Mean Depths			
Reach Number	Average (m)	Max. (m)	Min. (m)	STD (m)	Average (m)	Max. (m)	Min. (m)	STD (m)
1	0.3	0.7	0.1	0.2	0.2	0.5	0.1	0.1
2	0.3	0.6	0.1	0.2	0.1	0.4	0.1	0.1
3	0.2	0.4	0.1	0.1	0.1	0.2	0.1	0.1
4	0.6	1.0	0.1	0.1	0.3	0.5	0.1	0.2
5	0.3	0.7	0.1	0.2	0.1	0.4	0.0	0.1
6	0.3	0.8	0.1	0.2	0.2	0.5	0.1	0.1
7	0.2	0.7	0.1	0.1	0.1	0.5	0.0	0.1
8	0.3	0.9	0.1	0.3	0.2	0.7	0.1	0.2
9	0.4	1.5	0.1	0.3	0.2	0.8	0.0	0.2
10	0.5	1.2	0.1	0.3	0.3	1.1	0.1	0.2
11	0.5	1.3	0.1	0.3	0.3	0.9	0.1	0.2
12	0.4	0.8	0.1	0.3	0.2	0.5	0.1	0.2
13	0.7	1.8	0.1	0.5	0.4	1.2	0.1	0.3
14	0.6	1.0	0.1	0.3	0.3	0.7	0.1	0.2
15	0.5	1.2	0.1	0.3	0.2	0.9	0.0	0.2

Table B2. (continued)

	1991 Wetted Widths				1991 Bankful Width			
Reach Number	Average (m)	Max. (m)	Min. (m)	STD (m)	Average (m)	Max. (m)	Min. (m)	STD (m)
1	2.3	4.0	0.7	0.9	3.9	5.8	1.2	1.3
2	3.3	4.5	2.0	0.8	4.8	7.2	3.0	1.2
3	2.3	3.0	1.6	0.6	5.1	6.1	3.8	1.2
4	5.8	8.3	2.4	2.5	6.9	9.0	3.2	2.7
5	3.3	5.9	0.9	1.5	5.1	7.7	3.2	1.1
6	3.3	5.7	1.3	1.2	6.0	8.1	4.7	1.0
7	4.3	6.6	2.3	1.2	6.9	11.5	4.8	1.5
8	4.6	8.6	1.7	1.7	7.6	12.8	4.0	2.3
9	3.5	10.7	1.2	2.5	7.9	11.9	4.6	2.0
10	4.9	8.5	1.6	2.2	8.3	14.5	6.3	1.1
11	8.0	23.0	3.6	5.0	10.4	26.5	6.3	5.2
12	6.2	7.7	4.4	1.3	7.3	8.8	6.0	1.1
13	6.1	11.8	2.1	2.8	8.7	13.9	4.8	2.5
14	8.0	12.8	4.3	3.5	9.9	13.0	6.0	3.0
15	6.6	13.6	2.9	3.0	9.7	15.6	6.0	2.8

	1991 5 m Thalweg Depths			
Reach Number	Average (m)	Max. (m)	Min. (m)	STD (m)
1	0.3	0.6	0.1	0.1
2	0.2	0.9	0.0	0.1
3	0.2	0.4	0.1	0.1
4	0.9	1.6	0.2	0.1
5	0.2	0.6	0.0	0.1
6	0.2	0.7	0.1	0.1
7	0.2	0.7	0.1	0.1
8	0.2	0.8	0.0	0.2
9	0.3	1.0	0.0	0.2
10	0.4	1.1	0.0	0.3
11	0.6	1.6	0.0	0.4
12	0.4	0.9	0.1	0.3
13	0.4	1.4	0.0	0.2
14	0.6	1.6	0.1	0.4
15	0.4	1.3	0.0	0.3

APPENDIX C
STATISTICAL RESULTS FROM REACH COMPARISONS BETWEEN 1984 AND 1991 DEPTHS AND WIDTHS

The 1991 data was compared to 1984 mean depth and width, and maximum depth and width. In 1991, the depth measurements were taken every 5 meters, and the width measurements every 30 meters. In 1984 the measurements were taken at every habitat unit.

Table C1. Statistical results from reach t-test comparisons of 1991 thalweg depths to 1984 mean depths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	84 < 91	t-test	<.01	85/39	0.98
2	84 < 91	LOG	<.01	68/23	0.87
3	84 < 91	LOG	<.01	21/8	0.85
4	84 < 91	SQRT	<.01	25/12	1.73
5	84 < 91	t-test	<.01	102/52	1.63
6	84 < 91	t-test	0.03	100/30	0.91
7	84 < 91	t-test	<.01	100/49	1.98
8	NSD	t-test	0.15	98/53	0.94
9	NSD	t-test	0.09	114/45	0.93
10	84 < 91	t-test	0.04	140/61	1.11
11	84 < 91	LOG	<.01	111/69	0.63
12	NSD	LOG	0.08	40/11	0.91
13	NSD	t-test	0.18	97/32	1.19
14	84 < 91	LOG	<.01	33/13	1.08
15	84 < 91	LOG	<.01	106/38	0.88

[a] a t-test was performed on logarithim (LOG) or square-root (SQRT) transformed data.
[b] S^2 indicates sample varience

Table C2. Statistical results from reach t-test comparisons of 1991 thalweg depths to 1984 maximum depths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	NSD	t-test	0.12	85/39	0.57
2	NSD	t-test	0.06	68/23	0.61
3	NSD	t-test	0.99	21/8	.77
4	84 < 91	t-test	0.02	25/12	1.35
5	NSD	LOG	0.09	102/52	0.59
6	NSD	wilcoxon	0.50	100/30	NA
7	NSD	t-test	0.28	100/49	0.78
8	84 > 91	LOG	0.04	98/53	0.85
9	NSD	LOG	0.15	114/45	0.82
10	84 > 91	t-test	0.01	140/61	0.57
11	84 < 91	t-test	0.01	111/69	1.09
12	NSD	t-test	0.75	40/11	1.13
13	84 > 91	LOG	<.01	97/32	1.28
14	NSD	t-test	0.55	33/13	1.34
15	NSD	t-test	0.45	106/38	0.84

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.

Table C3. Statistical results from reach t-test comparisons of 1991 widths to 1984 mean widths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	84 > 91	t-test	<.01	15/39	0.95
2	84 > 91	t-test	<.01	11/23	0.56
3	NSD	t-test	0.11	5/8	0.53
4	NSD	LOG	0.17	5/12	0.79
5	NSD	t-test	0.55	17/52	1.06
6	NSD	wilcoxon	0.81	16/30	NA
7	NSD	wilcoxon	0.98	17/49	NA
8	NSD	t-test	0.58	16/53	0.54
9	84 > 91	t-test	0.04	18/45	0.91
10	84 > 91	SQRT	0.05	24/61	0.60
11	84 < 91	LOG	<.01	18/69	0.71
12	NSD	wilcoxon	0.57	7/11	NA
13	NSD	t-test	0.42	18/33	0.84
14	NSD	LOG	0.09	4/13	0.70
15	84 < 91	LOG	<.01	18/38	0.96

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.

Table C4. Statistical results from reach t-test comparisons of 1991 widths to 1984 maximum widths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	84 > 91	t-test	<.01	15/39	0.63
2	84 > 91	t-test	<.01	11/23	0.54
3	84 > 91	LOG	0.01	5/8	10.5
4	NSD	t-test	0.54	5/12	1.8
5	84 > 91	t-test	0.02	17/52	0.79
6	NSD	wilcoxon	0.13	16/30	NA
7	NSD	wilcoxon	0.08	17/49	NA
8	NSD	LOG	0.45	16/53	0.60
9	84 > 91	LOG	<.01	18/45	1.14
10	84 > 91	LOG	<.01	24/62	0.73
11	NSD	LOG	0.09	18/70	0.72
12	NSD	wilcoxon	0.58	7/11	NA
13	NSD	t-test	0.62	18/32	0.64
14	NSD	t-test	0.36	4/13	1.86
15	NSD	t-test	0.32	18/37	1.29

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.

Table C5. Statistical results from reach t-tests comparisons of 1991 width to depth ratios to 1984 maximum width to depth ratios.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	84 > 91	LOG	<.01	15/39	1.32
2	NSD	wilcoxon	0.22	11/24	NA
3	NSD	t-test	0.56	5/7	0.67
4	NSD	LOG	0.09	5/12	0.78
5	NSD	LOG	0.52	17/52	0.76
6	NSD	LOG	0.11	16/30	0.64
7	NSD	t-test	0.93	17/49	1.13
8	NSD	t-test	0.74	16/53	0.90
9	NSD	wilcoxon	0.13	19/45	NA
10	NSD	LOG	0.15	24/32	1.49
11	NSD	wilcoxon	0.69	18/68	NA
12	NSD	t-test	0.94	7/11	0.80
13	91 > 84	LOG	0.03	18/32	0.91
14	NSD	wilcoxon	0.39	4/13	NA
15	NSD	LOG	0.33	19/37	0.70

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.

Table C6. Statistical results from reach t-test comparisons of 1991 pool depths to 1984 mean pool depths without beaver ponds.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	NSD	t-test	0.44	8/10	0.91
2	91 > 84	LOG	<.01	5/8	0.93
3	NSD	t-test	0.10	16/48	1.06
4	NSD	wilcoxon	0.14	14/68	NA
5	91 > 84	t-test	0.42	18/49	1.42

Table C7. Statistical results from reach t-test comparisons of 1991 pool depths to 1984 mean pool depths with beaver ponds.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
3	NSD	t-test	0.06	22/49	1.46
4	NSD	LOG	0.29	33/75	0.94
5	91 > 84	t-test	0.01	35/52	1.01

[a] T-tests were performed on logarithim (LOG) transformed data.

[b] S^2 indicates sample varience.

Table C8. Statistical results from reach t-test comparisons of 1991 pool depths to 1984 maximum pool depths without beaver ponds.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	84 > 91	t-test	<.01	8/10	1.64
2	NSD	LOG	0.31	5/8	0.97
3	84 > 91	t-test	<.01	16/48	0.75
4	84 > 91	LOG	<.01	19/68	1.83
5	84 > 91	t-test	.012	18/49	0.74

Table C9. Statistical results from reach t-test comparisons of 1991 pool depths to 1984 maximum pool depths with beaver ponds.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
3	84 > 91	t-test	<.01	22/49	1.04
4	84 > 91	t-test	<.01	33/72	0.71
5	84 > 91	LOG	<.01	35/52	1.0

[a] T-tests were performed on logarithim (LOG) transformed data.

[b] S^2 indicates sample varience.

Table C10. Statistical results from reach t-test comparisons of 1991 riffle depths to 1984 mean riffle depths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	91 > 84	LOG	<.01	6/24	1.05
2	NO RIFFLES IN 1991				
3	91 > 84	wilcoxon	<.01	14/78	NA
4	91 > 84	LOG	0.01	14/50	1.48
5	NSD	wilcoxon	0.68	6/27	NA

Table C11. Statistical results from reach t-test comparisons of 1991 riffle depths to 1984 maximum riffle depths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	91 > 84	LOG	<.01	6/24	1.07
2	NO RIFFLES IN 1991				
3	NSD	LOG	0.23	12/78	0.86
4	84 > 91	LOG	<.01	14/50	0.62
5	84 > 91	LOG	<.01	6/27	0.64

[a] T-tests were performed on logarithim (LOG) transformed data. Wilcoxon (wilcoxon) test was used when transformation was not successful.

[b] S^2 indicates sample varience.

Table C12. Statistical results from reach t-test comparisons of 1991 glide depths to 1984 mean glide depths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	NSD	t-test	0.68	13/22	1.0
2		NO GLIDES IN 1991			
3	91 > 84	LOG	<.01	32/57	1.62
4	91 > 84	t-test	<.01	14/51	1.74
5	NSD	t-test	0.51	6/15	1.18

Table C13. Statistical results from reach t-test comparisons of 1991 glide depths to 1984 maximum glide depths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	84 > 91	t-test	<.01	13/22	0.71
2		NO GLIDES IN 1991			
3	84 > 91	t-test	<.01	32/57	1.04
4	84 > 91	LOG	<.01	14/51	0.65
5	84 > 91	LOG	<.01	6/16	1.98

[a] T-tests were performed on logarithim (LOG) transformed data.

[b] S^2 indicates sample varience.

Table C14. Statistical results from reach t-test comparisons of 1991 pool widths to 1984 mean pool widths without beaver ponds.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	NSD	t-test	0.09	8/10	1.78
2	NSD	wilcoxon	0.41	5/8	NA
3	NSD	LOG	0.40	21/48	0.60
4	84 > 91	LOG	<.01	14/67	1.16
5	NSD	t-test	0.23	18/49	1.02

Table C15. Statistical results from reach t-test comparisons of 1991 pool widths to 1984 mean pool widths with beaver ponds.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
3	NSD	t-test	> 0.05	22/49	1.46
4	NSD	LOG	> 0.05	71/33	0.58
5	91 > 84	t-test	0.01	35/22	1.01

[a] T-tests were performed on logarithim (LOG) transformed data. Wilcoxon (wilcoxon) test was used when transformation was not successful.

[b] S^2 indicates sample varience.

Table C16. Statistical results from reach t-test comparisons of 1991 riffle widths to 1984 mean riffle widths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	84 > 91	t-test	0.02	6/24	0.59
2		NO RIFFLES IN 1991			
3	NSD	t-test	0.30	12/78	0.66
4	NSD	t-test	0.56	14/50	1.45
5	NSD	t-test	0.17	6/27	1.73

Table C17. Statistical results from reach by reach comparisons of 1991 glide widths to 1984 mean glide widths.

Reach #	Result	Test Used [a]	p-value	Sample Number (91/84)	Ratio of S^2 [b] (91/84)
1	84 > 91	LOG	<.01	13/22	1.1
2		NO GLIDES IN 1991			
3	NSD	LOG	0.20	32/57	1.02
4	84 > 91	LOG	0.02	14/51	1.20
5	NSD	LOG	0.46	6/16	0.83

[a] T-tests were performed on logarithim (LOG) transformed data.

[b] S^2 indicates sample varience.

APPENDIX D

1991 COMARISONS OF BEAVER-DOMINATED REACHES TO NON-BEAVER REACHES AND NON-BEAVER TO NON-BEAVER REACHES

Table D1. Statistical results from t-tests comparisons of average thalweg depth for reaches dominated by beaver ponds (BP) to reaches without beaver ponds (NOBP).

Reaches Compared (BP:NOBP)	Result	Test Used [a]	p-value	Sample Sizes (BP/NOBP)	Ratio of S^2 [b] (BP/NOBP)
4:3	4 > 3	LOG	< 0.01	5/5	0.89
4:5	4 > 5	SQRT	< 0.01	5/17	1.38
11:10	11 > 10	t-test	<0.01	18/24	1.94

Table D2. Statistical results from t-tests comparisons of average thalweg depth between reaches without beaver ponds.

Reaches Compared	Result	Test Used [a]	p-value	Sample Sizes	Ratio of S^2 [b]
5:6	NSD	t-test	>0.05	17/16	0.79
6:7	NSD	LOG	>0.05	16/17	0.91
7:8	NSD	LOG	>0.05	17/16	0.87
8:9	NSD	t-test	>0.05	16/18	0.72
9:10	NSD	t-test	>0.05	18/24	1.35

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.

Table D3. Statistical results from t-tests comparisons of average 5-m thalweg depth for reaches dominated by beaver ponds (BP) to reaches without beaver ponds (NOBP).

Reaches Compared (BP:NOBP)	Result	Test Used [a]	p-value	Sample Sizes (BP/NOBP)	Ratio of S^2 [b] (BP/NOBP)
4:3	4 > 3	LOG	< 0.01	25/21	1.35
4:5	4 > 5	LOG	< 0.01	25/102	0.87
11:10	11 > 10	LOG	< 0.01	111/140	0.64
14:13	14 > 13	t-test	< 0.01	33/97	1.37

Table D4. Statistical results from t-tests comparisons of average 5-m thalweg depth between reaches without beaver ponds.

Reaches Compared	Result	Test Used [a]	p-value	Sample Sizes	Ratio of S^2 [b]
5:6	NSD	t-test	> 0.05	102/100	0.97
6:7	NSD	t-test	> 0.05	100/100	1.20
7:8	NSD	t-test	> 0.05	100/98	0.61
8:9	9 > 8	LOG	< 0.05	98/114	0.84
9:10	10 > 9	LOG	0.05	114/140	0.94

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.

Table D5. Statistical results from t-tests comparisons of average wetted width for reaches dominated by beaver ponds (Bp) to reaches without beaver ponds (NOBP).

Reaches Compared (BP:NOBP)	Result	Test Used [a]	p-value	Sample Sizes (BP/NOBP)	Ratio of S^2 [b] (BP/NOBP)
4:3	4 > 3	wilcoxon	< 0.01	5/5	NA
4:5	4 > 5	LOG	< 0.05	5/17	0.09
11:10	11 > 10	LOG	< 0.01	18/24	0.78
14:13	NSD	t-test	> 0.05	4/18	1.64

Table D6. Statistical results from t-tests comparisons of average wetted widths between reaches without beaver ponds.

Reaches Compared	Result	Test Used [a]	p-value	Sample Sizes	Ratio of S^2 [b]
5:6	NSD	t-test	> 0.05	17/16	1.61
6:7	7 > 6	t-test	0.02	16/17	0.93
7:8	NSD	t-test	> 0.05	17/16	1.85
8:9	NSD	wilcoxon	> 0.05	16/18	NA
9:10	NSD	t-test	> 0.05	18/24	1.35

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.

APPENDIX E

1984 COMARISONS OF BEAVER-DOMINATED REACHES TO NON-BEAVER REACHES AND NON-BEAVER REACHES TO NON-BEAVER REACHES

Table E1. Statistical results from t-tests comparisons of average 1984 mean depths for reaches dominated by beaver ponds (BP) to reaches without beaver ponds (NOBP).

Reaches Compared (BP:NOBP)	Result	Test Used [a]	p-value	Sample Sizes (BP/NOBP)	Ratio of S^2 [b] (BP/NOBP)
4:3	NSD	wilcoxon	0.05	12/3	NA
4:5	4 > 5	SQRT	0.02	52/12	1.75
10:9	NSD	t-test	> 0.05	61/45	1.14
11:12	NSD	t-test	> 0.05	69/11	1.45
13:12	NSD	wilcoxon	> 0.05	32/11	NA

Table E2. Statistical results from t-tests comparisons of average 1984 mean depths between reaches without beaver ponds.

Reaches Compared	Result	Test Used [a]	p-value	Sample Sizes	Ratio of S^2 [b]
5:6	NSD	t-test	> 0.05	52/30	0.54
6:7	NSD	wilcoxon	> 0.05	30/49	NA
7:8	8>7	wilcoxon	0.01	49/53	NA
8:9	NSD	t-test	> 0.05	53/45	0.55

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.

Table E3. Statistical results from t-tests comparisons of average 1984 maximum depths for reaches dominated by beaver ponds (BP) to reaches without beaver ponds (NOBP).

Reaches Compared (BP:NOBP)	Result	Test Used [a]	p-value	Sample Sizes (BP/NOBP)	Ratio of S^2 [b] (BP/NOBP)
4:3	4 > 3	wilcoxon	0.04	12/8	NA
4:5	4 > 5	SQRT	< 0.01	52/12	1.82
10:9	NSD	t-test	> 0.05	61/45	1.00
11:12	NSD	t-test	> 0.05	69/11	1.83
13:12	NSD	SQRT	> 0.05	32/11	1.89

Table E4. Statistical results from t-tests comparisons of average 1984 maximum depths between reaches without beaver ponds.

Reaches Compared	Result	Test Used [a]	p-value	Sample Sizes	Ratio of S^2 [b]
5:6	NSD	t-test	> 0.05	52/30	0.75
6:7	NSD	wilcoxon	> 0.05	30/49	NA
7:8	NSD	wilcoxon	> 0.05	49/53	NA
8:9	NSD	t-test	> 0.05	53/45	0.54

[a] T-tests were performed on logarithim (LOG) and square-root (SQRT) transformed data, the wilcoxon test (wilcoxon) was used when transformation were unsuccessful.

[b] S^2 indicates sample varience.