JOHNSON + GERHARDT

INVESTIGATION OF THE SOURCE, DISTRIBUTION, AND IMPACTS OF SEDIMENT DEPOSITION IN LONG - GREGORY CANYON, BOULDER MOUNTAIN PARKS, COLORADO

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Submitted to:

City of Boulder Open Space and Mountain Parks

March 5, 2001

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EXECUTIVE SUMMARY

Highway runoff can create environmental impacts if contaminant loads are high and steps are not taken to remove them before the runoff reaches receiving waters. Common road contaminants include heavy metals, hydrocarbons, inorganic salts, fertilizers, asphalt particles, deicing agents, and sediment such as traction control sand. In Boulder Mountain Parks, road sediment was considered by the staff to be a potential source of anthropogenic contamination in the Long-Gregory watershed that could be causing ecological impacts in sensitive riparian and other natural areas. This study was initiated to investigate the source, distribution, and impacts of sediment derived primarily from winter sanding treatments of Flagstaff Road on riparian and upland habitats within the Long-Gregory Creek watershed.

The goals of this project were to: (1) map the distribution of road-derived sediment within upland and riparian areas of the Long-Gregory Creek watershed and compare the distribution with Flagstaff Road input sources, (2) develop a reference "fingerprint" of road sediment and compare this fingerprint to the sediment deposited in impacted areas and the substrate found in unimpacted areas, (3) determine the effects of road-derived sediment deposition on surficial soil characteristics, (4) determine the impact of road-derived sediment on riparian vegetation by comparing species composition along impacted stream reaches to that in unimpacted (reference) reaches, and (5) determine whether road-derived sediment deposition has affected the channel morphology of Long-Gregory Creek.

Sediment deposition in each of five upland gully systems and along the entire 2 km stretch of Long-Gregory Creek within Boulder Mountain Park was mapped. Sediment consistent in texture and appearance to traction control sand was mapped throughout the five gully systems and along Long Creek. Mapped deposits often reached depths of greater than 20 cm. Such sediment deposition was not observed in Long Creek above the uppermost gully system nor in any reference canyon. The source of this sediment can easily be traced to Flagstaff Road by following the input gullies to their up-slope terminuses. These terminuses were always located at road culverts or drainage trenches.

Sediment mapping identified areas of rapid, un-natural sediment accumulation. It also identified Flagstaff Road as the probable, primary source of deposited sediment, located the point-sources of sediment input to Long-Gregory Creek riparian areas and showed that natural gullies provide the transport mechanism for road-derived sediment. To conclusively demonstrate that rapidly accumulated sediment in gullies and Long-Gregory Creek was primarily composed of traction sand and road base, sediment collected in depositional areas was compared to the substrate in unimpacted reference areas and to samples of traction sand and road base provided by Boulder County and obtained at sand depots on Flagstaff Road.

To carry out this comparison, we systematically placed and sampled plots every 100 m along the Long-Gregory Creek riparian zone, – from Long Creek's headwaters to a major break in topography and geology at approximately 1980 m (6500 ft.) of elevation. Reference plots were similarly placed along the four tributary reference streams located in the Long-Gregory watershed.

At each plot we sampled soils and vegetation, mapped sediment deposition, and collected additional environmental data. Channel cross-sections were measured at all plots except those in Greenman Springs Canyon. Plots were also placed along the length of the gully systems and at a side-slope deposition area. These plots were similarly sampled, except vegetation data was not collected from gully system plots

Samples from the upper soils layers of plots exhibiting accelerated sediment accumulation were statistically more similar to reference samples of road traction sand and road base than to native soils. In both uplands and riparian areas, soil from impacted plots typically contained a deep surface horizon of coarse sand and gravel. Based on our analyses, we have determined that the majority of rapidly accumulated sediment has originated from Flagstaff Road. This result clearly supports the findings made during the sediment mapping portion of this study, and corroborates the assertion that Flagstaff Road maintenance operations are supplying large amounts of allochthonous sediment to Long-Gregory Creek.

The ecological and environmental impacts of this road-derived sediment were examined by comparative study of impacted areas and non-impacted (reference) areas. Reference areas were the other four streams within the Long-Gregory watershed and reaches of Long Creek in which no road-derived sediment had accumulated. After preliminary examination, we determined that accumulated sediment would most likely affect riparian zone plant species composition and channel morphology. Since these attributes are some of the most important to the maintenance of natural riparian conditions we focused study on the evaluation of impacts to these components.

Multivariate statistical analyses show that road-derived sediment accumulation has significantly altered the plant species composition within impacted stream reaches. Vegetation impacts included a shift in species composition to more ruderal, disturbance-tolerating species, preclusion of some characteristic and sensitive riparian species, burial of herbaceous and woody vegetation, and likely stressing of rare species populations. The accumulation of road-derived sediment has also affected channel morphology by creating wider and shallower channel cross-sections. These morphological impacts likely affect stream hydraulics, sediment dynamics, water relations and invertebrate populations, although it was beyond the scope of this study to quantify such impacts. Analyses of the channel conditions where road-derived deposition has occured suggest that much of Long Creek that is not currently accumulating road sediment could be the site of future deposition if high levels of sediment input are not reduced.

This study has shown that road-sediment accumulations have caused demonstrable impacts to Boulder Mountain Parks' riparian and natural areas. Reduction of road-sediment inputs to Long-Gregory Creek must be undertaken to mitigate ecological impacts and allow for ecological restoration. Fortunately, sediment input occurs primarily via five point-sources in the form of hillside gullies. Reduction of sediment flow down these gullies could be accomplished through structural or procedural measures. Any such method must be carried out in cooperation with the Boulder County Transportation Department. This department has been aware of potential road sediment impacts in Boulder Mountain Parks and been proactive in addressing this problem. With the results of this study mitigative efforts can be focused at the most significant impacts sources thus saving both time and effort.

INTRODUCTION

Across the country, significant volumes of road runoff are discharged into wetlands and waterways, creating the potential for numerous environmental impacts (Kobriger et al. 1983). Highway runoff can have environmental impacts if steps are not taken to remove contaminants before runoff reaches receiving waters. Common contaminants include heavy metals, hydrocarbons, inorganic salts, fertilizers, asphalt particles deicing agents, and sediment (Kobriger et al. 1983, Turner-Fairbank Highway Research Center 1999, Faure et al. 2000).

The fate and impact of road-derived contaminants introduced into adjacent watersheds varies according to the type of contaminant (Forman and Alexander 1998). Soluble contaminants may be flushed through a watershed quickly during high water flow periods or seep into groundwater and remain within the system for longer periods. Chemical contaminants such as chloride, heavy metals, and petroleum, may reach toxic levels in soils, plants, and wildlife, particularly when water flow is low and contaminant concentrations are high, or when contaminants linger in the system. Solid contaminants, such as sediment distributed during road construction or applied for vehicle traction control, require higher flow velocities to move through the system because of their relatively high mass. Significant amounts of road-derived sediment are delivered to stream channels through upland topographic features and road maintenance structures which channelize water flow and produce the high volume and velocity of flow required to transport larger sediment particles. Because of the relatively high water flows required to transport sediment through the watershed, the movement of sediment through drainage areas and stream channels varies over time in relation to the hydrologic regime. Where topography slows water velocity and when seasonal flows decrease, road-derived sediment accumulates.

Watersheds are open systems with inflows and outflows of energy and matter (Leopold and Maddock 1953). Within a watershed, four primary variables influence stream channel morphology: 1) discharge, 2) sediment load, 3) valley or canyon slope, and 4) bed and bank composition (Hey 1978). Of these, the operation of Flagstaff Road directly influences discharge dynamics and sediment load. These two factors then interact to in turn influence bed and bank composition.

Stream channels adjust their shape and characteristics in response to environmental changes, such as alterations in sediment regime, hydrologic inputs, or flow blockages (e.g. dead-fall jams). Channel variables that change most strongly in response to environmental perturbations are: 1) cross-sectional morphology, 2) bed configuration, 3) channel pattern, and 4) bed slope (Knighton 1984). Of these, cross-sectional morphology changes most rapidly with alterations in water flow or sediment load. Several key characteristics of smaller order mountain streams, such as those found in the Long-Gregory watershed, influence channel morphology and sediment dynamics. Streams in forested mountainous areas typically occupy narrow, v-shaped canyon bottoms which are formed by bedrock or colluvium over many reaches. Because of the lack of a wide flood-plain, these streams interact directly with the adjacent hillslopes through erosion, water and sediment runoff, and flow path barriers such as boulders and resistant rock formations (Grant 1988). In narrow, mountain streams, woody debris also contributes to the formation and dynamics of channel morphology, promoting the development of pools and mid-channel bars (Heede 1972, 1985). In high gradient reaches, woody debris often creates channels with a stepped profile, as the debris reduces water velocity and creates conditions for the deposition and storage of large volumes of sediment (Keller and Swanson 1979, Marston 1982).

Flagstaff Road is a paved road that crosses Boulder Mountain Parks from east to west through the Long-Gregory Canyon. During the winter months, Boulder County Transportation Department is responsible for treating the road with traction sand to improve driving safety on the steep and curved road. From 1994 to 1999, the county estimates that an average of 229.5 tons of traction sand were distributed along the uppermost 5.51 miles of Flagstaff Road each year, at an average sanding rate of 41.65 tons/mile/year (Plank 2000). Sweeping operations are used to remove sediment from the road surface, but the County estimates that only 30-50 tons of introduced sediment are removed each year, with the remainder being transported through the Long-Gregory watershed. The residual traction sediment, 180-200 tons/year, leaves the road surface primarily through water runoff.

Over the past several years, Boulder Mountain Parks identified areas of the Long-Gregory Canyon containing significant accumulations of sediment that were similar in appearance to traction sand and that seemed to emanate from Flagstaff Road. Deposition of road-derived sediment was identified in and along the channel of Long Creek and in upland erosion areas below the road. This study was conducted to investigate the source, distribution, and impacts of road-derives sediment deposition in Long-Gregory Canyon.

In initiating this study, we believed that two characteristics of Flagstaff Road were controlling the introduction of water and sediment runoff to Long-Gregory Canyon: road design and road operation. Road design influences the velocity, location, and direction of water and sediment runoff. For example, the location and design of culverts, direction and degree of road pitch, and the alignment of the road through the local topography may all influence the location, intensity, and timing of water and sediment inputs to Long Canyon. In addition to road design, we believed that road maintenance operations could increase the input of sediment into Long Canyon hillslopes and the Long Creek channel. Sanding for traction control on Flagstaff Road, involving the application of over 200 tons of traction sand each winter, introduces an additional source of relatively homogenous and large-grained sediment to the Long-Gregory system. This sediment is primarily coarse sand, and flows into the stream via several culverts, drainage trenches, and diffuse erosion slopes. We also believed that naturally occurring processes would also influence the distribution and impacts of road-derives sediment. Stream flow volume and timing, channel and hillside grade, and naturally occurring channel obstacles such as boulders and woody debris influence sediment transport in all streams, suggesting that a consideration of these features would help explain sediment distribution and the location and degree of ecological impact, as well as providing insight into the potential for additional sediment accumulation.

Based on these considerations, we addressed three general questions. First, could gully erosion and point-sources of sediment input linked to road characteristics and drainage structures?

We assumed that if Flagstaff Road were the source of the identified sediment, the distribution of sediment throughout the canyon could be tied to features and processes of Flagstaff Road. Second, is the rapidly accumulated sediment found on new, sparsely vegetated bars and channel bottoms quantitatively similar to the sand and road base used on Flagstaff Road? We hypothesized that the sediment found in areas of significant sediment deposition would be similar to reference samples of traction sand and road base and different from sediment deposits composed of native soils. And third, did the presence of rapidly accumulated sediment alter the ecological characteristics of affected riparian areas. Thus, we hypothesized that statistically significant soil, geomorphological and vegetation differences existed between impacted and unimpacted sites.

The study was conducted from March-December 2000 along Flagstaff Road and within 5 major canyons of the Long-Gregory Watershed. We had five primary objectives:

1. Map the distribution of road-derived sediment in upland areas and within the riparian areas of Long-Gregory Creek and compare the distribution to the location of potential Flagstaff Road input sources and natural stream and deposition processes.

2. Develop a "fingerprint" of road-derived source sediment and compare deposited sediment from impacted areas and reference areas to this fingerprint.

3. Determine the effects of road-derived sediment deposition on surface soil characteristics.

4. Determine the impact of road-derived sediment on riparian vegetation by comparing species composition in areas of varying impact to reference vegetation stands, and relate both vegetation and impact level to stream channel.

5. Determine the impact of road-derived sediment deposition on the morphology of the Long Creek channel.

METHODS

The problem of road sand accumulation in Boulder Mountain Parks natural areas was first identified by park staff and rangers. Several areas of significant sand deposition and transport were noted, but no systematic survey of the Long-Gregory watershed had occurred. We made an initial study area reconnaissance with BMP staff to locate known areas of deposition along Flagstaff Road and Long Creek. An overview of the sampling scheme and analyses used to assess the potential impacts of deposition is provided below, followed by detailed methods and rationales for the utilization of each method and to which questions the methods were applied.

Summary of sampling design

We made a thorough examination of the study area to identify the significant runoff gullies originating at Flagstaff Road and the location of heavy deposition in Long-Gregory Canyon. We located five major gully systems draining into Long-Gregory Creek from Flagstaff Road. Sediment deposition along the entire length each of these gullies and along 2 km of the channel and riparian zone of Long-Gregory Creek was mapped using the line-intercept method. ArcView was used to map the location and extent of all deposition in relation to other geographic features and to quantify the relationship between slope and sediment deposition.

To compare natural and sediment-impacted stream conditions, we systematically placed and sampled plots every 100 m along 2 km of Long Creek's channel and riparian area – from its headwaters to a major change in topography and geology at 1980 m (6500 ft.) of elevation . In order to obtain reference samples unimpacted by Flagstaff Road sediment, we selected and sampled plots along the other four major tributary streams Greenman Springs Creek, Panther Creek, Left-hand Canyon Creek, and Eleven O'clock Canyon Creek (Fig. 1). The authors named Left-hand Canyon and Eleven O'clock canyon of convenience since they were previously unnamed. This study approach not only allowed us to address questions about sediment impacts, but it also provides a significant addition to the biological inventory of Boulder Mountain Parks.

At each plot along the five stream reaches, we sampled soils and vegetation, mapped sediment deposition, and collected other basic environmental data. Soil profiles were described in the field and samples of the top 20 cm of soil was collected to determine particle size distribution.

Field Methods

Sediment Mapping

Sediment deposition along each identified gully was mapped using the line-intercept method. Gullies were surveyed along their entire length from Flagstaff Road to Long Creek. Beginning at a landmark along the shoulder of Flagstaff Road, a 100 m tape line was extended down each runoff

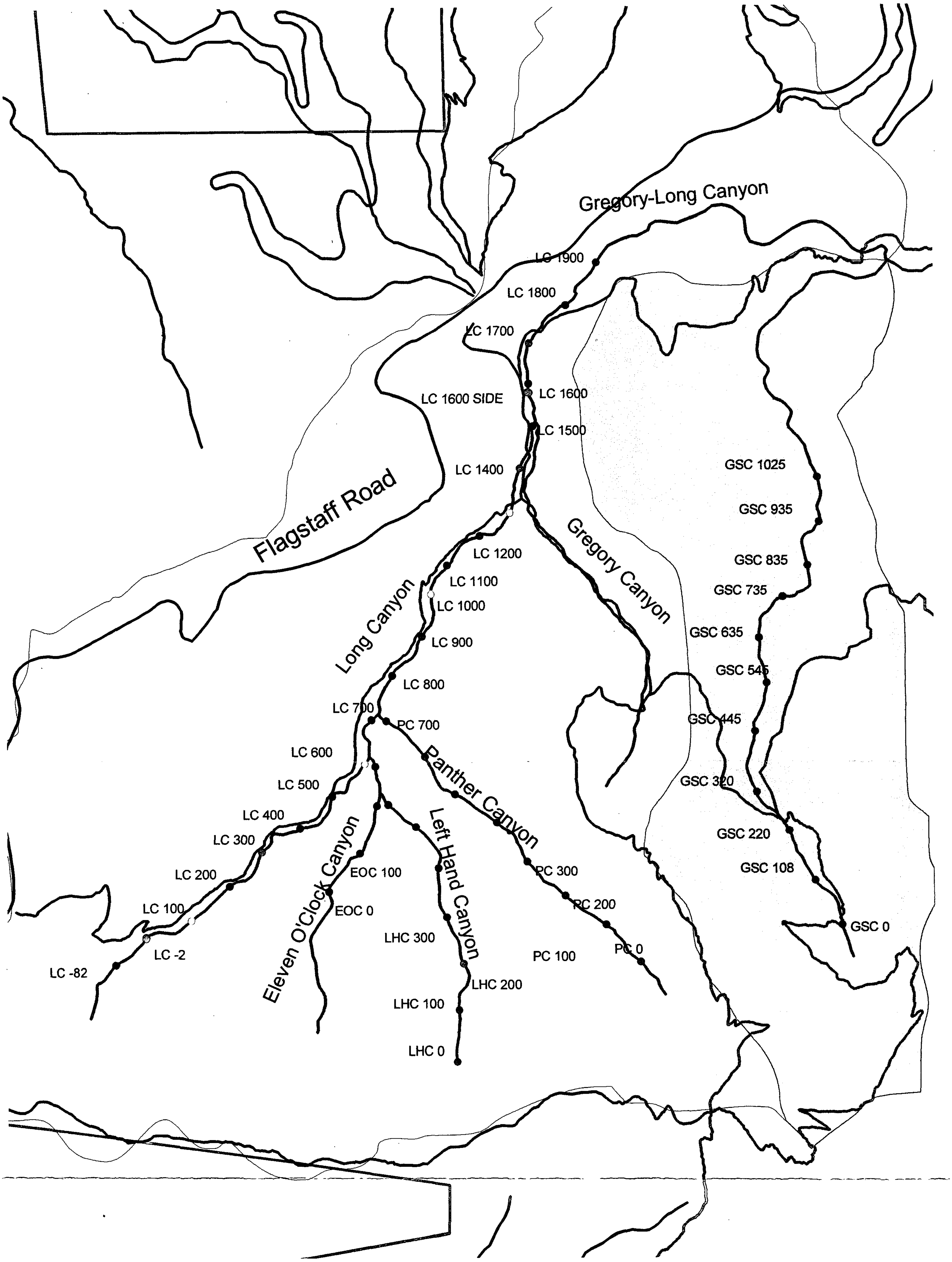

Figure 1. Map of the study area within the Long-Gregory and Greenman Springs Watersheds. Study plots are indicated by colored dots corresponding the plot impact level (see legend). Plot labels are indicate the number of meters the plot is from the start point or headwaters.

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gully. When significant fresh sand deposition was encountered within the gully channel, the endpoints of the deposition were measured from the extended tape measure. This method provided data on the location and linear extent of deposits. Because of the number and form of deposits, it was not possible to measure deposit volume. The locations of minor side gullies were mapped but were not surveyed using the line-intercept method.

The line-intercept approach was also used to map deposition starting near the headwaters of Long Creek and extending 2.0 km downstream. Deposits within the channel and along channel banks and terraces were mapped if they showed appreciable accumulation of bare, well-sorted, homogeneous, coarse sand similar in character to that placed on Flagstaff Road for traction control (Fig. 2). Deposits such as these are easily discernable from the typical channel features found in Mountain Parks' streams (Figs. 3 and 4). Indicators of rapid accumulation were lack or scarcity of typical riparian vegetation, lack or burial of coarse, channel bed material, and burial of channel features and riparian vegetation. The locations of natural input and Flagstaff Road-induced gullies were recorded from the tape line.

Approximately 500 m downstream of the Green Mountain Lodge, Long Creek begins to dive steeply through a granite-bounded canyon with its grade easing near the Green Mountain Trail Head. This section of stream was surveyed on foot with J. Mantione of BMP, but sediment deposition was not recorded using the line-intercept method, due to the excessively steep and rugged terrain. Very little sediment accumulation was noted in this reach, presumably due to the steep gradient. When sediment deposition was encountered its location was mapped on an aerial photograph using landmarks for reference. The length of these few deposits were visually estimated.

Plot selection and sampling design

To determine if road-derived sediment has impacted the Gregory-Long Creek channel and associated habitat, we studied riparian soils and vegetation in all the major streams within the entire Long-Gregory Canyon watershed, including Greenman Springs Creek (Fig. 1). Gregory Creek from its headwaters to Green Mountain Lodge was not sampled because it lacked channel development and true riparian vegetation.

Within each canyon studied, sample plots were placed approximately every 100 m. Plot spacing deviated from 100 m only to exclude sharp ecological breaks, such as rock slabs or abrupt openings that would introduce unwanted heterogeneity into sample plots. This form of objective sample location was chosen to facilitate statistical comparison of plot vegetational compositions and to eliminate bias in sample site selection. Plot characteristics and locations are provided in Table 1 and Fig. 1.

Fig. 2. Road sediment bars and deposition in the channel bottom. New bars are scarcely colonized by plant species and are primarily composed of coarse sand and gravel. Photograph taken at LC 300.

Fig. 3. A natural channel and bar. The bar to the left in the picture is well colonized by riparian species including long-lived perennials such as hazel nut. Sediment accumulation on old bars is slow enough that significant organic matter is incorporated into the soil profile. Photograph taken at LC 900.

Fig. 4. Close up of a old bar near LC 500. Notice the dense vegetation, including shrub species, and the dark soils indicating accumulation of organic matter.

Deposition patterns and environmental characteristics of plots

To relate both the subplot- and plot-level vegetation composition to sediment deposition patterns, we quantified sediment depositional patterns within plots using the line-intercept method. A tape measure was extended down the center of each study plot, and the endpoints of bars were recorded. Due to complexities of channel morphology, only those bars located on the left side (facing downstream) of the channel were recorded. This method provided a statistical sampling of bars within plots rather than a total census of such deposits. Bars were classified based on soil and vegetation. If the bar was well colonized by riparian vegetation, especially woody vegetation, and a significant amount of organic material had been incorporated into the soil horizon, the deposit was classified as old bar and considered indicative of normal, relatively slow sediment accumulation. If the bar was bare or poorly colonized by predominantly ruderal riparian vegetation, and the soil was predominantly loose, sand and gravel with little organic material, the deposit was classified as new bar and considered indicative of recent and rapid deposition. Although deposits in the active channel were mapped at the stream-scale, channel deposits were not measured at the plot-scale since they do not directly affect the character of riparian vegetation. At each plot, channel gradient and aspect were measured with a hand clinometer and a compass.

Monitoring stations were installed at 6 plots along Long Creek to allow future comparisons of sediment accumulation or erosion dynamics. Half meter long pieces of 3/4" rebar were buried to a depth of about 30 cm, leaving an aboveground exposed length to serve as a permanent reference of soil elevation. The length of rebar exposed was recorded for each plot.

Soils

It appeared that road-derived sediment was being deposited in and along the stream channels of Long Creek. We sought to test the hypotheses that the deposition we subjectively considered to be road-derived was statistically related to reference samples of road-derived sediment and different from unimpacted soils.

Soil pits were dug in each plot to the depth of the underlying rocky substrate or 115 cm, whichever was shallower. Where possible, pits were located on recently deposited coarse sand sediments along the channel bank or terrace (new bar). As described above, fresh deposition is readily discernable from natural stream conditions. In plots lacking new bar, soil pits were located on older bars, or, if none were present, in the channel or on the bank. New bar material was preferentially sampled when present so that comparisons with road-derived sediment samples could be made.

Soil profiles were described for each soil pit to compare the characteristics and depths of soil horizons in impacted and unimpacted locations. In each plot, soil profiles were characterized by color and texture. The depth of each distinct soil horizon was measured. Texture determined by hand for each horizon, and soil color was estimated for the matrix of each horizon using Munsell soil color charts. If the pit extended to the water table, depth of the water table was recorded.

Table 1. Environmental characteristics of each study plot. Plot dimensions are for vegetation sampling. The columns for new bar and old bar contain channel feature data obtained using the line Intercept method. Total bar is the sum of old and new bar lengths. Impact level relates to the amount of new bar present, where: 0 = no new sediment deposits on channel banks; 1 = 1 - 15 % of plot covered by new bar; 2 = 15 - 50 % coverage; 3 = greater than 50% new bar coverage.

Station	**LC-2**	**LC-82**	**LC-100**	**LC-200**	**LC-300**	**LC-400**	**LC-500**	**LC-600**	**LC-800**	**LC-900**	**LC-1000**	**LC-1100**	**LC-1200**	**LC-1300**	**LC-1400**	**LC 1600 SIDE**
Elevation (ft)	7195	7265	7119	7071	7032	6999	6978	6938	6873	6838	6798	6782	6754	6718	6708	6679
Plot Dimensions	5 X 20	6 X 16.5	6 X 16.5	5 X 20	6 X 16.5	6 X 16.5	6 X 16.5	6 X 16.5	5 X 20	6 X 16.5	6 X 16.5	6 X 16.5	6 X 16.5	6 X 16.5	6 X 16.5	5 X 20
Slope (%)	23	11.5	17	14	6	10	15	10.5	21	8	10	8	6.5	5	3	0.5
Aspect (degrees)	52	29	22	30	48	40	38	340	20	?	338	22	60	2	5	348
New bar (m)	10.5	0	6	0	14.2	0	0	3.9	0	0	4	0	0	5	1.5	20
Old bar (m)	0	12.5	3.5	2.6	0	0	0	0	4.3	6	0	5	0	0	0	0
Total bar (m)	10.5	12.5	9.5	2.6	14.2	0	0	3.9	4.3	6	4	5	0	5	1.5	20
Impact Level	3	0	2	0	3	0	0	2	0	0	2	0	0	2	1	3

Station	**LC 1700**	**LC 1800**	**LC 1900**	**LC 1600**	**LHC-0**	**LHC-100**	**LHC-200**	**LHC-300**	**LHC-400**	**LHC-500**	**LHC-570**	**LHC-652**	**EOC-0**	**EOC-100**	**EOC-197**	**PC-0**
Elevation (ft)	6665	6647	6600	6682	7455	7343	7225	7114	7075	7017	6974	6951	7053	7018	6965	7359
Plot Dimensions	5 X 20	5 X 20	6 X 16.5	5 X 20	4 X 25	4 X 25	4 X 25	4 X 25	4 X 25	4 X 25	5 X 20	5 X 20	6 X 16.5	5 X 20	4 X 25	6 X 16.5
Slope (%)	7	7	10	3	40	24	25	17	17.5	13	9	9	18	6	14	34
Aspect (degrees)	12	47	36	324	340	351	350	350	22	358	340	340	0	290	338	282
New bar (m)	2	0	0	20	0	0	2	0	0	0	0	0	0	0	0	0
Old bar (m)	0	0	0	0	0	5	2	3	3	0	2	0	0	10.5	0	0
Total bar (m)	2	0	0	20	0	5	4	3	3	0	2	0	0	10.5	0	0
Impact Level	1	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0

Table 1. con't

Station	PC-100	PC-200	PC-300	PC-400	PC-500	PC-600	PC-700	GSC-0(1)	GSC-108(2)	GSC-220(3)	GSC-320	GSC-445(4)	GSC-545	GSC-635(5)	GSC-735	GSC-835	GSC-935	GSC-1025(7)
Elevation (ft)	7267	7186	7135	7080	7035	6989	6908	7335	7192	7080	7022	6926	6881	6829	6755	6712	6644	6597
Plot Dimensions	5 X 20	5 X 20	5 X 20	5 X 20	6 X 16.5	6 X 16.5	5 X 20	8 X 12	3 X 30	4 X 25	5 X 20	6 X 16.5	10 X 10	7 X 14	6 X 16.5	6 X 16.5	6 X 16.5	8 X 12.5
Slope (%)	20	21	23	15	8	18	21	33	?	21	25		25	23	?	15	16	
Aspect (degrees)	300	300	328	300	270	320	308	334	306	323	320		342	340	56		24	
New bar (m)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Old bar (m)	0	0	0	0	6	0	0	0	0	0	0	0	0	5	0	0	0	11
Total bar (m)	0	0	2.5	1	6	0	0	0	0	0	0	0	0	5	0	0	0	11
Impact Level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Particle size distribution (PSD) was determined for the upper sediment layer in each plot. We chose to collect data on PSD because it could be quantitatively compared to the PSD of road-derived sediment samples. A number of sampling methods have been designed for sampling sediment in sand bed rivers (International Standards Handbook 1983, Ashmore et al. 1989). These methods can not be applied intact to gravel or cobble bed channels, where the range of particle sizes can exceed four orders of magnitude (Church et al. 1987, Thoms 1991).

To estimate PSD, sediment from the top 20 cm of each soil pit was collected in two samples of equal volume. In order to be representative of the coarse fraction, sample volume must increase with particle size (DeVries 1970, International Standards Handbook 1983). Steep, mountainous streams such as those in BMP typically contain a wide range of particle sizes in and around stream channels, ranging in size from boulders to fine sands. Based on field estimates of maximum particle size at several of the sample sites, most methods would recommend a sample of over three tons for each site (DeVries 1970). This obviously was neither practicable nor desirable. Because of the undesirability of sampling and analyzing such huge volumes, the percent volume of coarse fragments is typically estimated in the field (Gee and Bauder 1986). Particles with a diameter > 2.5 cm (gravel/cobbles) were not collected, and the percent volume of these particles occurring in the top 20 cm of soil was estimated. Collected soil samples were oven-dried at 105 °C for 6 hours and physically dispersed by rolling to break clods. Samples were sifted through four sieves (sizes: #10 (2.0 mm), #20 (0.84 mm), #30 (0.59), #40 (0.43 mm)). This range of sieves sorted particles classified as gravel from the sands, and then sorted sands into classes generally corresponding to very coarse, coarse, coarse to medium, and medium sand and finer (Gee and Bauder 1986). Separating particles into classes smaller than medium sand was not necessary because the road-derived sediment is composed almost entirely of particles in the gravel to very coarse sand size class.

In uplands, sediment sampling was conducted at 26 locations along the length of six mapped sediment deposition areas and gully systems. Samples for impacted plots were taken from deposits of coarse particles of similar color and texture to road traction sand. When available, adjacent reference plots were sampled. Soil profiles were developed for a subset of sample plots. Particle size was determined as above.

Reference samples of road-derived sediment were obtained from four sources. Boulder County provided two samples of approximately 2 kg. One sample contained the 1/4" traction sand applied to Flagstaff Road as a treatment during winter driving conditions. The second sample was of the new road base material being used during road rebuilding. The third and fourth samples were collected from the shoulder of Flagstaff Road. Large deposits of new road base and traction sand were stockpiled along road turn-offs during the summer of 2000. We collected four samples each from depots of new road base and traction sand. Describing the profile of sediment depots was not useful, but soil color and PSD were determined using the methods described above.

Vegetation

Based on preliminary observations it appeared that riparian vegetation could be directly impacted or stressed by excessive sediment accumulation. We sought to determine whether riparian vegetation located in deposition zones in Long-Gregory Canyon was quantitatively different from 1) vegetation in non-depositional areas within Long-Gregory Canyon, and 2) vegetation found along channels in other canyons within the watershed. Stream reaches lacking significant road-derived deposition will be referred to as "reference reaches", since they are taken to represent natural or nearly pristine riparian conditions.

Within each plot, vegetation sampling methods followed D'Amico et al. (1997) and Gerhart and Johnson (1999), but in a slightly modified form. Study plots covered 100 m^2 and were roughly rectangular in shape except when following channel bends. Plot width was set based on width of riparian vegetation and ranged from 3 - 10 m. Corresponding plot lengths ranged from 10 - 30 m. Each study plot was divided along its length into three sub-plots. The vegetation within each sub-plot was evaluated separately to allow a finer-scale evaluation of vegetation and sediment patterns. Within each sub-plot the percent cover of each vascular plant species was visually estimated and recorded. Unknown species were collected and identified at the Colorado State University Herbarium.

Channel morphology

Streams respond to changes in sediment load by altering a number of morphological traits. The channel cross-section is relevant because it responds rapidly to changes in sediment input and flow. We hypothesized that if the stream's sediment budget was overloaded, the rapid accumulation of road-derived sediment in impacted areas would change the cross-section of stream channels as the channel and adjacent banks are buried with sediment.

We measured channel cross-sections in 40 riparian plots (Greenman Springs Canyon was not measured). Measurements extended from beyond the riparian vegetation border on each side of the stream and were taken approximately every meter across the riparian zone. Where abrupt changes in stream side topography occurred, measurements were made at closer intervals to capture small scale patterns. Channel depth was measured by sighting a stadia rod through an Abney level. The distance of each point from the transect endpoint was measured using a Sonin Electronic Distance Measurer with a target. The target of the unit was taped to the top of the extendable stadia rod. This technique was quite accurate, allowing us to measure even small-scale (2-3 cm) variation in channel topography.

Analyses

Mapping

The location and extent of all deposits were digitized in an ArcView Geographic Information System (GIS). Gully system starting points and flow paths were identified on digitized aerial photographs and other geographic resources supplied by BMP. The location of the Flagstaff Road centerline and existing drainage culverts were provided by Boulder County. These data were included within the GIS and used to examine the relationship between road structures and sediment flow paths. Sediment deposits were mapped in the GIS using the distance measuring tool and drawn as a line theme. Based on these data, the origins and major pathways of sediment flow were also mapped in ArcView.

Topographical contours were drawn in ArcView using USGS Digital Elevation Model (DEM) data with a 20 ft. grid size. A map of topographical slope was also generated. Using these data, the relationship between slope and sediment deposition was quantified with spatial analysis in ArcView. Upon close examination of the alignment of Long-Gregory Creek in relation to the topographical slope and contour themes, it became evident that there were occasional incongruities between these themes, e.g., at times the creek channel would be drawn traversing a hillside. In cases of obvious channel misplacement, the alignment of Long-Gregory Creek within the study area was corrected before analysis.

Soils

Data for soil color and horizon depths are discussed but no quantitative analyses were conducted on these data. General linear models were used to compare particle size distributions using Systat Version 7.02. Riparian and upland soils were analyzed separately by particle size class. To normalize the data and stabilize variances, percent data were transformed (arcsin(square root (x)) for analysis.

Analyses tested for differences in PSD by comparing the percent of particles in each size class. For the model of riparian soils, three independent variables were included. These independent factors were: (1) degree of impact – 3 levels: impacted, unimpacted, road-derived; (2) canyon – 5 levels: Long-Gregory, Panther, Left-hand, Eleven O'clock, Greenman Springs, and Road; and pit location – 5 levels: new bar, old bar, channel, bank, road. Degree of impact was based on the plot-level mapping of bars. Plots with new bar were classified as impacted; all other plots except road plots were classified as unimpacted by this variable. Interactions between variables were not included because too many interaction cells had sample sizes of zero (e.g., all new bar was in Long-Gregory Canyon). Results were considered significant if $p < 0.05$. When independent variables had a significant effect, we conducted post-hoc, pairwise Bonferroni comparisons (Zar 1984).

One-way analysis of variance was used to compare upland soils with impact as the independent factor (3 levels: impacted, unimpacted reference, road). Post-hoc, pairwise Bonferroni comparisons were used to separate means when significant differences were found. The percent surface ground cover occupied by plant litter and sand-gravel sediment in uplands was compared for impacted and unimpacted references sites using t-tests. Percent data were transformed before analysis.

Vegetation

Uni and multi-variate statistical techniques were used to evaluate patterns in riparian vegetation and test whether vegetation from depositional areas could be statistically discerned from that of reference reaches. Vegetational data were transformed using the formula $x_i = \text{Log}(x+1)$, where x is the percent cover of a species expressed as a decimal. This transformation is widely applied in vegetation science to reduce the overriding influence of very common and abundant species (ter Braak 1998).

Detrended correspondence analysis (DCA) (Hill 1979) was used to ordinate, or arrange plots according to their vegetational composition. DCA algorithms arrange species along ordination axes according to the presence and abundance of each species. Ordination axes graphically represent changes in species composition. In other words, plots located near one another along graph axes are vegetationally similar. Such transitions in vegetation are known as vegetation gradients. Since the composition of plant communities is determined by local environmental conditions, the vegetational gradients revealed in DCA can be used to infer gradients in environmental conditions.

DCA was applied using the Canoco version 4.02 program. Woody species were made passive (no influence) in this analysis since these species generally respond slowly to environmental perturbations and their abundance would mask recent changes in ecological conditions. Twenty-six segments were used for detrending and bi-plot scaling was in force. Within BMP, elevation is a strong determinant of riparian vegetation (Gerhart and Johnson 1999). To control for the effect of elevation and provide more powerful statistical comparisons of plots located at different elevations, elevation was included as a covariate in the DCA using a technique called partial detrended correspondence analysis (Jongman et al. 1995).

To graphically correlate the presence of freshly accumulated sediment with vegetational composition, plots were classified into four categories (0-3) according to percent of the plot length covered by new bar. Plots lacking new bars were classified as “0". Plots with new bar covering 0-15% of their length were classified as “1" (minimal accumulation), those with new bar covering >15 - 50 % of their length were classified as “2" (moderate accumulation), and those with >50 % new bar cover were classified as “3" (high accumulation).

The statistical significance of the groups described above was tested using a Multiple Response Permutation Procedure (MRPP) (Zimmerman et al. 1985). This test was used to determine whether plots contained within the defined categories were more similar to one another than to the plots within other categories based on species composition. That is, the test determines the statistical existence of the plot categories. If categories differ significantly, it suggests that the amount of sediment deposition can be used to predict species composition, or conversely, that it is likely that sediment accumulation has significantly affected species composition.

As a related test, vegetational composition was correlated directly with the length of new bar present in plots. DCA axis 1 scores were regressed against the length of new bar found within the plots. Pearson correlation coefficients were calculated to determine the strength of the linear relationship between new bar accumulation and differences in species composition.

Channel morphology

Channel morphology was described using the width/depth ratio (w/d), defined as the ratio of bankfull width to bankfull depth (Rosgen 1996). Plots located in headwaters were not included in analyses since they have poorly developed channels. Width/depth ratios in impacted and non-impacted channel reaches were compared using a one-side t-test assuming unequal variances.

RESULTS AND DISCUSSION

Sediment and Erosion Mapping

Features mapped in this section are deposits of material similar in color and texture to traction sand applied to Flagstaff Road. For the purposes of this section, unstabilized, scarcely vegetated deposits of coarse sand and gravel containing little organic matter are considered to be recently deposited and derived from Flagstaff Road sediment sources. This road-derived sediment was mapped in upland gully systems and riparian areas. Mapped sediment deposits should be assumed to have originated from Flagstaff Road unless otherwise stated.

In upland gullies and along side-slope deposition areas, road-derived deposits were recognized by a lack of herbaceous vegetation due to burial, accumulated sand along woody plant stems and trunks, lack of surface litter, and a homogenous surface particle cover. Road-derived deposition in riparian areas was recognized by similar characteristics. Because deposition within the channel bottom does not have a direct effect on vegetation, we classified road-derived deposits as new bars when they formed point bars or stream channel islands (Fig. 2). This was done to distinguish them from road-derived deposition within the channel bottom (Fig. 6). These road-derived deposits are noticeably different from more natural stream sediments (Fig. 5). The active channels of unimpacted streams typically have a coarse, cobbled bed with surface particles ranging from small to large (Fig. 3 and 5). In contrast to new bars, point bars and channel islands comprised of natural sediment loads (i.e. "old bars") are well colonized by vegetation, especially woody vegetation, have well developed stratigraphy, and a relatively high percentage of organic carbon throughout the upper soil profile (Fig. 3 and 4).

An overview of road-derived sediment flow paths and deposition is shown in Fig. 7. Five major gully systems transport water, sediment and debris from Flagstaff Road to the Long Creek channel. Four of the five gully systems outlet directly to the channel. Gully System 2 and 3 adjoin to form a continuous flow path to Long Creek. Road-derived sediment enters these gully systems in one of three forms: (1) channelized flow developing from a drainage trench cut tangentially to the radius of a road curve; (2) channelized flow originating from a road drainage culvert; (3) diffuse side-slope deposition which becomes channelized. More than one of these forms was present within some gully systems.

Drainage Trenches

Drainage trenches have been installed along Flagstaff Road to rapidly and efficiently convey storm runoff and melt-water away from the road surface. These trenches appear to be the primary input source of sediment to gullies that drain into Long-Gregory Canyon . Road drainage trenches are generally cut tangent to the outside radius of road curves (see points labeled with a "T" in Fig. 7). This orientation allows runoff flowing down road straightaways to maintain its linear momentum at road curves, and allows road runoff to maintain a high velocity as it leaves the road surface and enters existing gullies. Flagstaff Road itself is also frequently pitched toward the canyon to facilitate

Fig. 5. Photograph taken at LC 1900 showing an unimpacted stream reach. Notice the cobbley bed material and woody debris.

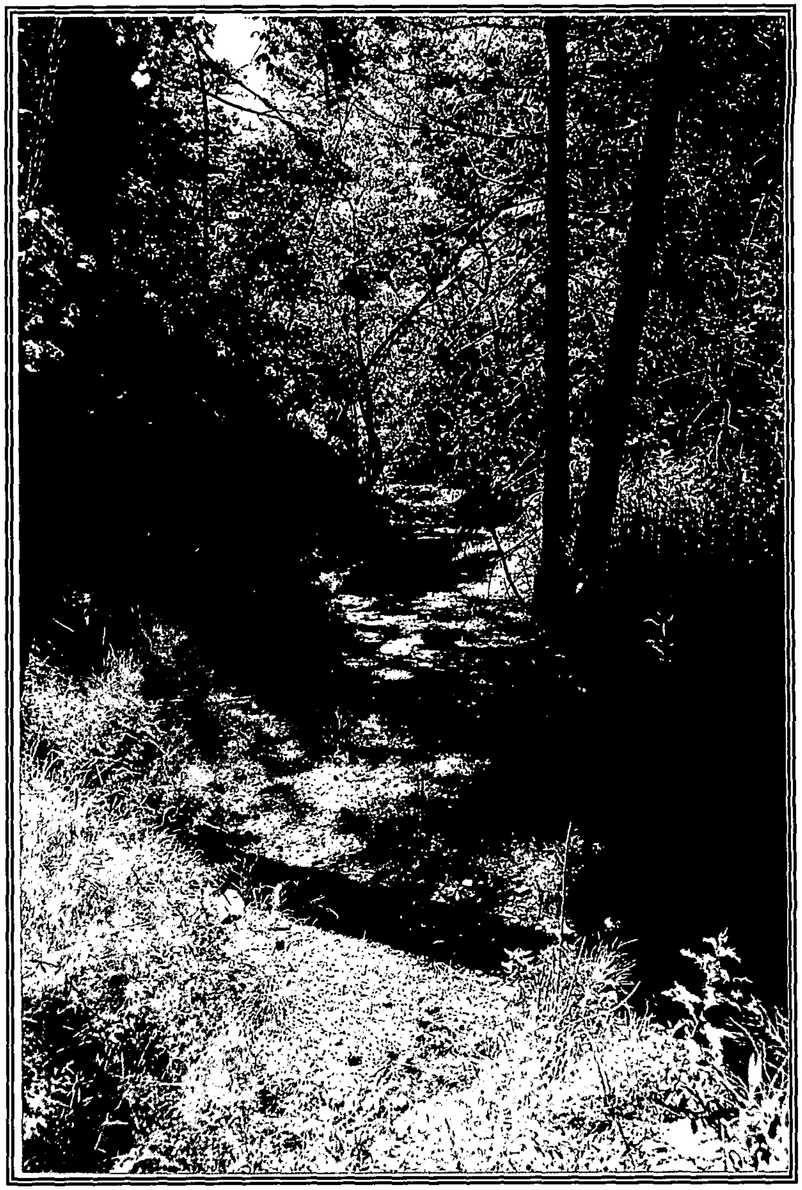

Fig. 6. A heavily impacted channel reach. Note the fine textured bed load and lack of cobbles. The channel profile has been filled with fine-textured sediment. The channel edges and new bars have been colonized with disturbance loving species predominately horsetail, thistle, and blue grass.

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Figure 7. Overview of road sediment flow paths and deposition points (shown in red). All Flow paths (yellow lines) emanate from Flagstaff Road and travel directly or obliquely towards the Long-Gregory Channel. Flowpaths originate at road drainage culverts or drainage trenches cut tangentially to the radii of the road curves.

surface runoff to the canyon-side. The road pitch allows traction sand deposited on the road to be naturally washed to the canyon by storm flow and snowmelt.

Drainage trenches generally terminate at existing side-slope gullies. We are unsure whether the road designers intentionally incorporated these flow connections, or whether they arose simply by happenstance. Because the natural gullies are the most efficient path to transport water and sediment away from the road, it seems likely they were taken advantage of by the road engineers.

Drainage trenches are an efficient method of conveying runoff from the road since they take advantage of fast moving water's ability to carry high loads of sediment and other debris. However, this method of runoff management is also probably the most environmentally detrimental. The high velocity flows not only carry large loads of sediment into Long-Gregory Canyon but also have significant erosive power which can cause severe gullying.

The gullies adjoining runoff trenches have been significantly affected by road runoff. In high gradient reaches, gullies have been entrenched by the high energy runoff waters (Fig. 8), while in lower gradient gully reaches significant sediment deposition has occurred (Fig. 9). The relationship between channel slope and deposition is discussed further below.

Culverts

Culverts along Flagstaff Road travel beneath the road, directing water and sediment from the inside of the road to the canyon side-slope. To reduce the velocity of runoff water before it exits into the canyon, culverts are generally installed perpendicular to the road grade and have a low pitch relative to the surrounding slopes. Because of this placement and configuration, runoff from culverts seems to include less sediment than the runoff from drainage trenches. Based on our observations, culverts contribute more to gully creation, while sediment transfer and deposition originates primarily at drainage trenches. This observation seems especially relevant to the culverts located above the steep-sided canyon reach just upstream of the Greenman Springs Creek - Long Creek confluence. Figures 10 and 11 show examples of gully formation caused by culvert runoff. The gully shown in Figure 10 was formed in a steep side-slope. This gully has a fairly linear flow path and has little or no in-channel sediment accumulation due to the high gradient and resulting high water velocities. Figure 11 shows another gully created by culvert outflow. This gully is located on a slope with more variable gradient and has areas of erosion and entrenchment (as shown in Fig. 11), alternating with large areas of sediment deposition on slope breaks.

Side-slope Deposition

Sediment deposition on side-slopes usually results from erosion of traction sand depots or features we called sand dikes. During the snow months, traction sand depots are placed along Flagstaff Road turnouts to support road sanding operations. Sand dikes are long piles of sand that collect on the road side after plowing and sweeping operations (Fig. 12). Sediment from both sources is carried down-slope by precipitation, snowmelt and wind. Where these areas are not directly

Fig. 8. Gully erosion at the head of Gully System 2. A road drainage trench is located just to the right of the photographer.

Fig. 9. Sediment deposition along a low gradient reach of Gully System 2. Notice the burial of the log and vegetation near the center of the photograph.

Fig. 10. Severe gully erosion cause by culvert runoff. The culvert can be seen above BMP Ranger Steve Armstead's left shoulder. The gully formed by this culvert is often greater than 1.5 m deep. This section of the gully is deeper than the ranger's hip. This photograph was taken at a culvert below the parking area for Green Mountain Lodge, in a very steep reach of Gregory-Long Canyon.

Fig. 11. Gully formation below the culvert feeding GS 4. The culvert opening can be seen just below the road grade, near the center of the photograph. This gully has formed in what was previously an undissected hill slope.

Fig. 12. A sediment dike lining a pull out on Flagstaff Road. The height of the dike, which was over 1 m, can be gauged by comparison with the tree in the foreground. This photograph was taken above GS 4.

connected to any gully systems, sediment typically travels down the side-slope only a short way, and environmental impacts are limited to a thin strip of forest adjacent to the road. In two cases, however, road-derived sediment spreads over a large area and has been subject to secondary gullying (Fig. 7). Both of these areas link to gully systems and serve as important sediment sources for their adjoining gullies. Characteristics of these sites will be discussed in the next section.

Discussion of Sediment Deposition Areas and Gully Systems

Side-slope Deposition Area 1 (SSD 1)

Large amounts of traction sand are applied to the steep, tight hairpin curves at SSD 1 (Fig. 7). At the southern most turn, sediment is conveyed from the road to the side-slope by way of a drainage trench. This side-slope is relatively undissected and sediment is broadly dispersed along the utility right-of-way that is present (Fig. 13). Sand from this side-slope washes downhill to Flagstaff Road where it is transported for approximately 75 m to the head of Gully System 1.

On the slope inside of the second hairpin, sediment washes downslope from sand dikes along the roadside. The entire hillside below this section of road is buried in traction sand to depths of more than a meter. Sand from this hill slope is transported to Flagstaff Road and finally to the head of Gully System 1. SSD 1 is the most severe example of sediment accumulation that we observed. Fortunately, this deposition covers a relatively small section of upland douglas fir/ponderosa pine forest – the commonest forest type in the Mountain Parks. While sediment accumulation in upland forests is undesirable and causes ecological impacts, we feel the primary problem associated with this site is that it is a major sediment source feeding into Gully System 1 (GS 1), which empties into the headwaters of Long Creek.

Gully System 1 (GS 1)

Gully System 1 is a significant point source of road and natural sediment for upper Long Creek. The gully initiates at a road drainage trench that is supplied with sediment and runoff by SSD 1 and other non-point sources along Flagstaff Road (Fig. 7). The quantity and velocity of water exiting the drainage trench have combined with the receiving slope's steep topographical gradient to cause significant head-cutting and entrenchment of this natural drainage. In places, the gully has been entrenched more than 1.5 m deep and 2 m wide. The relatively recent nature of this gully erosion is evidenced by the exposure of tree roots near the top of gully channel. Both road sediment and the additional sediment generated by the entrenchment have been transported and deposited into the Long Creek approximately 200 m below its headwaters (Fig. 14).

GS 1 is a highly significant source of excess sediment for Gregory-Long Creek. This gully is the sole point-source of road-derived sediment for most of Long Creek above its confluence with Gregory Creek. Mitigation of sediment flow down this gully is critical for reducing the accumulation of road-derived sediment within Long Creek.

Fig. 13. A view northeast along the upper depositional zone of SSD 1. The sparse and buried vegetation can be seen throughout the photograph. This elongated area has had trees removed because it is a utility right-of-way. Such vegetation removal has further exacerbated the problem of erosion and sediment export.

Fig. 14. Looking towards the outlet of GS 1 into Long Creek. A delta of deposited traction sand can be seen in the foreground and center of the photograph.

Gully System 2 (GS 2)

Gully System 2 is also fed by a drainage trench (Fig. 7). Runoff from the road has alternately caused entrenchment of the shallow drainage that existed here (Fig. 15) or accumulation of large deposits of road sand and debris (Fig. 15). GS 2 runs roughly parallel to Flagstaff road through upland Douglas fir - ponderosa pine forest. Runoff and sediment flow within this gully is augmented by inputs from two secondary drainage trenches and a culvert. GS 2 is the only gully system that does not flow uninterrupted down to Long Creek, but rather terminates at a sharp bend in Flagstaff Road. At the bend, the sediment load of GS2 is either temporarily deposited near the road-side, continues traveling down GS 3 into Long Creek, or flows down Flagstaff Road to a lower drainage point.

Gully System 3 (GS 3)

Gully System 3 is the largest and most complex gully system. It is actually a continuation of GS 2, with the continuity between the systems interrupted for only a few meters by Flagstaff Road. GS3 is also fed by a trench, two culverts, and a large area of side-slope deposition (Fig. 7). From its origin to its terminus in Long Creek, this gully travels over 0.5 km, making it similar in length to many of the streams within the watershed. GS 3 transports and deposits large amounts of road-derived sediment and debris into Long Creek (Fig. 16). Inputs from this gully system must be strongly reduced to limit future impacts and to facilitate any type of ecological restoration plan.

Gully System 4 (GS 4)

Gully System 4 does not form a long or extensive channel network, but still conveys a large amount of sediment downslope into Long Creek. GS 4 is initially forked, with one tine originating at a culvert and the other at a drainage trench (Figs. 7 and 11). The slope below these features does not appear to have been historically channelized with gullies, or channelization was minimal. Other than the channel that has formed below the culvert, the hill slope is not dissected by channels. Near the junction of the two forks of GS 4, the topographical gradient decreases and an extensive pile of road-derived sediment has accumulated.

GS 4 enters Long Creek about 1800 m below the headwaters, and approximately 200 m below the confluence of Long and Gregory Creeks. At the outlet of this gully in the low-gradient canyon bottom, an extensive delta of road-derived sediment has formed (Fig. 17). Gully runoff continues in the canyon bottom as channelized flow for approximately 20 m within an abandoned channel before it confluxes with the main channel of Long Creek. The reach immediately above and below this confluence contains the largest deposit of road-derived sediment in Long Canyon.

This situation resembles the channel changes that occur at certain natural confluences. In western Colorado, the Little Snake River has flashy flows and transports a large amount of coarse sand (Elliot et al. 1984). Where it empties into the Yampa River it covers the gravel and cobble channel bottom of the Yampa with a layer of sand (0.6 mm; Elliot et al. 1984). The similarity between the gully-stream confluence and this natural example of the response of channels to channelized input of high sediment loads suggests that GS4 transports large volumes of sediment into the Long Creek channel.

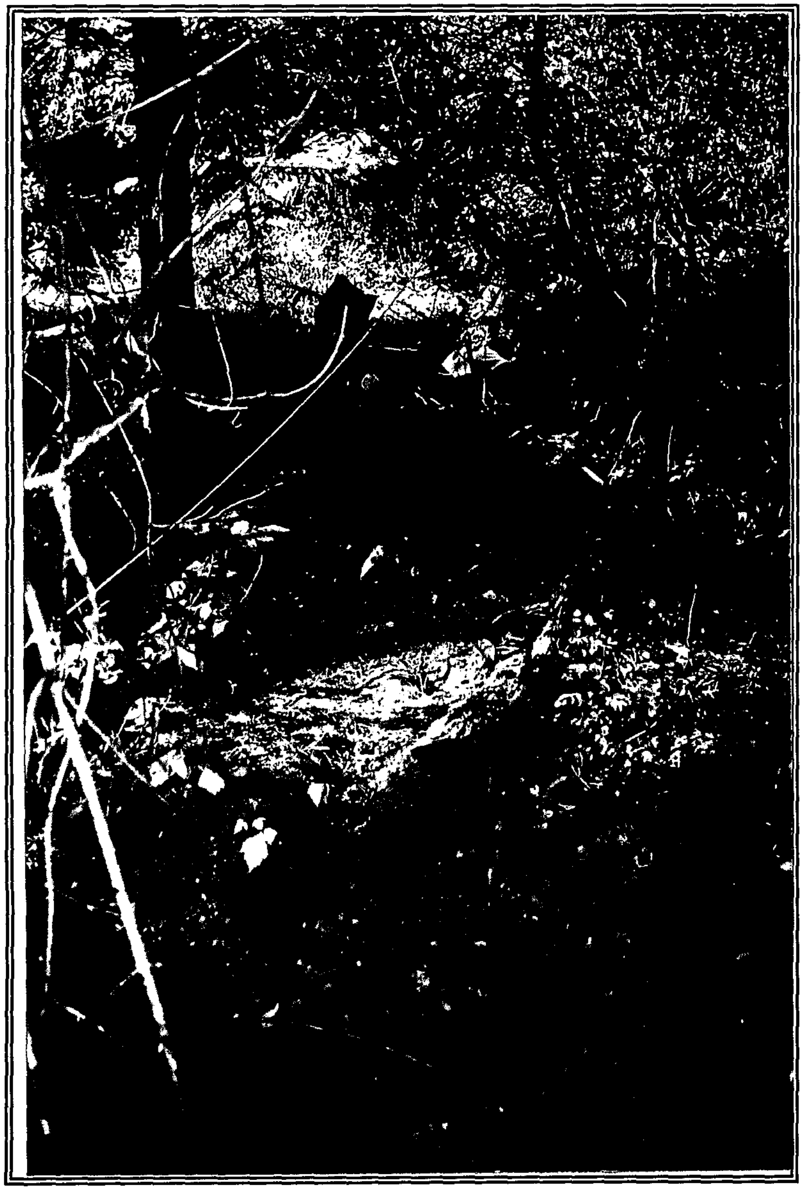


Fig. 15. Sediment deposition along a low-gradient stretch of GS 2. The natural gully channel has been completely filled with traction sand. Burial of channel boulders and coarse woody debris can be seen in the middle of the photograph.

Fig. 16. The outlet of GS 3 at plot LC 1100. The gully mouth can be seen at the photograph center. Deposited sediment, including both traction sand and native materials can be seen at the bottom of the photograph.

Fig. 17. A portion of the large depositional area located at the outlet of GS 4. The entire foreground area is covered in traction sand. The channel at the left of the photograph is an abandoned channel of Long-Gregory Creek that acts as an extension of GS 4. This photograph was taken at plot GS 1600 side.

Gully System 5 (GS 5)

Gully System 5 originates at a culvert and proceeds rather directly down slope, flowing briefly along the Green Mountain Lodge access road before entering the Long-Gregory floodplain. This gully appears to be a comparatively small source of road runoff, however inputs may still have significant impacts.

Down-canyon from GS 5, gullies form below most road culverts and drainage trenches. Gully systems formed by these road features were not mapped both because of the precipitous terrain and the observation that these gullies seem to contribute relatively little road-derived sediment to the creek.

Patterns of Deposition in Gregory-Long Creek

General Conditions

Road-derived sediment and debris were not observed in Long Creek above GS 1, which strongly suggests that GS 1 is the uppermost point-source of road sediment to Long Creek. Road sediment was directly observed in the Long Creek channel at its junction with GS 1 and is frequently found downstream, often in deep deposits. The source of this sediment can easily be traced to Flagstaff Road by following the input gullies to their up-slope terminuses.

Quantifying the volume of road-derived sediment entering Long creek was beyond the scope of this study. However, it is clear that the input of sediment (including traction sand, road base, and native soil) significantly overburdens the stream's sediment budget. Flow in the stream is intermittent, with the channel being dry during much of the year, and the hydrograph is strongly storm driven (Gerhardt and Johnson 1999). The generally low flow volume severely limits the amount of sediment that can be transported by this stream, while the sporadic flow regime limits the temporal window during which sediment movement can occur.

The surplus sediment being introduced into the channel cannot consistently be transported by the natural stream flows. Stream flow volume is typically low in these streams although large, flashy flows can occur as a result of severe storm events. The amount of road-derived sediment deposited into the channel greatly surpasses the mean transport capability of the stream as evidenced by the large quantities of road sediment deposited along the channel. When high flow events do occur they tend to be short-lived. Therefore, during these extreme events the stream may be competent to move a significant amount of sediment, but flow duration is too short to flush much of the mobilized sediment out of the system. Such a flow regime would cause sediment to migrate down the channel in an iterative fashion, being deposited, subsequently mobilized during a flow event, and then redeposited downstream.

The Relationship of Slope and Deposition

A stream's ability to carry sediment is related to its flow velocity (Dunne and Leupold 1978). Stream waters transport fine-grained sediment as suspended load, and roll or bounce large particles along the channel bottom as bedload. When and where flow velocity decreases, the capacity of a stream to carry sediment decreases, and sediment is deposited. Examples of features that might cause local reductions in flow velocity and, therefore, deposition are low gradients, changes in channel morphology, and natural dams.

The relationship between channel gradient and sediment deposition was examined in two ways. First, channel slope at each study plot was compared to the length of plot covered by new bar (this does not include deposition limited to the channel bottoms). Second, the average slope of each mapped sediment deposit within Long Creek was calculated with the aid of a U.S.G.S. digital elevation model in ArcView. This second comparison analyzed road-derived sediment deposition in both the channel bottom and on new bars.

There was a significant negative correlation between the incidence of new bars and the log of percent slope measured in the study plots (Fig. 18). The greatest length of new bar was found in the lowest gradient plots, especially LC 1600 and LC 1600 side. Less commonly, new bar had formed in reaches with up to a 25 % grade. On these steeper grades, road-derived sediment accumulated in small-scale breaks in channel gradient and behind natural dams.

Figure 19 shows the distribution of slopes within the mapped sediment deposits along the length of Long Creek. Approximately one third of all road-derived deposition occurs on slopes of 10 % or less. Sediment with particles the size of most road-derived sediment deposits on steeper slopes only in association with other geomorphic features. The distribution of channel slopes across all of Long Creek is very similar to the distribution of slopes with sediment deposition (Fig 19). This similarity suggests that road-derived sediment is well distributed across the array of channel slopes present in the canyon except in reaches with a greater than 35 % grade. The similarity in distributions further suggests that sites suitable for sediment deposition exist down the length of the canyon. Thus, if the input of road-derived sediment continues, depositional impacts are likely to spread into currently unimpacted reaches.

Conclusions

Based on our observations, the majority of sediment comprising the new bars and channel bottom deposits clearly emanates from Flagstaff Road. This assertion is supported by the fact that road operations are an obvious a source of the coarse sand of which new bars are primarily comprised. These bars and deposits are very similar in color and texture to the traction sand applied to the road, and road sediment can unmistakably be seen entering and descending down side-slope gullies into Long Creek.

Road-derived sediment is transported to Long Creek primarily via five gully systems. Once sediment enters the creek it accumulates as new bars or in the channel bottom along the entire reach down to 6500 ft. of elevation. Below 6500 ft., topography and geology change, the channel gradient steepens considerably, and little sediment was found in, or near the channel. Road-derived sediment most commonly is deposited in areas with 5 - 10 % slopes, but sediment was found in channels with

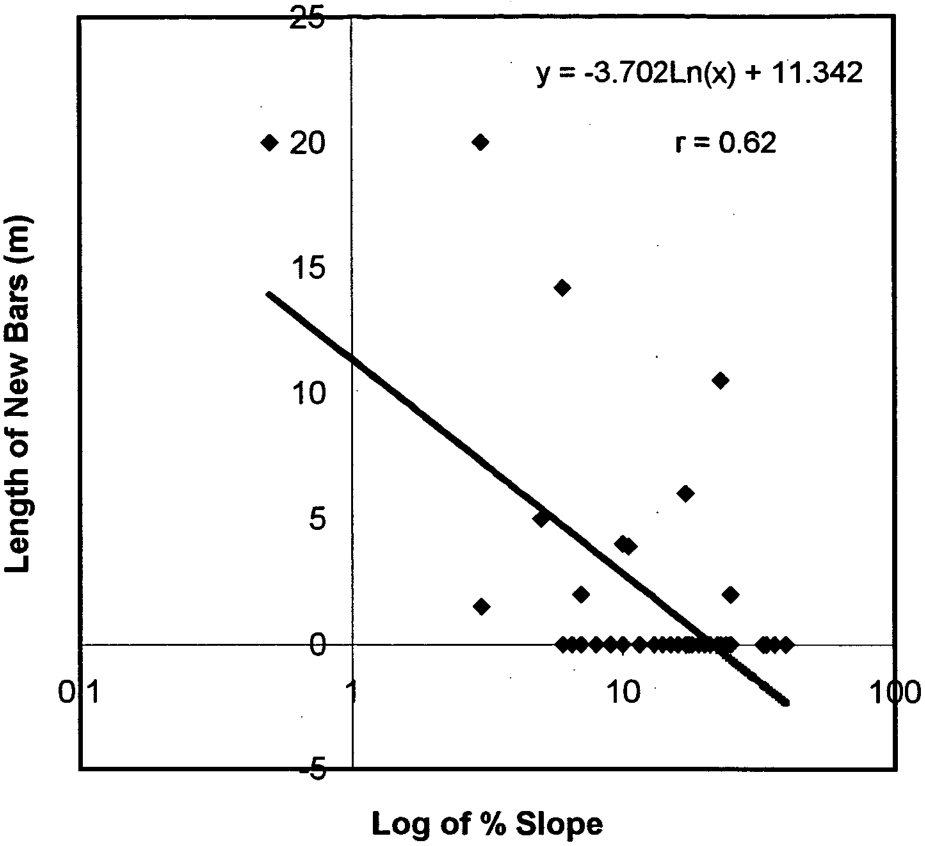


Figure 18. The log value of percent slope versus the length of new bar within the 50 study plots. The regression formula and correlation coefficient (r) are provided on the graph.

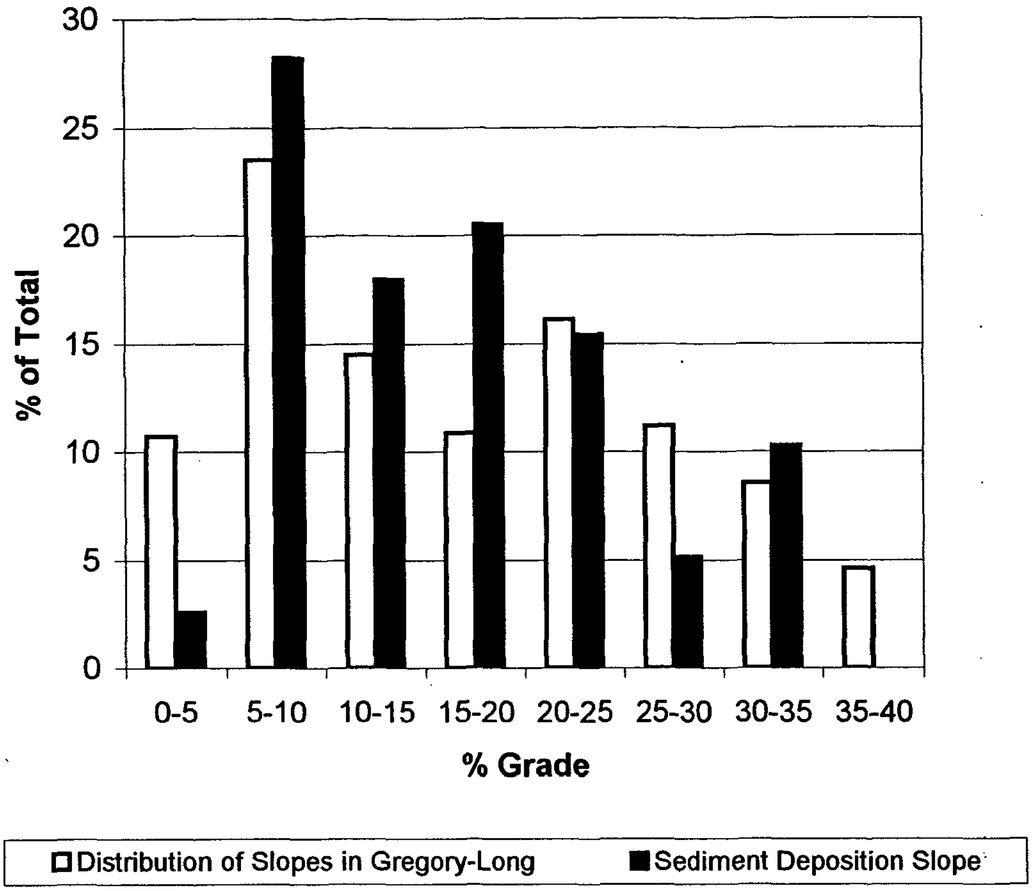


Figure 19. The distribution of channel slopes within Gregory-Long Canyon and the distribution slopes within sediment deposits. Gradient data were obtained USGS Digital Elevation Model data.

gradients up to 35 %. Deposition on steeper slopes seems unlikely since erosion occurs at a maximum on slopes of approximately 40 degrees (Horton 1945). Over one-third of Long Creek's length flows over slopes < 10 % , and nearly half flows over slopes <15%. Our observations and analyses indicate that sediment impacts can spread more broadly throughout the canyon bottom if high sediment inputs continue.

Soils

Stream channel sites

For analysis of the riparian soils, we classified the location from which each soil sample was collected as one of the following locations: road, bank, new bar, old bar, or channel. As described in the Methods, soils were sampled from new bar when possible, then old bar, channel, and bank in decreasing priority. Statistical analyses tested for a difference between canyons, pit locations, and impact classification (based on length of new bar in a plot as described above).

The location from which soils were collected had a strong influence on particle size distribution ($p < 0.001$ for all particle size classes). Overall, road-derived sediment was the coarsest soil tested and soils collected from stream banks were the finest-grained (Fig. 20). Sediment from old bars was the next finest soil sampled. Samples from channels were relatively coarse and also contained the highest percent of unsampled large particles (> 2.5 cm). If the distributions were determined over a wider particles size (using additional field sampling methods) channel sediment would probably appear much coarser, especially in the range of large gravel, cobbles, and boulders. New bar had the distribution closest to road-derived sediment, but generally contained less of the largest particles than road sediment. We conducted a post hoc pairwise-comparison of means to determine whether individual locations could be distinguished from the road material. In general, channel and new bar sediments had different distributions than bank and, to a smaller degree, old bar. Pairwise comparisons could not separate road sediment from other locations, probably because only four sources of reference road sediment were available and sample size was therefore low.

Impact as defined by length of new bar in a plot did not have a significant effect on soil particle size distribution, with the percent of particles in all sizes similar between impacted and unimpacted sites (all $p > 0.70$, Fig. 20). Road-derived sediment appears to be coarser based on Fig. 20, however, the variation in all impact classes was relatively high for the largest particle size. It is not necessarily surprising that length of new bar within in a plot did not have a large effect on particle size distribution. For example, for soils collected from deep new bar deposits at two different sites, the length of the bar is not necessarily controlling particle size. While the length and location of new bar obviously reflect past deposition and influence the particle size distribution of additional sediment, we found no effect of bar length on sand and gravel particle distribution.

In comparing road-derived sediment to all other samples, several points should be considered. The mean for road-derived sediment included both road base and traction sand. When compared to

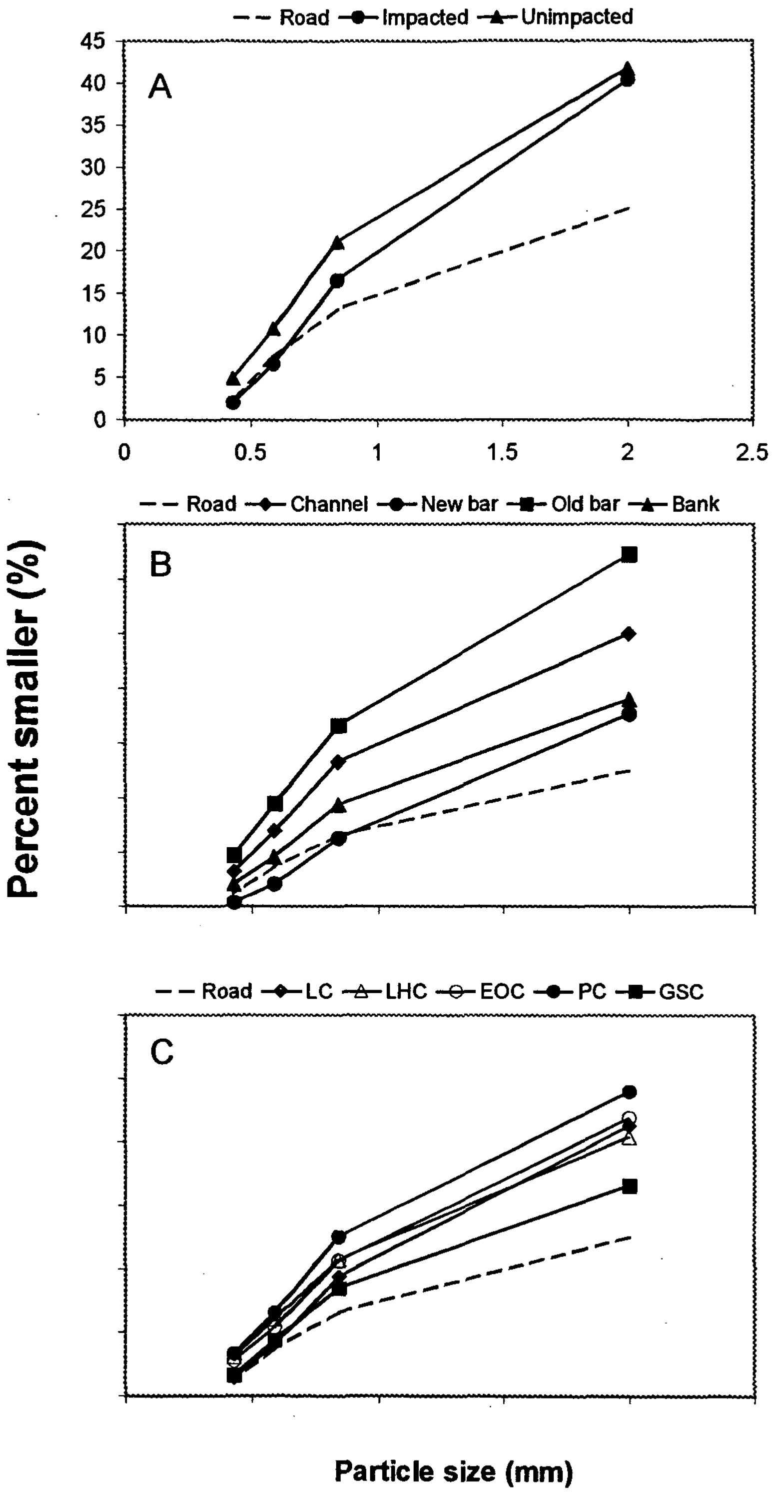


Fig. 20. Mean particle size distributions comparing (A) impacted and unimpacted plots, (B) pit location, and (C) canyons. The y-axis represents the percent of composed of particles smaller than the indicated diameter on the x-axis. Points indicate means; sample sizes were not equal.

traction sand, road base had a higher percentage of both the largest particles and the finest particles. If compared solely to traction sand, both new bar and channel samples would match more closely than is indicated in Fig. 20. We decided to pool all road-derived sediment for these analyses instead of trying to differentiate among the four road-derived sample sources for three primary reasons. First, we received one sample each of traction sand and new road base material from the county, and sampled the only stockpiled sources of traction sand and new road base available along the shoulder of Flagstaff Road. However, sample sizes are too low to compare individual road-derived sources to stream system sediments. Second, the road-derived sources we sampled contained sediment that had not been spread onto the road and had not been pulverized by traffic. Traffic undoubtedly crushes many of the largest particles into smaller gravel or sands, and many of the finer particles are removed from the road by wind before being transported down the gully systems by water. And third, in many runoff flow conditions, water velocity is low enough that particles are differentially deposited in the gully systems and the particle distribution of sediment reaching the stream channel differs from that on the road. Because of these factors, we decided that a composite mean from all four road-derived sediment sources was probably the best approximation possible for introduced sediment.

Upland Sites

Sediment sampling was conducted in road-derived sediment deposits along the length of six mapped sediment deposition areas and gully systems. Reference samples from adjacent non-impacted areas were collected when possible. Comparable reference plots were available for 15 of the 26 upland sites sampled.

Soil color at sampled locations (generally 2.5Y 5/3 to 2.5Y 5/2) was similar to road-derived sediment (2.5Y 5/2 to 5Y 5/2). In contrast, soils from reference plots were generally darker and redder (10YR 3/2 to 7.5YR 4/3). Soil profiles were not compared statistically, however, noticeable differences were observed. In reference plots, the upper soil layer usually contained a mixture of plant litter in various stages of decomposition. Soil horizons below this litter layer were typically composed of medium to find sands, often containing scattered particles of large gravel. Because reference sites were still located within natural gully systems, thin horizons of buried sand and fine gravel were sometimes found, indicating past episodes of temporary rapid deposition. Roots were typically present within the upper 15 cm. The upper soil layer in impacted plots was much simpler, consisting of predominantly very coarse sand and gravel to an average depth of 23.5 cm.

The particle size distribution of soils from road-derived sediment deposition and from reference sites were significantly different. All particle sizes tested differed between impacted and reference plots (all $p < 0.001$; Table 2). In general, sediment from impacted plots was coarser, with a majority of the soil mass being contributed by gravel. In reference plots, more than 50% of the particle mass was contributed by sand (< 2.0 mm), while in impacted plots, slightly less than 25% was contributed by sand. (Fig. 21). For all particle classes smaller than gravel, non-impacted sites had significantly higher percentages than impacted sites. Particle size distribution in impacted plots was nearly identical to the average PSD of road-derived sediment (Bonferroni $p = 1.0$), however both

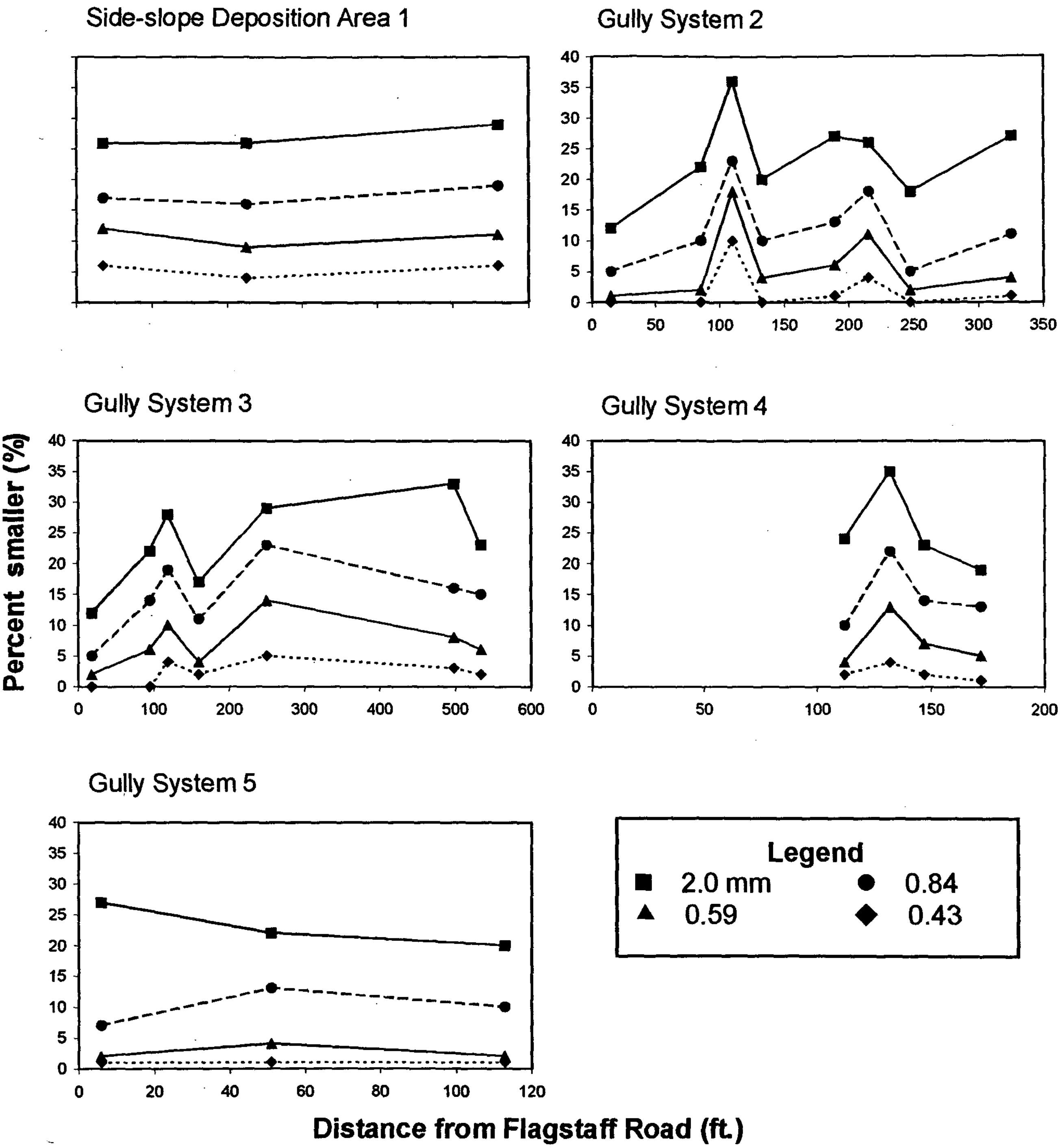


Fig. 21. Plot of particle size data in impacted plots against distance from Flagstaff Road for 5 side-slope deposition areas or gully systems. Values on the y-axis are percent of sediment smaller than a given particle size (2.0, 0.84, 0.59, and 0.43 mm); values on the x-axis are feet from Flagstaff Road. Sites with the most coarse-grained soils will have all points near zero on the y-axis.

mpacted soils and road-derived sediment differed significantly from unimpacted soils (Bonferroni $p < 0.001$). These results show that sediment transported through and deposited along gully systems can be linked to road-derived sources through the strong similarities in particle size distribution and very similar soil colors. These results corroborate the similar findings of the sediment mapping.

We had planned to run regression analysis on particle size data to determine if sediment in impacted plots become more dissimilar from the road-derived material with distance from the road. However, plots of particle data against distance from Flagstaff Road suggest that there is no consistent change in PSD as sediment moves down the side-slope deposition areas or gully systems (Fig. 21). In other words, within each deposition or gully system, local conditions are important in controlling the location and depth of road-derived sediment deposits. For Fig.21, low values on the y-axis generally indicate coarse-grained soils. When the value of the 2.0 mm line is near zero, the soils is almost all gravel. In contrast, high values, especially for the 0.43 mm line, indicate a finer-grained soil.

Table 2. Summary statistics for particle size distribution in impacted (I) and non-impacted (N) upland sites below Flagstaff Road. Data were transformed for analyses. Sample size was 26 for impacted plots and 15 for non-impacted plots. A separate analysis was run for each particle size class. P-values were < 0.001 for all size classes. Summary statistics for the road-derived material (Road) is provided for comparison.

Particle class	Particle size	Impact vs. Non-impacted	Mean % smaller than	Median % smaller than	Standard deviation
Gravel	> 2.0mm	I	24	24	6.4
		N	52	54	8.2
		Road	25	23	12.0
Very coarse sand	2.0 > grain size < 0.84	I	13	13	5.3
		N	35	36	6.0
		Road	13	13	5.2
Coarse sand	0.84 > grain size < 0.59	I	6	6	4.4
		N	21	21	3.8
		Road	7	7	3.0
Medium sand	0.59 > grain size < 0.43	I	2	2	2.4
		N	9	8	3.2
		Road	2	2	1.2

During our reconnaissance trip with BMP personnel, initial recognition of impacted sites, especially in uplands, was based on surface cover. The ground cover of impacted areas consisted of deposits of coarse-grained sediment; in non-impacted areas, patchy herbaceous vegetation and plant litter typically covered the surface and surface particle size appeared more variable, ranging from fine sand to boulders. We compared the surface cover of impacted and unimpacted plots to determine whether road-derived sediment was altering ground cover. The cover of litter was significantly higher in reference plots, and the surface cover of coarse sand and gravel was significantly higher in impacted plots ($p < 0.001$, Table 3)

Table 3. Summary statistics for surface cover data in impacted (I) and non-impacted (N) upland sites below Flagstaff Road. Data were transformed for analyses. Sample size was 26 for impacted plots and 15 for non-impacted plots. A separate analysis was run for each particle size class. P-values were < 0.001 for both variables.

Surface cover	Impact vs. Unimpacted	Mean % cover	Median % cover	Standard deviation
Sand-gravel	I	86.6	96	19.6
	N	9	0	25.6
Litter	I	12.1	0	17.8
	N	74.3	100	40.6

Discussion

Soil color can be used to recognize and describe soil horizons. Soil color is quantified through three characteristics: hue, value and chroma. Hue can be considered the dominant color (yellow, red, blue, etc.). Soils with the same hue, can have different values, a property that quantifies the relative lightness or darkness of the color. And finally, color is classified based on chroma, the strength or purity of the color. Soil color is important because it can be used to infer past or ongoing processes. For example, dark colors - those with low value and chroma - near the surface indicate the accumulation of organic matter from decomposition or deposition. While soil color can serve as a guide to interpreting past and ongoing soil processes, color itself does not affect system processes. We used soil color to help the fingerprint road-derived sediment and compare deposits assumed to be derived from road runoff with road-derived source samples and with deposition assumed to be composed of native materials. In general, the soil color of new bar and in-channel (2.5Y 5/3 to 2.5Y 5/2) was similar to road-derived sediment (2.5Y 5/2 to 5Y 5/2). Where deposition was shallow or color was estimated on sediments not contributed by Flagstaff Road, soil color was typically redder (10YR 3/2 to 7.5YR 4/3) and/or darker (2.5Y 2.5/1) in the top 20 cm.

Soil texture is determined by the size distribution of particles (i.e. percent of sand, silt, and clay). The particle size distribution of a soil is influenced by the parent or source material and weathering, as well as erosion, transportation, and deposition (Knighton 1984, Julien 1995). Unlike soil color, which basically reflects soil processes, soil texture directly influences many soil processes. Because of the relationship between surface area and volume, a fine-grained soil has a much greater internal surface area than a soil with a coarser texture. The larger surface area created by small particles generally increases the biological and chemical activity of the soil, affecting nutrient and organic matter content. High gravel content, like that found in road-derived sediment, prevents the development of soil structure (Birkeland 1999), increasing the movement of water through the soil and altering the susceptibility of the soil to erosion. Texture also influences soil water-holding capacity, infiltration rate, and resistance to erosion (Hillel 1982, Gurnell and Petts 1995, Birkeland 1999). It is therefore an important determinant of growing conditions for riparian vegetation. The rapid accumulation of sediment can also, of course, impact vegetation directly through burial.

Soil profiles based on color and texture indicate that new bar areas have a simple stratigraphy within the upper 20 cm, typically being only a single horizon of coarse sand and gravel. Below this road-derived sediment, a buried layer of litter, decomposing organic material, or cobbles was often found, indicating the location of former surface layers. In some plots, layers of coarse sand and gravel alternated with horizons similar to those found in old bar soils. Because most erosion occurs during floods or peak flow stages (Horton 1945), these alternating strata provide evidence of pulsed deposition caused by storm and runoff events, which were flowed by decreases in flow.

To track road-derived pollutants through ecological systems and link pollutants to environmental impacts, it is advantageous if the pollutants can be accurately characterized through a type of pollutant "fingerprint." Such fingerprints can take the form of detailed molecular descriptions in the case of chemical pollutants (Rauch et al. 2000). When road-derived sediment is the contaminant of concern, a similar approach can be used by fully describing introduced sediment through characteristics such particle size distribution (Ketcheson and Megahan 1996, Kurashige and Fusejima 1997). The particle-size distribution of road-derived sediment shows a preponderance of gravel and very coarse sand (Fig. 20). Statistical comparisons with the PSD of other sampled soils showed that new bar and in-channel, road-derived sediment was distinct from old bar and bank soils, and more similar to road-derived source samples. However, pairwise comparisons between road-derived source sediment and other soils did not reveal significant differences. These findings are likely a result of the small number of reference samples available for road sediment and the variation in percent gravel between traction sand and new road base sources. The ability of the fingerprinting technique to track sediment over long-distances is limited by: 1) the selective transport or deposition into gullies and upper reaches of road-derived sediment based on particle size, and 2) the input of native soils to the channels sediment load. These limitations make exact matches based on particle size distribution unlikely, especially for sediment being transported through the active channel. Deposits of road-derived sediment in uplands matched the source samples more closely, probably because deposits are closer to the source and less influenced by native sediment inputs.

Vegetation

General Conditions

The vegetational composition of 50 plots, divided into 150 subplots, was examined in this study (Fig. 1). These plots covered all major streams between approximately 7500 - 6500 ft. of elevation within the expanded Long-Gregory watershed.

The most easily interpretable results from vegetational analyses emerged from examining the vegetation within the 50 100 m^2 plots, rather than considering the subplots separately. Species cover values for the plots were calculated as the arithmetic average of the species cover values from the three subplots. All analyses discussed were conducted on these average cover values.

Species cover data are presented in Appendix 1. In total, 170 vascular plant species were found within the study plots. Individual plots were rich in plant species, with mean richness averaging 36 species per plot. Boulder Mountain Park riparian areas are typically densely vegetated, except for the bare active channel, and have a complex vegetational structure. Mean plant coverage is109 % due to this dense, multiple layer canopy. Typically the riparian vegetation in the Long-Gregory watershed consists of an open upper conifer-dominated canopy containing by douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*)(Fig. 22). Scattered broad-leaved species such as cottonwood (*Populus deltoides* and *P. angustifolia*) and trembling aspen (*Populus tremuloides*) are also commonly found within this upper canopy. Generally, this upper canopy is not an integral part of the riparian system but rather is spatially associated with it. The coniferous species, in particular, tend to grow on the upland hill slopes and overhang the riparian zone. Although not directly part of the riparian community, these species strongly influence riparian vegetation by shading the understory vegetation. Such shading helps produce the cool, moist environment required to support the unique species assemblages found in BMP canyons.

A lower canopy was present in most plots. This canopy is often multi-layered, dense and closed, but can also be open and consist of scattered understory trees or large shrubs. Characteristic dominant species in the lower canopy are mountain maple (*Acer glabrum*), river birch (*Betula fontinalis*), and mountain ash (*Sorbus scopulina*) (Figs. 22 and 23). Trembling aspen individuals are not uncommon in this layer. Below the lower canopy, a multi-tiered shrub layer is almost always present, including a dense upper layer and a more patchy lower layer. The upper layer is dominated by tall shrubs and small trees, predominately hazel nut (*Corylus cornuta*), mountain maple, wax flower (*Jamesia americana*), river birch and choke cherry (*Prunus virginiana*), often forming a tunnel of vegetation over the active channel (Fig. 24). The lower shrub layer may contain smaller individuals of the species found in the upper canopy mixed in with small statured shrubs and sub-shrubs such as rose (*Rosa woodsii*), Boulder raspberry (*Rubus deliciosus*), thimbleberry (*R. parviflorus*), wild raspberry (*R. idaeus*), wax currant (*Ribes cereum*), common gooseberry (*R. inerme*), nine bark (*Physocarpus opulifolius*), and white snowberry (*Symphoricarpos albus*).

The herbaceous layer is the lowest, most variable, and most species rich vegetation layer. Variability in this layer is control externally by elevation and internally differences in soil moisture, hydrology and by the shading effects of the higher canopy layers. Sites with relatively open upper canopies have a higher prevalence of grass and mesic forb species, especially bracken fern (*Pteridium*

Fig. 22. Photograph of a typical, open upper tree canopy (background). Near the center, is an individual of the lower canopy. A high shrub canopy is just above center, while a lower shrub canopy is to the right of the channel. A lush herbaceous layer is evident throughout the photograph. Plot GSC 445.

Fig. 23. Patchy, lower tree and lower shrub canopies at GSC 320. The herbaceous layer is somewhat patchy being comprised mainly of tall herbs and sub-shrubs.

aquilinum) (Fig. 25). Sites below partially closed canopies are the most species rich and are dominated by moisture-loving, broad-leaved forb species, particularly cow parsnip (*Heracleum sphondylium*), tall coneflower (*Rudbeckia ampla*), false Solomon's seal (*Maianthemum amplexicaule* and *M. stellatum*), twisted stalk (*Streptopus fassettii*), sweet cicely (*Osmorhiza depauperata* and *O. chilensis*), violet (*Viola rydbergii*) and enchanter's nightshade (*Circaea alpina*) (Figs. 26 and 27). The weakly hydrophytic sedges *Carex deweyana* and, to a lesser degree, *C. disperma* are also quite common in this community type. This community type is the most common one sampled during this study.

In the shade of the densest canopies, the herbaceous layer is quite sparse. The vegetation that does exist is comprised of scattered individuals of shade tolerant species such as violet, sweet cicely and *Arnica cordifolia*.

The Effect of Sediment Accumulation on Riparian Vegetational Communities

Fig. 28 shows results of a DCA of herbaceous and subshrub species composition data, after factoring out the effects of elevation. Data points have been coded according to the depositional category into which the plot was classified: 0 indicates no appreciable accumulation of new sediment, while 3 indicates high levels of new sediment accumulation (see Methods for additional explanation). As is evident in the figure, the four impact classes are well disbursed along axis 1, strongly suggesting that accelerated sediment accumulation is an important environmental component affecting vegetational composition. Impact classes are not dispersed along axis 2, indicating that environmental factors such as slope, aspect and/or geology influence plot placement on axis 2. In light of the these results and the questions addressed in this study, axis 1 will be focused on throughout the rest of this report.

DCA axes are divided into units of the standard deviation of species turnover (or SD). Axis units are scaled such that a species appears, rises to its highest abundance, and then disappears over 4 SD units (Gauch 1982). A full turnover in species composition occurs over 4 SD units, while a 50 % turnover occurs over approximately 1 SD unit. Plots impacted by road-derived sediment are located from the left end of axis 1 to approximately its center, with the most highly impacted sites tending toward the left side of the graph. The full width of axis 1 spans just under 3.5 SD units, showing that the most highly impacted sites (LC 1600 & LC 1600 side channel) share only a few species in common with many of the unimpacted sites. In fact, the species composition at these two sites is at least 50 % different from any non-impacted site.

Regression and correlation analyses were used to examine the relationship between the axis 1 vegetational gradient and the amount of road-derived sediment accumulation within plots (Fig. 29). The Pearson correlation coefficient for these two factors is 0.56 and highly significant ($p < 0.001$). The slope of the regression line is also significantly different from zero ($p < 0.001$). These results demonstrate that differences in the amount of new sediment are highly correlated with the differences in vegetational composition mapped on axis 1 of the DCA, and that changes in vegetation increase linearly with increasing deposition. Based on the DCA and correlation analysis we conclude that it

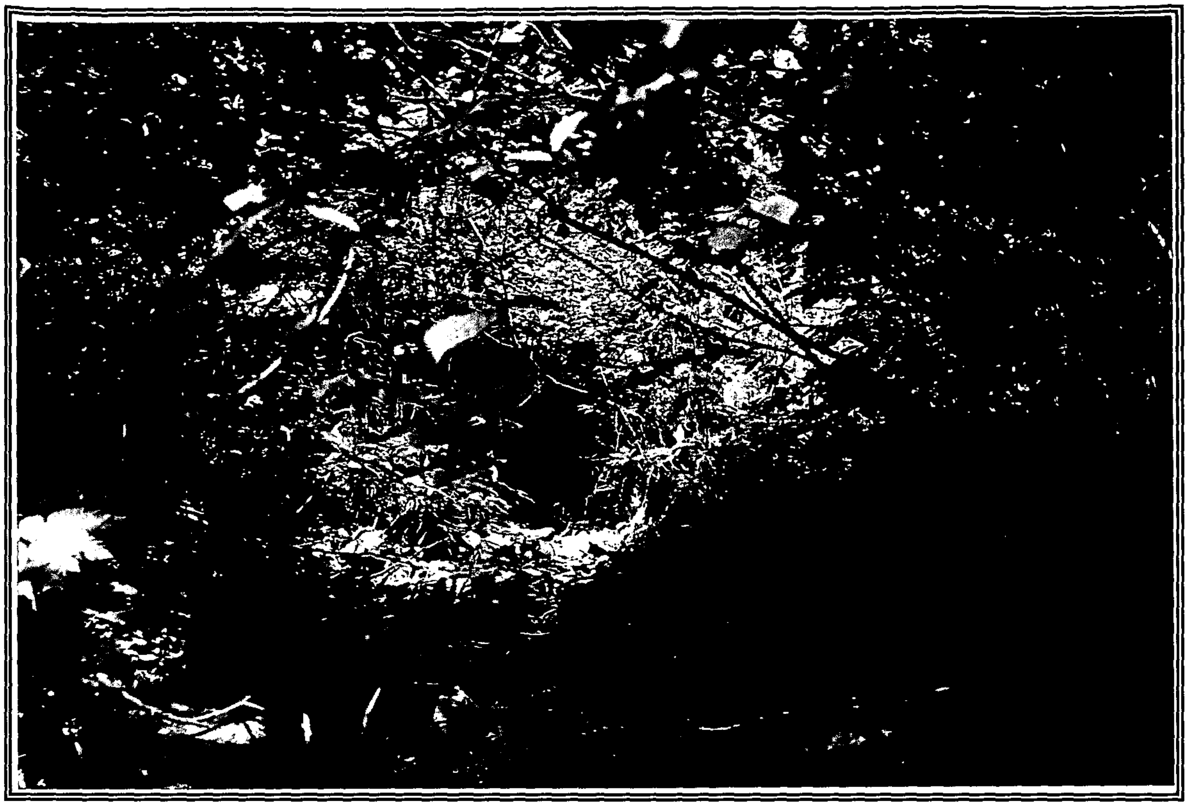


Fig. 24. An unimpacted reach of Long Creek at LC 900. The hazel nut shrub canopy forms a dense tunnel of vegetation. Notice the coarse bed material and lack of fine material on the channel bottom. The herbaceous layer is low and somewhat scarce due to the dense shade.

Fig. 25. A typical open canopied riparian setting in Panther Canyon at PC 100. Not uncommonly bracken fern dominates this type of habitat, as is show in this photograph. A tall canopy of river birch and mountain maple can be seen beyond the fern opening.

Figs. 26 and 27. Example of the lush herbaceous layer found in Boulder Mountain Park riparian areas. Twenty-three and thirty-one species were found in theses plots, respectively. The understory in LHC 200 (Fig. 26) is relatively tall being dominated by tall coneflower, twisted stalk, cow parsnip and bush honey suckle. The more deeply shaded LC -82 (Fig. 27) has a lower canopy dominated by bracken, cow parsnip and other shade tolerant species.

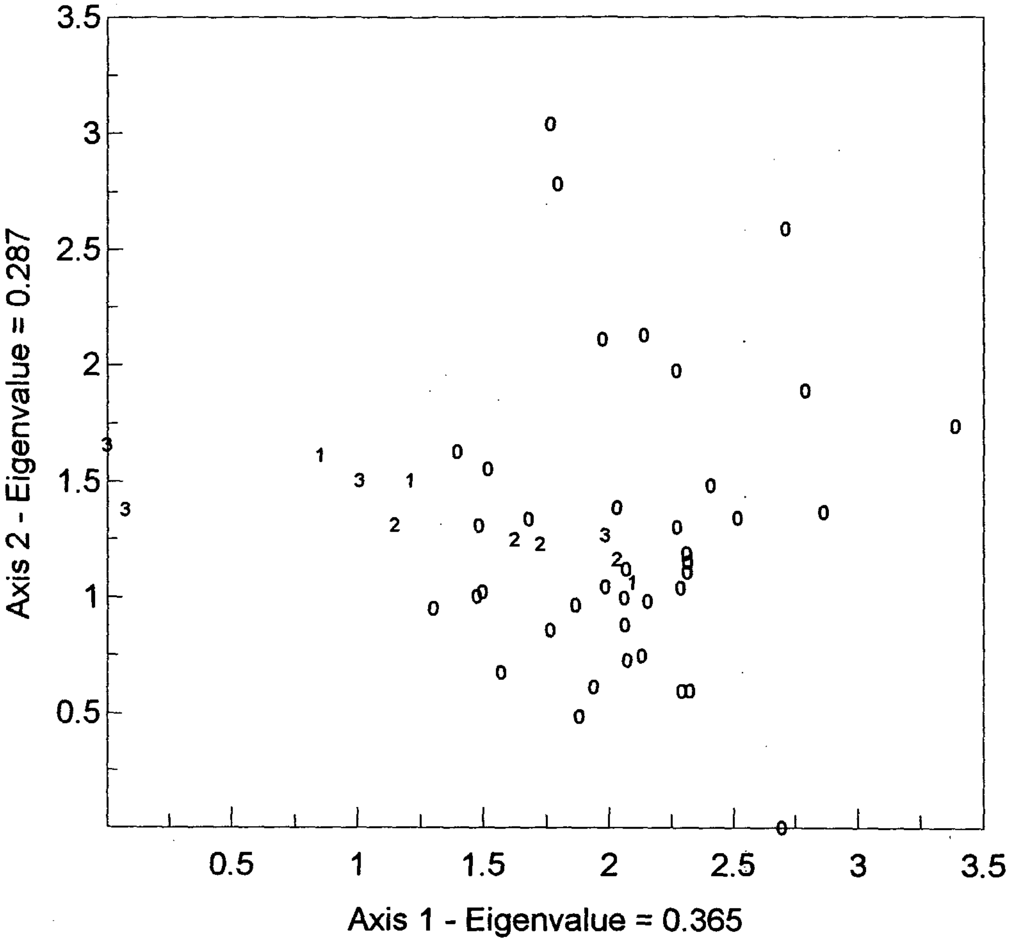


Fig. 28. DCA of vegetation plots. Sediment impact levels were used as plot markers. Impacted plots tended to be grouped to the left in the graph.

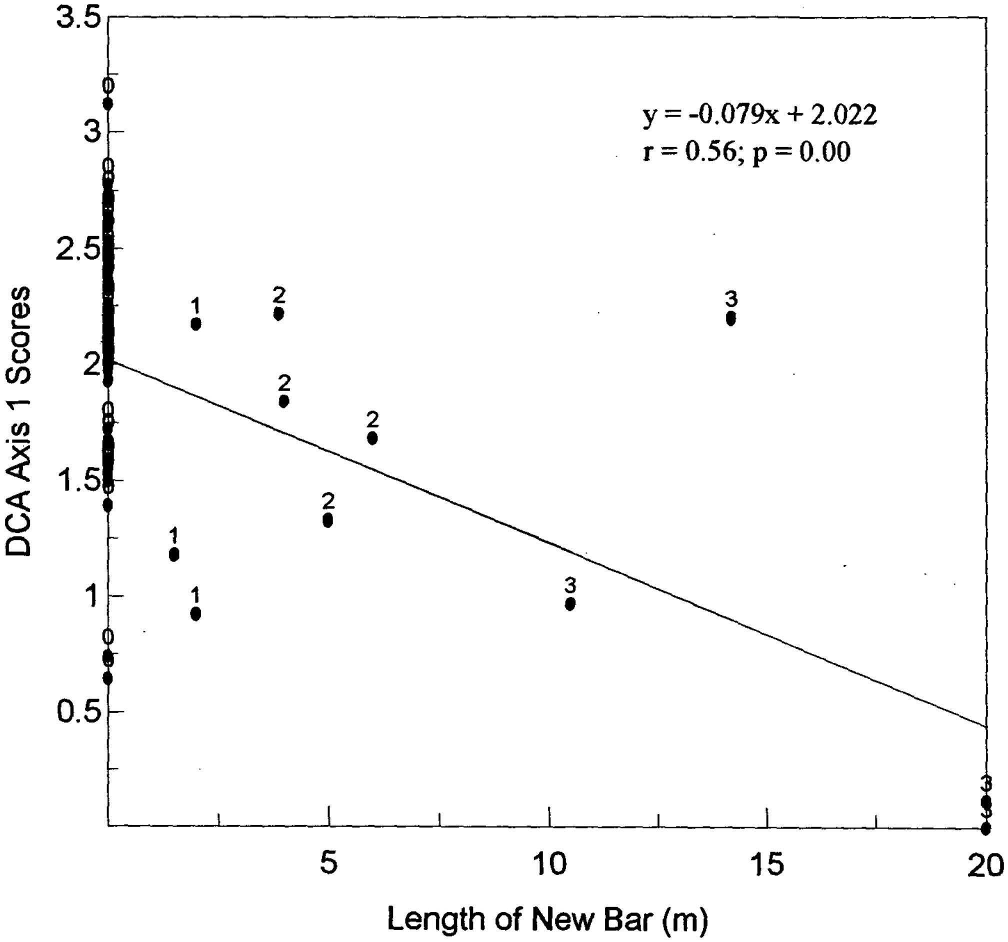


Fig. 29. Regression of DCA axis1 scores on the length of new bar measured in the study plots. The correlation coefficient for these factors in 0.56 which is highly significant. This analysis shows that sediment deposition is strongly correletated with changes in riparian vegetation.

is highly likely that sediment accumulation significantly impacts the vegetational composition of BMP riparian areas.

A final statistical analysis was performed to test whether plots classified *a priori* as being impacted by road-derived sediment deposition could statistically be discerned from unimpacted plots based on species composition. The null hypothesis used in this test was that the ecological distance of plots within *a priori* categories is greater than or equal to the ecological distance between random assemblages of plots. In other words, we tested whether the classification of plots based on deposition is irrelevant based on species composition. Plots were placed into one of two categories for the purpose of this analysis – plots in which new bars were present and those with no new bars. A Multiple Response Permutation Procedure (MRPP) was performed to test this hypothesis. The distance measure used in this analysis was Sorensen's Index. Statistics from this analysis are presented in Table 4.

Based on species composition, the ecological distance within the two groups defined by the presence of new bar is much smaller than the distance within randomly assembled groups ($p < 0.001$). This result leads us to reject the null hypothesis and conclude that vegetational composition in sediment impacted plots is statistically different from that of unimpacted plots. Or conversely, that sediment deposition causes statistically significant changes in riparian vegetation.

Table 4. Analytical statistics from the MRPP. The p-value indicates the significance of the groups being tested.

Group	Average Distance	Average Distance of Randomly Assembled Groups
Unimpacted (Group 0)	0.583	0.611
Impacted (Groups 1, 2, and 3)	0.582	0.611
Probability of Smaller or Equal Distances (p-value)		0.000

Although differences in species composition between sediment impacted and non-impacted plots were significant, statistical differences in species richness and total herbaceous cover were not detected. This result does not fit well with our field observations in which we perceived apparent differences in the herbaceous cover and richness of impacted versus non-impacted plots. The unexpected statistical results could be the result of within-plot sediment deposition and vegetational heterogeneity. Or, of course, the statistical results could be correct and sediment deposition may not have altered richness or total herbaceous cover.

Reaction of Individual Species to Sediment Accumulation

Differences in the presence and abundance of individual species due to sediment impacts were evident in our analyses, although no species seems to be wholly endemic to disturbed areas within BMP. Only five species were found in impacted plots that were not also found in unimpacted plots: *Juncus longistylis, Lysimachia vulgaris, Panicum* sp., *Thalictrum fendleri,* and *Veronica peregrina.* All of these species were found on only one occasion. Table 5 shows the average abundance of species within each of the four sediment impact categories. See Appendix 1 for species abundance data within individual plots.

Species could be grouped into two categories based on their reaction to sediment impacts: those species whose abundance tends to be higher in impacted areas, and those species whose abundance tends to be lower in impacted areas. *Agrostis gigantea* (red top), *Equisetum arvense* (horsetail), *E. hyemale* (horsetail), *Lysimachia vulgaris* (loosestrife), *Glyceria striata* (managrass), *Solidago missouriensis* (golden rod), *Lactuca serriola* (wild lettuce), *Cirsium arvense* (Canada thistle), and *Pteridium aquilinum* all tended to be more abundant in impacted plots. *Agrostis gigantea, Lysimachia vulgaris,* and *Cirsium arvense* are all adventive, weedy species commonly found in disturbed areas. Further, the weedy *Lactuca serriola* tended to replace the native *Lactuca canadensis* in areas subjected to road-derived sediment deposition. It should be noted that the loosestrife found in plot LC 1500 is not the noxious weed called purple loosestrife (*Lythrum salicaria*). Loosestrife was abundant in LC 1500 but not found elsewhere.

Equisetum arvense, E. hyemale, Solidago missouriensis, Glyceria striata, and *Pteridium aquilinum* are native species commonly associated with disturbed habitats. All of these species tended to be associated with stream depositional features, both new bar and old bar, thus illustrating the affinity of the species for disturbed areas regardless of origin. Changes in the abundance of *E. arvense* closely followed the disturbance gradient, with its abundance increasing as the amount of road-derived sediment deposition increased (Fig. 6). This species was also most abundant in moist or wet, sandy areas with open to partially open canopies. *E. hyemale*, too, prefers sandy sites such as those associated with road sediment deposition, but is more abundant in areas that are relatively drier and shadier than those preferred by *E. arvense. Solidago missouriensis, Glyceria striata,* and *Pteridium aquilinum* all favor the open canopied situations commonly found in depositional areas.

Several species commonly found in unimpacted sites showed an aversion to sediment impacted sites. Orchid species including the sensitive twayblade (*Listera convallarioides*) and *Limnorchis* sp. were only found in non- or minimally impacted sites. A very similar pattern was displayed by the male and female ferns (*Dryopteris filix-mas* and *Athyrium filix-femina,* respectively), which were also only found in non- or minimally impacted areas. Other species that showed a negative affinity for sediment impacted sites are *Maianthemum amplexicaule, Viola scopulorum, Carex geyeri, Ligusticum porteri,* and *Physocarpus opulifolius.*

Table 5. Average percent cover of individual species according to sediment impact level measured as length of new bar. Impact level 0 indicates no new bars; impact level 3 indicates that more than 50% of the plot length was occupied by new bar.

		Impact level			
Species Name	Abbreviation	3	2	1	0
Acer glabrum	Ace gla	2.4	6.1	t	7.7
Acetosella vulgaris	Ace vul	t			t
Achillea millefolium	Ach mil		t	t	t
Aconitum columbianum	Aco col	t		t	t
Actaea rubra	Act rub		t		t
Agrostis exerata	Agr exa	1.7	t	t	
Agrostis gigantea	Agr gig	4.0	t	t	t
Agrostis scabra	Agr sca	t	t		t
Aletes acaulis	Ale aca				t
Amelanchier alnifolia	Ame aln				1.4
Anaphalis margaritacea	Ana mar			t	t
Anemone cylindrica	Ane cyl				t
Angelica ampla	Ang amp				t
Antennaria spp.	Ant spp				t
Antennaria parviflora	Ant par				t
Antennaria rosea	Ant ros				t
Apocynum androsaemifolium	Apo and				t
Aquilegia coerulea	Aqu coe				t
Aralia nudicaulis	Ara nud	t	t		t
Arctostaphylos uvi-ursi	Arc uvi				1.2
Arnica cordifolia	Arn cor	t	t	t	t
Artemisia ludoviciana	Art lud			2.0	t
Aster foliaceous	Ast fol		t		t
Aster laevis	Ast lae				t
Aster porteri	Ast por				t
Aster spp.	Ast spp	t	t	t	t
Asteraceae	Asteraceae				t
Athyrium filix-femina	Ath fil				2.5
Betula fontinalis	Bet fon	22.0	21.2	40.9	24.1
Betula papyrifera	Bet pap	65.3			13.9
Botrypus virginianus	Bot vir				t
Bromopsis lanatipes	Bro lan	t	t	t	t
Bromopsis pubescens	Bro pub				t
Calamagrostis canadensis	Cal can	t			t
Calamagrostis stricta	Cal str				t
Campanula rotundifolia	Cam rot				t
Carex deweyana	Car dew	t	4.3	2.7	2.9
Carex disperma	Car dis				t
Carex geyeri	Car gey	t	t	1.7	2.3
Carex hasseyi	Car has				t
Carex limnophila	Car lim	t			t
Carex microptera	Car mic	t			t
Carex spp.	Car spp				t
Cerastium fontanum	Cer fon				t

Species Name	Abbreviation	Impact level			
		3	2	1	0
Cerastium nutans	Cer nut		t		t
Chamerion angustifolium	Cha ang				t
Chimaphila umbellata	Chi umb				t
Circaea alpina	Cir alp	1.6	4.4	t	3.5
Cirsium arvense	Cir arv	2.1		t	t
Cirsium spp.	Cir spp	t	t	t	t
Clematis ligusticifolia	Cle lig				t
Conioselinum scopulorum	Con sco	t	t	t	t
Cornus stolonifera/Swida sericea	Cor sto	6.7	20.0	15.3	23.7
Corylus cornuta	Cor cor		t	t	7.6
Crunocallis chamissoi	Cru cha				t
Cryptogramma acrostichoides	Cry acr				t
Cylactis pubescens	Cyl pub				t
Cynoglossum officinale	Cyn off				t
Cystopteris fragilis	Cys fra	t	t	t	t
Dactylis glomerata	Dac glo	t	t	t	1.3
Danthonia spicata	Dan spi				t
Deschampsia cespitosa	Des ces				t
Disporum trachycarpum	Dis tra				t
Dodecatheon pulchellum	Dod pul	t	t	t	t
Drymocallis fissa	Dry fis				t
Dryopteris filix-mas	Dry fil				t
Elymus canadensis	Ely can				t
Elymus glaucus	Ely gla	t	t	t	t
Elymus trachycaulus	Ely tra				t
Epilobium ciliatum	Epi cil				t
Epilobium hornemannii	Epi hor	t	t		t
Epilobium spp.	Epi spp	t			t
Equisetum arvense	Equ arv	34.6	7.5	4.0	1.1
Equisetum hyemale	Equ hym	4.4	3.0	7.0	2.1
Equisetum laevigatum	Equ lae				t
Erigeron formosissimus	Eri for				t
Erigeron speciosus	Eri spe				t
Erigeron spp.	Eri spp				t
Eupatorium maculatum	Eup mac				t
Fragaria spp.	Fra ame	t	t	t	t
Galium septentrionale	Gal sep				t
Galium triflorum	Gal tri	t	t	t	t
Geranium richardsonii	Ger ric	t	t	t	t
Geum macrophyllum	Geu mac	t	t	t	t
Glyceria striata	Gly str	1.4	t		t
Goodyera oblongifolia	Goo obl				t
Heracleum sphondylium	Her sph	2.9	6.6	t	3.1
Heterotheca villosa	Het vill				t
Heuchera bracteata	Heu bra				t
Hydrophyllum fendleri	Hyd fen	t	1.3	t	t
Jamesia americana	Jam ame		1.1	1.2	6.1
Juncus longistylis	Jun lon			t	
Juniperus communis	Jun com		t	2.7	t

Species Name	Abbreviation	Impact level			
		3	2	1	0
Juniperus scopulorum	Jun sco				1.2
Lactuca canadensis	Lac can	t			t
Lactuca serriola	Lac ser	t	t	t	t
Ligusticum porteri	Lig por		t		1.3
Limnorchis hyperborea	Lim hyp			t	t
Limnorchis spp.	Lim spp				t
Listera convallarioides	Lis con			t	t
Lonicera involucrata	Lon invo	2.3	t	1.6	1.4
Luzula parviflora	Luz par			t	t
Lysimachia vulgaris	Lys vul			5.0	
Mahonia repens	Mah rep	t	t	t	t
Maianthemum amplexicaule	Mia amp	t	t	t	t
Maianthemum stellatum	Mia ste	t			t
Medicago lupulina	Med lup	t			t
Mentha arvensis	Men arv	t			t
Mertensia lanceolata	Mer lan				t
Monarda fistulosa	Mon fis		t	t	t
Muhlenbergia racemosa	Muh rac				t
Orthilia secunda	Oro sec				t
Oryzopsis asperifolia	Ory asp	t	t		t
Osmorhiza chilensis	Osm chi	t	t	t	t
Osmorhiza depauperata	Osm dep	t	t		t
Oxalis dillenii	Oxa dil				t
Panicum spp.	Pan spp.		t		
Parthenocissus inserta	Par ins				t
Phleum pratense	Phl pra	2.0		1.4	1.3
Physocarpus opuliferous	Phy opu				2.0
Picea pungens	Pic pun				t
Pinus contorta	Pin cor				t
Pinus ponderosa	Pin pon	4.8	2.7	21.7	6.3
Plantago major	Pla maj	t		t	t
Poa compressa	Poa com				t
Poa nervosa	Poa ner				t
Poa pratensis	Poa pra	t	t	t	t
Poa spp.	Poa spp		t		4.0
Polypodium amorphum	Pol amo				t
Populus angustifolia	Pop ang				23.4
Populus tremuloides	Pop tre	3.3	2.6	6.3	2.2
Prunella vulgaris	Pru vul		t	t	t
Prunus virginiana	Pru vir	t	1.1	t	1.5
Pseudotsuga menziesii	Pse men	21.9	8.9	10.8	12.5
Pseudocymopterus montanus	Pse mon				t
Pteridium aquilinum	Ptr aqu	26.2	15.7	t	12.1
Pyrola chlorantha	Pyr chl				t
Pyrola rotundifolia	Pyr rot	t		t	t
Quercus gambelii	Que gam				t
Ranunculus acriformis	Ran acr				t
Ranunculus maconii	Ran mac				t
Ribes aureum	Rib aur				t

		Impact level			
Species Name	Abbreviation	3	2	1	0
Ribes cereum	Rib cer		3.0	t	1.0
Ribes inerme	Rib ine		t		t
Rosa woodsii	Ros woo	t	3.0	t	t
Rubus deliciosus	Rub del	t	2.0	3.3	1.8
Rubus idaeus	Rub ide	1.6	t	t	t
Rubus parviflorus	Rub par				t
Rubus pubescens	rub pub				t
Rudbeckia ampla	Rud amp	1.7	1.5	2.6	2.6
Salix bebbiana	Sal beb	5.3		2.7	t
Salix exigua	Salix exi	1.9		7.3	8.3
Salix monticola	Sal mon	t		t	2.3
Sambucus canadensis	Sam can		t		t
Sanicula marilandica	San mar	t	t	t	t
Sedum lanceolatum	Sed lan				t
Senecio sp.	Sen spp		t		
Smilax lasioneuron	Smi las				t
Solidago canadensis	Sol can				t
Solidago missouriensis	Sol mis	1.7		t	t
Solidago spathulata	Sol spa				2.7
Sorbus scopulina	Sor sco				2.0
Stellaria jamesiana	Ste jam				t
Stenactis (Erigeron) strigosus	Ste str				t
Streptopus amplexiflorus	Str fas	2.1	1.5	t	1.8
Symphoricarpos albus	sym alb	t	t	t	t
Taraxacum officinale	Tar off	t	t	t	t
Thalictrum fendleri	Tha fen	t			
Thermopsis divaricarpa	The div		t	t	t
Thlaspi spp.	Tha spp				t
Toxicodendron rydbergii	Tox ryd			t	1.7
Trifolium pratense	Tri pra				t
Trifolium repens	Tri rep			t	t
Trifolium spp.	Tri spp				t
Turritius glabra	Tur gla				t
Urtica gracilis	Urt gra				t
Verbascum thapsus	Ver tha				t
Verbena hastata	Ver has	t			t
Veronica americana	Ver ame				t
Veronica peregrina	Ver per	t			
Viola rydbergii	Vio ryd				1.4
Viola scopulorum	Vio sco	t	t	t	t
Vitus riparia	Vit rip			t	t
Unknowns					
Tight grass	Tight grass				
Tiny grass	Tiny grass				t
Small Grass	Small Grass	t	t		t
Grass 2	Grass 2	t			
Total Cover		117.5	92.3	85.2	104.3

A species that does not fit into either of the above categories is paper birch (*Betula papyrifera*). This species is found in two stands (LC 300 and LC 700). The LC 300 paper birch population has probably been present for much longer than Flagstaff Road has been in existence. The stream reach inhabited by this population is now heavily impacted by road-derived sediment accumulation (Fig. 2) and the birch show signs of significant stress (Fig. 30). A conclusive link between sediment deposition and birch stress was not investigated in this study, but such a nexus seems probable.

The Effect of Sediment Accumulation on Upland Vegetational Communities

During preliminary investigations it became apparent that impacts to upland vegetational communities were relatively small and isolated. The majority of road sediment deposited in upland areas was deposited within the five major gullies leading from Flagstaff Road to the Long-Gregory drainage. Due to the high level of disturbance naturally present in such features, gullies tend to have little or no vegetation regardless of their proximity to Flagstaff Road. In light of these observations, the vegetational composition of gullies subjected increased runoff from to Flagstaff Road were not quantitatively examined. This is not to suggest that runoff from Flagstaff Road has no effect on the characteristics of gullies within BMP, but rather that additional runoff and sedimentation due to the road have only small impacts the vegetational character of these features.

The other type of upland area in which road sediment was observed are the hill slopes below Flagstaff Road (see Sediment Mapping). Two such areas have been subjected to significant road-derived sediment deposition (Fig. 7). As with gully vegetation, after preliminary examination of the impacted hill slopes it appeared quite likely that it would not be possible to detect differences in vegetation due to sediment accumulation. This was mainly due to the fact that natural understory vegetation in the upland forests of BMP is quite patchy, with large unvegetated areas being interspersed with small patches of dense vegetation. Further, hill slope impacts tended to be isolated and relatively well contained.

To investigate the hypothesis that hill slope impacts would be difficult to quantify, a comparison of vegetational composition in impacted and non-impacted areas of the southern most hillside deposition site (SSD1) was performed. At this site, study plots were laid out in transects in areas subjected to road sediment deposition and adjacent areas without deposition. The visual difference between these areas was quite apparent (Figs. 31 and 32). Mean understory plant cover in non-impacted plots was 15.5 % (standard deviation [SD] = 17.1 %), while cover in impacted plots was 8.8 % (SD = 13.41 %). Although impacted plots apparently showed a reduction in total plant coverage, the difference between these two means was not statistically significant ($p = 0.23$). Similarly, species richness in the non-impacted plots was 2.6 species/plot (SD = 1.8), while that of impacted plots was 1.4 (SD = 1.79). As with total cover this difference was not statistically significant ($p = 0.08$). The lack of significance in this comparison probably resulted from the high variance associated with each of these parameters, rather than a lack of actual vegetational impacts. Statistically detecting such differences in the highly variable richness and cover could only be accomplished by examining a very large number of plots. We felt that quantifying sediment impacts

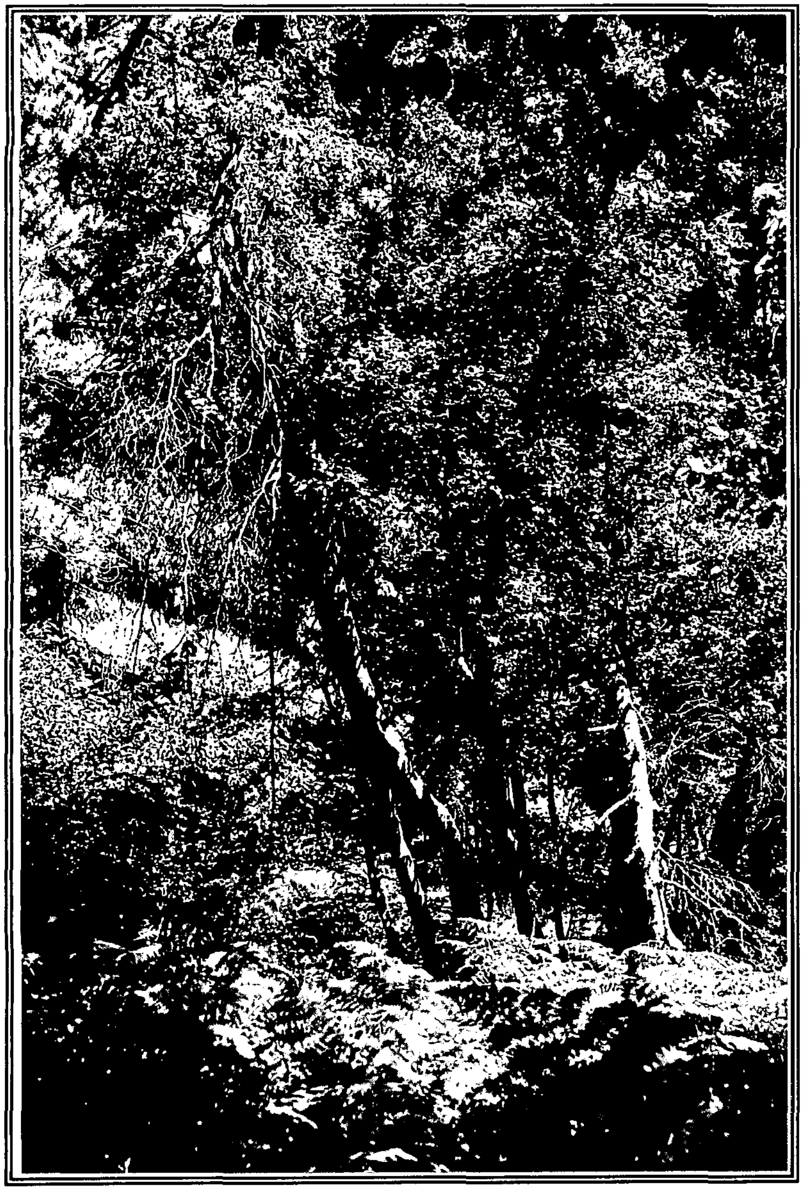


Fig. 30. Paper birch at LC 300. These trees are showing significant stress. Large dead branches can be seen hanging in the upper left and near the lower right of the photograph. Numerous other large dead branches are hidden in the canopy as well. The bases of these trees are buried in road sediment, but it is unclear whether the sediment has caused this stress.

Fig. 33. A juniper shrub being buried by road sediment at SSD 1. The lack of surficial rocky debris is uncharacteristic of this habitat type.

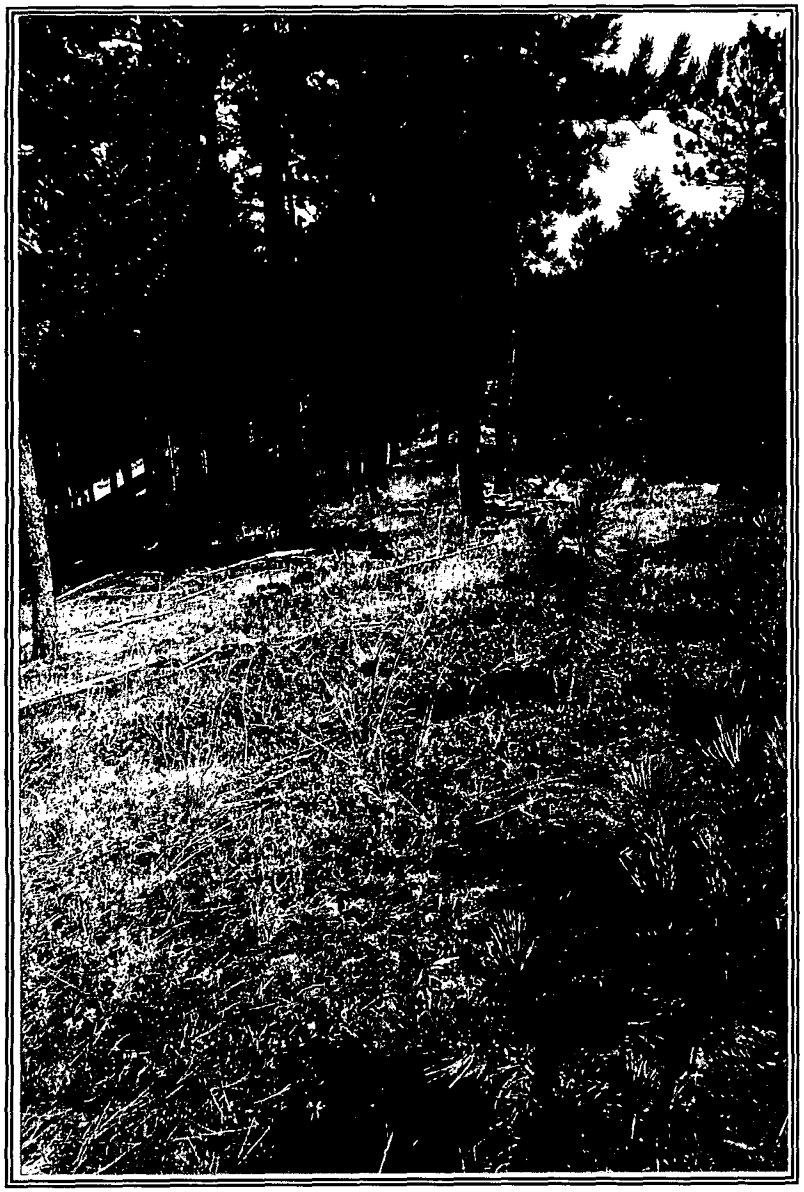


Fig. 31. An unimpacted section of Douglas fir - ponderosa pine forest At SSD 1. As is typical in these forests, the floor is well covered with patches of spreading sub-shrubs, isolated herbs, grasses and litter.

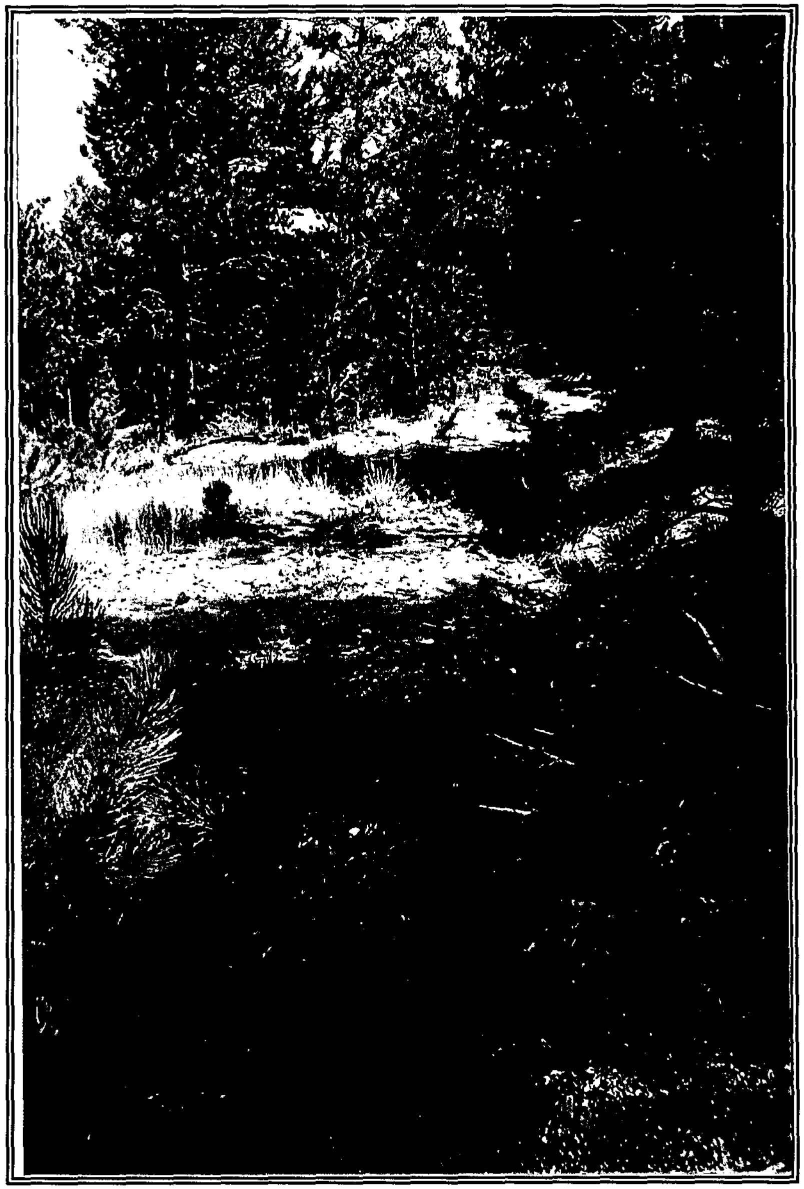


Fig. 32. Heavily impacted Douglas fir - ponderosa pine forest. An incipient gully can be seen in the foreground leading to a depositional surface. Note the lack of ground cover including litter.

in sensitive riparian areas was a higher priority than a thorough investigation of impacts of sediment accumulation in the small number of upland sites, and no additional analysis of upland impacts was conducted.

Anecdotal observations of the effects of road-derived sediment deposition on upland vegetation suggest that burial of slow growing vegetation appears to be the main effect (Fig. 33). Figs. 31 and 32 show the herbaceous vegetation layer in a non-impacted and an impacted upland community. These photographs were taken within a few meters of each other. Compared to unimpacted areas, impacted areas clearly show an accumulation of road-derived sediment and a marked lack of vegetation cover. Tree bases were frequently buried by road-derived sediment, although this did not cause observable stress in the individuals examined. The greatest effect of sediment deposition on tree species is probably on stand reproduction through a reduction in seedling survival.

Conclusions

Vegetational differences between plots were significantly correlated with the amount of road-derived sediment within plots. While correlation analyses cannot definitively demonstrate causality, these results strongly suggest that the presence of new bars impacts the riparian environment and produces changes in species composition. Hypothesis testing corroborated this finding, showing that vegetation in impacted plots is similar to that in other impacted plots, but statistically different from vegetation in unimpacted plots.

Impacted plots tend to have a higher frequency and abundance of weedy, adventive species, as well as native species which inhabit disturbed environments. Sensitive plant species such as orchids and several ferns were not found in impacted areas, suggesting that the rapid accumulation of coarse sediment precludes the growth of these important Mountain Park species. A regionally endemic population of paper birch is found in an area of high impact, and trees currently show signs of severe stress. The link between sediment deposition and birch stress was not investigated specifically. However, such a link seems likely, suggesting that continued sediment deposition in the birch population sites could ultimately lead to there extirpation. No statistical differences in plant cover or richness were detected between intact and sediment impacted sites, although the outcome of these statistical results is in conflict with personal observations.

Vegetation impacts will likely increase if the input of road-derived sediment deposition is not successfully reduced. Based on the geographic analyses (see Sediment Mapping), sediment impacts can spread to currently unimpacted stream reaches.

Although the primary goal of this study was to obtain data for evaluation of potential sedimentation impacts it is also a valuable part of the general inventory of BMP riparian vegetation. To our knowledge, there has not been another study that has gathered fine-scale, objective vegetation data such as this within a whole watershed.

Impacts to Stream Morphology

Channel cross-sections were measured at plots in all but Greenman Springs Canyon. Channel morphology was described using the width/depth ratio (w/d), defined as the ratio of bankfull width to bankfull depth (Rosgen 1996). Table 6 provides stream channel morphometric data. Cross-sections taken in headwaters were not included in these analyses since headwater reaches have only poorly developed channels, and thus their morphology is atypical of BMP streams.

In comparisons of w/d ratios, higher values indicate relatively broad, shallow channel configurations. Width/depth ratios in impacted and non-impacted channel reaches were compared using a one-side t-test assuming unequal variances. The cross-section at LC -2 was not included in this analysis because it had been significantly entrenched by local gully runoff. Mean w/d in unimpacted reaches was 6.2 (SD = 3.3), while in impacted reaches it was 8.5 (SD = 2.7). These values are statistically different ($p = 0.02$) indicating that the accumulation of road-derived sediment in Long Creek has been sufficiently high to cause local changes in channel morphology. Figure 34 provides a comparison of representative channel cross-sections from impacted and non-impacted reaches of Long Creek. A full library of cross-sections is provided in Appendix 2. To facilitate comparison, the cross-sections used in this comparison were obtained in geomorphologically similar reaches.

The higher w/d ratios found in impacted versus unimpacted reaches seem to result from the filling of the active channel with sediment; although Schumm (1960) showed that channel morphology also is strongly controlled by the characteristics of sediment in the channel perimeter. In Figure 34, the unimpacted channels have a definite, confined active-channel set into a narrow floodplain, while the active channel in impacted reaches has been filled with sediment and is barely discernable (Figs. 6 and 34). Impacted channels also frequently acquire a braided channel configuration indicative of high sediment loads (Dunne and Leopold 1978).

Channel morphology is one of the basic attributes of any stream. These results have shown that road-derived sediment deposition has significantly altered stream morphology in a number reaches. Alterations in stream morphology modify fluvial characteristics such as hydraulics, flow dynamics, and sediment translocation. Channel burial and over-bank sediment deposition cover channel structure including rocks, woody debris, and microtopographical features. Such burial severely degrades aquatic invertebrate habitat by covering cobbles which are critical for their survival. It also significantly degrades riparian plant species habitat by burying slow growing vegetation, altering soil moisture characteristics and chemistry.

Table 6. Stream morphology data. The impact level column indicates whether sediment accumulation was found in the plot.

Station	Bankfull Width	Bankfull Depth	W/D Ratio	Impact level
LHC-0	6.13	1.36	4.51	Headwater
PC-0	4.32	0.50	8.64	Headwater
EOC-0	5.51	0.65	8.48	Headwater
LC-1400	9.41	0.91	10.34	Impacted
LC 1700	2.69	0.46	5.91	Impacted
LHC-200	3.25	0.60	5.42	Impacted
LC-100	4.79	0.72	6.65	Impacted
LC-600	5.13	0.55	9.33	Impacted
LC-1000	5.80	1.02	5.69	Impacted
LC-1300	6.40	0.77	8.31	Impacted
LC-300	8.73	0.63	13.86	Impacted
LC 1600 SIDE	5.53	0.50	11.06	Impacted
LC 1600	4.63	0.55	8.42	Impacted
LC-2	4.23	0.91	4.65	Impacted
LC-82	1.22	0.82	1.49	Unimpacted
LC-200	4.97	0.82	6.06	Unimpacted
LC-400	6.21	0.95	6.54	Unimpacted
LC-500	3.57	0.88	4.06	Unimpacted
LC-800	3.84	0.65	5.91	Unimpacted
LC-900	4.46	0.60	7.43	Unimpacted
LC-1100	3.24	0.98	3.31	Unimpacted
LC-1200	8.10	0.60	13.50	Unimpacted
LC 1800	9.40	0.60	15.67	Unimpacted
LC 1900	7.91	0.91	8.69	Unimpacted
LHC-100	3.93	0.80	4.91	Unimpacted
LHC-300	2.70	0.80	3.38	Unimpacted
LHC-400	3.75	0.70	5.36	Unimpacted
LHC-500	3.10	0.70	4.43	Unimpacted
LHC-570	3.75	0.75	5.00	Unimpacted
LHC-652	3.10	0.80	3.88	Unimpacted
EOC-100	6.06	0.56	10.82	Unimpacted
EOC-197	3.42	0.95	3.60	Unimpacted
PC-100	5.39	0.63	8.56	Unimpacted
PC-200	2.75	0.80	3.44	Unimpacted
PC-300	5.90	0.75	7.87	Unimpacted
PC-400	3.45	0.68	5.07	Unimpacted
PC-500	3.95	1.00	3.94	Unimpacted
PC-600	5.50	0.95	5.79	Unimpacted
PC-700	4.08	0.65	6.28	Unimpacted

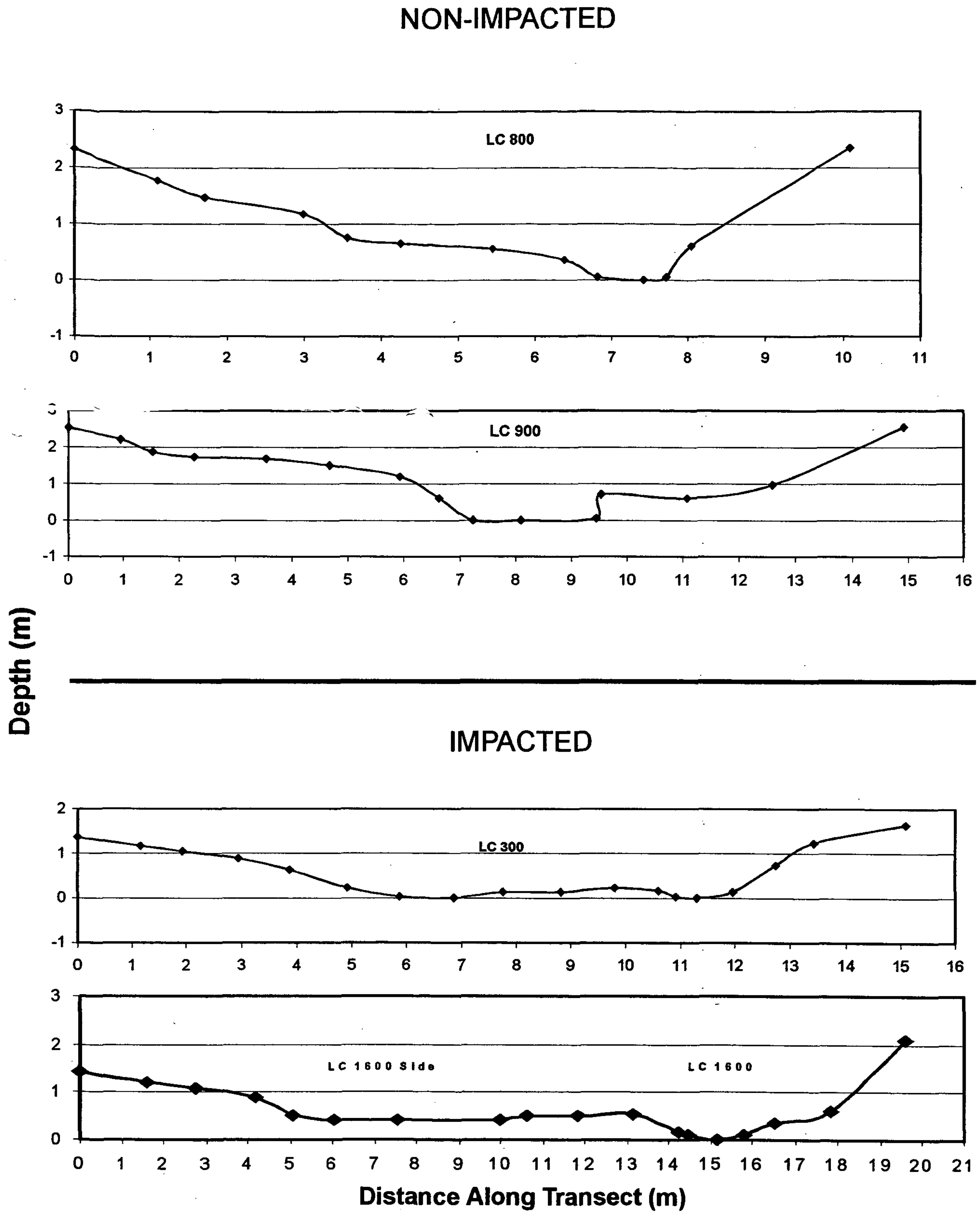


Figure 34. A comparison of channel cross-sections from non-impacted and impacted reaches of Long Creek. Cross-sections chosen for this comparison were located in geomorphologically similar channel reaches. A full library of cross-sections is provided in Appendix 2. Unimpacted channels have a definite, confined active-channel set into a narrow floodplain. The Active channel in sediment impacted reaches is often filled with sediment and barely discernable. Impacted channels also frequently acquire a braided channel configuration indicative of high sediment loads.

MANAGEMENT IMPLICATIONS

Major redistributions of sediment, including erosion of upland deposition sources, erosion of upstream bars, and deposition on new or existing bars, result from high flow events and the drop in discharge occurring immediately afterward. For example, the Lawn Lake Dam flood on the Fall River in Estes Park introduced a huge volume of sediment into the channel of the relatively small river. A study of the short-term changes in sediment transport and channel adjustments showed that a significant portion of the sediment traveled downstream from the input source during the first flood and where once the sediment settled it nearly filled the channel (Pitlick 1985). A similar situation, on a much smaller scale, probably occurs in Long Creek each runoff season and following strong storms. After the Lawn Lake flood, the cobble and gravel bed of the Fall River, similar to that found in Boulder Mountain Parks reference plots, was covered with a layer of sand. This channel bottom condition was seen in many impacted stretches of Long Creek.

Long-term changes in the Fall River channel included the development of braided stream immediately below the input source, and large changes in stream cross-sectional morphology between spring runoff and late summer base flow periods (Pitlick 1985). Similar morphological changes were described on Long-Gregory Creek during this study. Because of the importance of peak flow events on sediment distribution, knowledge of the Long Creek hydrograph is important for determining when sediment mobility is greatest, and possibly to guide the implementation or monitoring of mitigation and restoration measures. During a winter field trip to the study sites after significant snow had accumulated within the canyon, we observed stream depths and flows higher than those observed during summer months. This suggests that hydrograph of Long Creek is relatively complex and that because of the volume of water already flowing through the channel during the winter, brief snowmelt events during the winter may create flow conditions similar to or higher than early summer flows. We recommend that future studies consider monitoring stream flow throughout the year, possibly at stations established during a previous study (Gerhardt and Johnson 1999).

Suggested Mitigation Considerations

This study has shown that road-sediment accumulations have caused demonstrable impacts to Boulder Mountain Parks' riparian and natural areas. Reduction of road-sediment inputs to Long-Gregory Creek must be undertaken to mitigate ecological impacts and allow for ecological restoration. Fortunately, sediment input occurs primarily via only five point-sources in the form of hillside gullies. Reduction of sediment flow down these gullies could be accomplished through structural in the road or procedural changes in road maintenance. Any such method must be carried out in cooperation with the Boulder County Transportation Department. This department has been aware of potential road sediment impacts in Boulder Mountain Parks and been proactive in addressing this problem. With the results of this study, mitigative efforts can be focused at the most significant impacts sources thus saving both time and effort.

Road design features

Road design is important because it has both independent and interactive effects on water and sediment runoff. In other words, road design influences water runoff, hillslope erosion, and the location and intensity of stream channel inputs, whether are not the road is treated with traction sand or even used. Because road design controls water runoff, it also influences runoff of road treatment sand. For this reason, mitigation and/or restoration factors that focus on improving road design will help limit the impacts of both erosion and sediment runoff. Modifying road design features and/or managing the flow of runoff into the canyon will address: 1) the introduction of excess sediment to the hillslope and channel, 2) the gully erosion on upland slopes, and 3) the localized input of eroded hillslope soils into Long Creek. Potential mitigative actions include measures such as culvert and drainage trench modification, seeding of impacted areas immediately below road runoff structures, or the placement of rock or organic flow obstructions (e.g. rip-rap) within the gully systems. Fortunately, the majority of sediment input originates at a small number of discrete point-sources. Five sediment transport gullies are supplied by six road drainage trenches and five culverts. Roadside traction sand and road base depots also contribute to downslope sedimentation (Fig 7). We feel that improvements at these point-sources would sufficiently reduce the amount of sediment reaching Long Creek such that in channel restoration measures could be undertaken.

Road operation

Road operation controls the volume of excess sand introduced into the Canyon. Mitigation measures to reduce deposition through road operation modifications can focus on both limiting the initial application of sediment and increasing sediment removal. Current Boulder County Transportation Department policy attempts to address both issues. Where excess sediment runoff has been identified as a problem, Boulder County Transportation Department has reduced the rate of traction sand application. They also have made efforts to sweep and remove traction sand immediately after road conditions improve. Although test sections of road are selected to measure the effectiveness of these measures, results are not known (Plank 2000).

Potential Restoration Considerations

Restoration of channel morphology must begin with a mitigation of road sediment inputs. Once this causal mechanism is addressed symptomatic changes can be addressed. In most reaches channel morphology would probably be recovered a few years after the removal of surplus sediment inputs, and no further active remediation would be necessary. In other areas more proactive restoration approaches would be necessary to recover channel characteristics within a reasonable amount of time.

We suggest that any restoration efforts focus on the removal of sand deposits in the channel of Long Creek before considering extensive upland restoration. In the most heavily impacted reaches such as LC 300 and LC 1600, active removal of sediment and reconstruction of the channel profile should be undertaken. Removal of sediment from these areas would eliminate the chance of remobilization and redeposition in downstream riparian communities.

LITERATURE CITED

Anthony, D. J. (1992). Bedload transport and sorting in meander bends, Fall River, Rocky Mountain National Park, Colorado. Department of Earth Resources. Fort Collins, CO, Colorado State University: 280.

Ashemore, P. E., T. R. Yuzyk, et al. (1989). Bed material sampling error in sand bed rivers. Water Resources Res. **25**(10): 2195.

Brady, N. (1990). The Nature and Properties of Soils. NewYork, NY, MacMillan Publishing Company.

Brinson, M. M. (1993). A hydrogeomorphic classification for wetlands. Washington, DC, U.S. Army Corps of Engineers.

Center, T.-F. H. R. (1999). Is highway runoff a serious problem?, Turner-Fairbank Highway Research Center.

Church, M. A., D. G. McLean, et al. (1987). River bed gravels: Sampling and analysis. Sediment Transport in Gravel-Bed Rivers. C. R. Thorne, J. C. Bathurst and R. D. Hey. Chichester, U.K., WIley: 43-88.

DeVries, M. (1970). On the accuracy of bed-material sampling. J. Hydraul. Res. **8**: 523-533.

Dunne, T. and L. B. Leopold (1978). Water in environmental planning. New York, W.H. Freeman and Co.

Elliot, J. G., J. E. Kircher, et al. (1984). Sediment Transport in the Lower Yampa River, Northwestern Colorado, USGS: 44.

Faure, P., P. Landais, et al. (2000). Evidence for Diffuse Contamination of River Sediments by Road Asphalt; Particles. Environmental Science & Technology **34**: 1174-1181.

Forman, R. T. T. and L. E. Alexander (1998). Roads and their major ecological effects. Annual Review of Ecology and Systematics **29**: 207-231.

Gauch, H. G. (1982). Multivariate analysis in community ecology. Cambridge, U.K., Cambridge University Press.

Gee, G. W. and J. W. Bauder (1986). Particle-size Analysis. Methods of Soil Analysis Part 1. Physical and Mineralogical Methods. A. Klute. Madison, WI, American Society of Agronomy - Soil Science Society of America: 383-411.

Grant, G. E. (1988). The RAPID technique: a new method for evaluation off-site effects of forest practices on riparian zones, U.S.D.A. Forest Service General Technical Report.

Gurnell, A. and G. Petts (1995). Changing River Channels. New York, John Wiley and Sons.

Handbook, I. S. (1983). Liquid flow measurements in open channels-bed material sampling, ISO.

Heede, B. H. (1972). Flow and channel characteristics for two high mountain streams, U.S.D.A. Forest Service Research Paper: 12.

Heede, B. H. (1985). Channel adjustment to the removal of log steps: an experiment in a mountain stream. Environmental Management 9(5): 427-432.

Hey, R. D. (1978). Determinate hydraulic geometry of river channels. Proceeding of the American Society of Civil Engineers, Journal of the Hydraulics Division 104: 869-885.

Hill, M. O. (1979). Decorana - a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Ithaca, N.Y., Cornell University Press.

Hillel, D. (1982). Introduction to Soil Physics. New York, NY, Academic Press.

Horton, R. E. (1945). Erosional development of streams and their drainage basins. Geological Society of America Bulletin 56: 275-370.

Jongman, R. H. G., C. J. F. Ter Braak, et al. (1995). Data analysis in community and landscape ecology. Cambridge, Cambridge University Press.

Julien, P. Y. (1995). Erosion and sedimentation. New York, Cambridge University Press.

Keller, E. A. and F. J. Swanson (1979). Effects of large organic material on channel form and fluvial processes. Earth Surface Processes and Landforms **4**: 361-380.

Kellerhals, R. and D. I. Bray (1971). Sampling procedures for coarse fluvial sediments. J. Hydraul. Eng. **97**: 1165-1179.

Ketcheson, G. L. and W. F. Megahan (1996). Sediment production and downslope sediment transport from forest roads in granitic watersheds. Ogden, UT, U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 16.
Knighton, D. (1984). Fluvial forms and processes. London, Edward Arnold.

Kobriger, N. P., T. V. DuPuis, et al. (1983). Guidelines for the Management of Highway Runoff on Wetlands. Washington, D.C., Transportation Research Board, National Research Council.

Kurashige, Y. and Y. Fusejima (1997). Source identification of suspended sediment from grain-size distributions: I. Application of nonparametric statistical tests. Catena **31**: 39-52.

Leopold, L. B. and T. Maddock (1953). The hydraulic geometry of stream channels and some physiographic implications, U.S.G.S.: 56.

Marston, R. A. (1982). "The geomorphic significance of log steps in forest streams." Annals of the Association of American Geographers 72(1): 99-108.

Milhous, R. T. (1973). Sediment transport in a gravel-bottomed stream. Department of Civil Engineering. Corvallis, OR, Oregon State University: 232.

Mitsch, W. J. and J. G. Gooselink (1993). Wetlands. New York, NY, Van Nostrand Reinhold.

Pitlick, J. C. (1985). The effect of a major sediment influx on Fall River, Colorado. Fort Collins, CO, Colorado State University: 127.

Plank, T. (2000). Written communication to J. Mantione. Boulder, CO, Boulder County Transportation Department.

Rauch, S., G. M. Morrison, et al. (2000). Elemental association and fingerprinting of traffic-related metals in road sediments. Environmental Science & Technology **34**(3119-3123).

Ritter, D. F. (1978). Process Geomorphology, Wm. C. Brown Publishers, Dubuque, IA.

Rosgen, D. (1996). Applied River Morphology, Wildland Hydrology, Pagosa Springs, CO.

Schumm, S. (1960). The shape of alluvial channels in relation to sediment type. U.S. Geological Survey Prof. Paper 352-B.

Ter Braak, C. J. F. and P. Smilauer (1998). Canoco reference manual and user's guide to Canoco for Windows: software for Canonical Community Ordination (Version 4). Ithaca, NY, Microcomputer Power.

Thoms, M. C. (1991). A comparison of grab and freeze sampling techniques in the collection of gravel bed river sediment. Sedimentary Geology 78(3/4): 191-200.

Zimmerman, G. M., H. Goetz, et al. (1985). Use of an improved statistical method for group comparisons to study the effects of prairie fire. Ecology **66**: 606-611.

APPENDIX 1

SPECIES COMPOSITION DATA

Species Name	Abbreviation	LC-2	LC-82	LC-100	LC-200	LC-300	LC-400	LC-500	LC-600	LC-800	LC-900	LC-1000	LC-1100	LC-1200	LC-1300	LC-1400	LC-1600 side	LC-1700	LC-1800	LC-1900	LC 1600
Acer glabrum	Ace gla	t	3	12	t	3	1	t	7	3	13	5	16	13	t	t		2	3	12	4
Acetosella vulgaris	Ace vul																t		t		
Achillea millefolium	Ach mil		t	t	t		t	t			t		t	t		t		t		t	
Aconitum columbianum	Aco col	t	t			t				t				t							
Actaea rubra	Act rub			t			t		t	t		t									
Agrostis exerata	Agr exa									t		t	t	t			2	t	3		
Agrostis gigantea	Agr gig									t	t	t	t	2	1	t	4	1	4		4
Agrostis scabra	Agr sca														t		t				
Aletes acaulis	Ale aca																				
Amelanchier alnifolia	Ame aln													3					t		
Anaphalis margaritacea	Ana mar				t						t									t	
Anemone cylindrica	Ane cyl																		t		
Angelica ampla	Ang amp									t											
Antennaria spp.	Ant spp							t		t			t								
Antennaria parviflora	Ant par				t																
Antennaria rosea	Ant ros																				
Apocynum androsaemifolium	Apo and																				
Aquilegia coerulea	Aqu coe										t										
Aralia nudicaulis	Ara nud			t		t				t				5							
Arctostaphylos uvi-ursi	Arc uvi												2								
Arnica cordifolia	Arn cor	t	t	t	t	t	t		t	t	t									t	
Artemisia ludoviciana	Art lud							t													
Aster foliaceous	Ast fol				t		t		t			t									
Aster laevis	Ast lae				t																
Aster porteri	Ast por																				
Aster spp.	Ast spp				t			t	t		t	t	t				t	t		t	
Asteraceae	Asteraceae																				
Athyrium filix-femina	Ath fil																				
Betula fontinalis	Bet fon	10	29	47	3		5		14	6		7		7	17	21	45	48	5	38	11
Betula papyrifera	Bet pap				t	65	13														
Botrypus virginianus	Bot vir																				
Bromopsis lanatipes	Bro lan	t		t	t	t	t	1	t	2	t			t		t	t		2	t	
Bromopsis pubescens	Bro pub																				

Species Name	Abbreviation	LC-2	LC-82	LC-100	LC-200	LC-300	LC-400	LC-500	LC-600	LC-800	LC-900	LC-1000	LC-1100	LC-1200	LC-1300	LC-1400	LC-1600 side	LC-1700	LC-1800	LC-1900	LC 1600
Calamagrostis canadensis	Cal can																t				
Calamagrostis stricta	Cal str																				
Campanula rotundifolia	Cam rot						t				t		t	t					t	t	
Carex deweyana	Car dew	t	2	2	4		5	t	8		6	4	5	t	4	3				2	
Carex disperma	Car dis																				
Carex geyeri	Car gey		t	t	1	t				1					t						t
Carex hasseyi	Car has																				
Carex limnophila	Car lim																				t
Carex microptera	Car mic	t	t							t											t
Carex spp.	Car spp																				
Cerastium fontanum	Cer fon										t										
Cerastium nutans	Cer nut										t	t	t	t					t		
Chamerion angustifolium	Cha ang									t									t		
Chimaphila umbellata	Chi umb																				
Circaea alpina	Cir alp	2	9	2	3	3	6	1	8	4	3	4	t		3	t		t		t	t
Cirsium arvense	Cir arv	t									t		t			t		1	t	t	5
Cirsium spp.	Cir spp														t		t	t			
Clematis ligusticifolia	Cle lig													t					t		
Conioselinum scopulorum	Con sco			t	t	t		t		t	t	2	t	•	t	t			t		
Cornus stolonifera/Swida sericea	Cor sto	3		1	21	10	48	43	28	19	18	42	35	4	9	15	5				
Corylus cornuta	Cor cor										2	t	t	10				1	t		2
Crunocallis chamissoi	Cru cha																				
Cryptogramma acrostichoides	Cry acr																				
Cylactis pubescens	Cyl pub																				
Cynoglossum officinale	Cyn off																				
Cystopteris fragilis	Cys fra	t	t		t	t	t	t	t	t	t	t									
Dactylis glomerata	Dac glo				t					t			2	2	t			t	6	t	t
Danthonia spicata	Dan spi																				
Deschampsia cespitosa	Des ces																		t		

Species Name	Abbreviation	LC-2	LC-82	LC-100	LC-200	LC-300	LC-400	LC-500	LC-600	LC-800	LC-900	LC-1000	LC-1100	LC-1200	LC-1300	LC-1400	LC-1600 side	LC-1700	LC-1800	LC-1900	LC 1600
Disporum trachycarpum	Dis tra																				
Dodecatheon pulchellum	Dod pul				t	t				t		t			t			t		t	
Drymocallis fissa	Dry fis																		t		
Dryopteris filix-mas	Dry fil																				
Elymus canadensis	Ely can																				
Elymus glaucus	Ely gla	t	t	t	2	t	t	7	t	1	t	t		1	t	t			t		
Elymus trachycaulus	Ely tra												t	t							
Epilobium ciliatum	Epi cil																				
Epilobium hornemannii	Epi hor									t					t		1				t
Epilobium spp.	Epi spp		t			t															
Equisetum arvense	Equ arv	15		3	6										12	4	45			1	43
Equisetum hyemale	Equ hym						t				t	4	2		2	7				9	4
Equisetum laevigatum	Equ lae																				
Erigeron formosissimus	Eri for																		t		
Erigeron speciosus	Eri spe																				
Erigeron spp.	Eri spp																				
Eupatorium maculatum	Eup mac																				
Fragaria spp.	Fra ame		t				t	t	t	t	t		t			t	t	t		t	
Galium septentrionale	Gal sep							t			t		t								
Galium triflorum	Gal tri	t	t	t	t	t	t	t	t	t	t	t	t							t	
Geranium richardsonii	Ger ric	t	1	t	t				1	3	t	t			t	t	t			t	
Geum macrophyllum	Geu mac		t						t	t		t	t			t	t	t	t		
Glyceria striata	Gly str	1	4		t	t			t	t		t			1		3				2
Goodyera oblongifolia	Goo obl																				
Heracleum sphondylium	Her sph	4	9	7	7	2	2	1	13	7	2	6	3	t	1	t		1			
Heterotheca villosa	Het vill																				
Heuchera bracteata	Heu bra																				
Hydrophyllum fendleri	Hyd fen	t	t		1	t	1	2	4	t	t	t	1		t		t			t	
Jamesia americana	Jam ame								2	t		t	2	5				t			
Juncus longistylis	Jun lon																	t			
Juniperus communis	Jun com											t				t		5	t		4
Juniperus scopulorum	Jun sco																		t		
Lactuca canadensis	Lac can				t		t										t		t		
Lactuca serriola	Lac ser										t	t	t		t		t	t			

Species Name	Abbreviation	LC-2	LC-82	LC-100	LC-200	LC-300	LC-400	LC-500	LC-600	LC-800	LC-900	LC-1000	LC-1100	LC-1200	LC-1300	LC-1400	LC-1600 side	LC-1700	LC-1800	LC-1900	LC 1600
Ligusticum porteri	Lig por						3		t					5							
Limnorchis hyperborea	Lim hyp																	t	t		
Limnorchis spp.	Lim spp																				
Listera convallarioides	Lis con		t																		
Lonicera involucrata	Lon invo	2		t						1	3		t		t	t		t			
Luzula parviflora	Luz par				t					t								t			
Lysimachia vulgaris	Lys vul																	5			
Mahonia repens	Mah rep		t	t	t	t	t	t	1	t	t	t	t		t			t	t	t	
Maianthemum amplexicaule	Mia amp	t	t	t	t	t	t	t	t		t										
Maianthemum stellatum	Mia ste	t	t		t	t		t					t	t					t	t	t
Medicago lupulina	Med lup																		t		t
Mentha arvensis	Men arv																		t		t
Mertensia lanceolata	Mer lan																				
Monarda fistulosa	Mon fis							1	t	t	2	t	1	1		t		t	2	t	
Muhlenbergia racemosa	Muh rac																				
Orthilia secunda	Oro sec																				
Oryzopsis asperifolia	Ory asp				t	t		t	t	t		t	1	t	t				2		
Osmorhiza chilensis	Osm chi		t	t		t	t	7	1	t	t	2	t	t	t		t		t	t	
Osmorhiza depauperata	Osm dep	t						t	t												
Oxalis dillenii	Oxa dil																				
Panicum spp.	Pan spp.											t									
Parthenocissus inserta	Par ins																				
Phleum pratense	Phl pra							t			t		t	t		1	2	3	7	t	
Physocarpus opuliferous	Phy opu																		3		
Picea pungens	Pic pun																				
Pinus contorta	Pin cor																				
Pinus ponderosa	Pin pon	6	1					2			4	3	t	17		22	4		5		
Plantago major	Pla maj																t	t			t
Poa compressa	Poa com																				
Poa nervosa	Poa ner																		t		
Poa pratensis	Poa pra				t		1				t		t	t	t	t	t	t	t	t	t
Poa spp.	Poa spp							4	t												
Polypodium amorphum	Pol amo																				

Species Name	Abbreviation	LC-2	LC-82	LC-100	LC-200	LC-300	LC-400	LC-500	LC-600	LC-800	LC-900	LC-1000	LC-1100	LC-1200	LC-1300	LC-1400	LC-1600 side	LC-1700	LC-1800	LC-1900	LC 1600
Populus angustifolia	Pop ang																		23		
Populus tremuloides	Pop tre	4	2		t		10					t			5	6	3		t		
Prunella vulgaris	Pru vul			t	t		t		t	t	1	t	t		t			t			
Prunus virginiana	Pru vir	t						19	3	t		t	2	2	t	1		t	t	1	t
Pseudotsuga menziesii	Pse men	35	10	4	1		2	25	27	4	27	5	9	t	t	18	5		27	27	25
Pseudocymopterus montanus	Pse mon																				
Pteridium aquilinum	Ptr aqu	26	38	16		27	t	6													
Pyrola chlorantha	Pyr chl																				
Pyrola rotundifolia	Pyr rot	t																t			
Quercus gambelii	Que gam						t														
Ranunculus acriformis	Ran acr																		t		
Ranunculus maconii	Ran mac										t										
Ribes aureum	Rib aur																				
Ribes cereum	Rib cer				t									3	3			t		t	
Ribes inerme	Rib ine								t												
Rosa woodsii	Ros woo	t			t			2	4	t	t		t	t	2		1	t		3	t
Rubus deliciosus	Rub del					t	9			9	t				2						
Rubus idaeus	Rub ide			1	t	t	t	6			t	t	2			t		5		t	t
Rubus parviflorus	Rub par				2																
Rubus pubescens	rub pub																				
Rudbeckia ampla	Rud amp			2	2	2		2	t	9	4	2	2	t		t		1	1	t	
Salix bebbiana	Sal beb	10														3	3			2	2
Salix exigua	Salix exi																t	7	8		4
Salix monticola	Sal mon																	t		2	t
Sambucus canadensis	Sam can			t																	
Sanicula marilandica	San mar	t	t				t			t	t	t			t			t	t	t	t
Sedum lanceolatum	Sed lan																				
Senecio sp.	Sen spp														t						
Smilax lasioneuron	Smi las																				
Solidago canadensis	Sol can																				
Solidago missouriensis	Sol mis															t	1	t			2
Solidago spathulata	Sol spa																				
Sorbus scopulina	Sor sco						2														
Stellaria jamesiana	Ste jam				t																

Species Name	**Abbreviation**	**LC-2**	**LC-82**	**LC-100**	**LC-200**	**LC-300**	**LC-400**	**LC-500**	**LC-600**	**LC-800**	**LC-900**	**LC-1000**	**LC-1100**	**LC-1200**	**LC-1300**	**LC-1400**	**LC-1600 side**	**LC-1700**	**LC-1800**	**LC-1900**	**LC 1600**
Stenactis (Erigeron) strigosus	Ste str				t									t							
Streptopus amplexiflorus	Str fas	4	t	1		t			2												
Symphoricarpos albus	sym alb				t	t	t	t	1	t		t	t	t		t	t	t		t	
Taraxacum officinale	Tar off	t		t		t	t		t	t	t	t	t	t				t	t	t	t
Thalictrum fendleri	Tha fen	t																			
Thermopsis divaricarpa	The div											t		t		t			2		
Thlaspi spp.	Tha spp																				
Toxicodendron rydbergii	Tox ryd													3				t			
Trifolium pratense	Tri pra												t								
Trifolium repens	Tri rep				t													t	t		
Trifolium spp.	Tri spp																				
Turritius glabra	Tur gla																				
Urtica gracilis	Urt gra																				
Verbascum thapsus	Ver tha						t														
Verbena hastata	Ver has	t						t			t										
Veronica americana	Ver ame																				
Veronica peregrina	*Ver per*																*t*				
Viola rydbergii	*Vio ryd*																				
Viola scopulorum	*Vio sco*	*2*	*t*	*t*	*2*	*t*	*2*	*3*		*t*	*t*	*t*	*1*	*t*		*t*			*t*		*t*
Vitus riparia	*Vit rip*																	*t*			
Unknowns																					
Tight grass	*Tight grass(EOC197)*																				
Tiny grass	*Tiny grass*																				
Small Grass	Small Grass									*t*		*t*		*t*	*t*						*t*
Grass 2	Grass 2	t																			
Total Cover	**Total Cover**	124	109	98	56	111	110	133	124	68	85	84	85	81	63	102	128	74	113	100	106

Species Name	**Abbreviation**	**LHC-0**	**LHC-100**	**LHC-200**	**LHC-300**	**LHC-400**	**LHC-500**	**LHC-570**	**LHC-652**	**EOC-0**	**EOC-100**	**EOC-197**	**PC-0**	**PC-100**	**PC-200**	**PC-300**	**PC-400**	**PC-500**	**PC-600**	**PC-700**
Acer glabrum	Ace gla		1	t	2	2	7	1	12		9	6		8		t	3	t		t
Acetosella vulgaris	Ace vul																			
Achillea millefolium	Ach mil					t	t	t		t		t	t			t		t		
Aconitum columbianum	Aco col		t	t				t						t		t		t		t

Species Name	Abbreviation	LHC-0	LHC-100	LHC-200	LHC-300	LHC-400	LHC-500	LHC-570	LHC-652	EOC-0	EOC-100	EOC-197	PC-0	PC-100	PC-200	PC-300	PC-400	PC-500	PC-600	PC-700
Actaea rubra	Act rub					t	t			t	t		t	t	t					t
Agrostis exerata	Agr exa										t	t								
Agrostis gigantea	Agr gig							t					t					t		
Agrostis scabra	Agr sca												t					t		
Aletes acaulis	Ale aca																			
Amelanchier alnifolia	Ame aln																			
Anaphalis margaritacea	Ana mar			t				t												
Anemone cylindrica	Ane cyl												t							
Angelica ampla	Ang amp																	t	t	t
Antennaria spp.	Ant spp									t		t								
Antennaria parviflora	Ant par																			
Antennaria rosea	Ant ros																			
Apocynum androsaemifolium	Apo and							2												
Aquilegia coerulea	Aqu coe							t		t										
Aralia nudicaulis	Ara nud		3 t				t	t	t		t		1 t	t		1 t		1	t	t
Arctostaphylos uvi-ursi	Arc uvi								t											
Arnica cordifolia	Arn cor		1 t	t	t	t	t		t		t		t	t	t	t	t		t	t
Artemisia ludoviciana	Art lud			2		1		t												
Aster foliaceous	Ast fol	t					t													
Aster laevis	Ast lae									t		t	t	t				t		
Aster porteri	Ast por								t			t								
Aster spp.	Ast spp			t		t					t		t			t				
Asteraceae	Asteraceae	t																		
Athyrium filix-femina	Ath fil	t				t									t					
Betula fontinalis	Bet fon		9 15	53	7		13	15	29	2	35	13	53	23	28	32	16	37	6	18
Betula papyrifera	Bet pap																	28		
Botrypus virginianus	Bot vir																			
Bromopsis lanatipes	Bro lan	t		t				t	t			t	t					t		
Bromopsis pubescens	Bro pub																			
Calamagrostis canadensis	Cal can																	t		
Calamagrostis stricta	Cal str						t													
Campanula rotundifolia	Cam rot						t			t			t	t						
Carex deweyana	Car dew		t						16	4	2	t		t		1 5	t		3 5	3
Carex disperma	Car dis													t						
Carex geyeri	Car gey		4	2		5	8	7	t			9		1					2	

Species Name	Abbreviation	LHC-0	LHC-100	LHC-200	LHC-300	LHC-400	LHC-500	LHC-570	LHC-652	EOC-0	EOC-100	EOC-197	PC-0	PC-100	PC-200	PC-300	PC-400	PC-500	PC-600	PC-700
Carex hasseyi	Car has																			
Carex limnophila	Car lim		t															2		
Carex microptera	Car mic												t							
Carex spp.	Car spp													t						
Cerastium fontanum	Cer fon																			
Cerastium nutans	Cer nut	t																		
Chamerion angustifolium	Cha ang						t		t											
Chimaphila umbellata	Chi umb	t																		
Circaea alpina	Cir alp	t		2 2		1		t	t				t				t	t		t
Cirsium arvense	Cir arv											t					t			
Cirsium spp.	Cir spp																			
Clematis ligusticifolia	Cle lig								t			t	t							
Conioselinum scopulorum	Con sco	t	t			t	t	t	t		t	t	t	t			t	t		t
Cornus stolonifera/Swida sericea	Cor sto	t	t			48	18	42	40	3	31	16	8	27	15	35	67	12	87	77
Corylus cornuta	Cor cor			t														6		
Crunocallis chamissoi	Cru cha																			
Cryptogramma acrostichoides	Cry acr																			
Cylactis pubescens	Cyl pub												t		1					
Cynoglossum officinale	Cyn off																			
Cystopteris fragilis	Cys fra		t	t		t	t	t	t					t		t		t	t	t
Dactylis glomerata	Dac glo							t												
Danthonia spicata	Dan spi																			
Deschampsia cespitosa	Des ces																			
Disporum trachycarpum	Dis tra						t													
Dodecatheon pulchellum	Dod pul		t				t	t		t				t	t		t			
Drymocallis fissa	Dry fis											t								
Dryopteris filix-mas	Dry fil																			
Elymus canadensis	Ely can																			
Elymus glaucus	Ely gla	t	t			t	t	t					t			t	t	t	t	t
Elymus trachycaulus	Ely tra											t								
Epilobium ciliatum	Epi cil																			
Epilobium hornemannii	Epi hor		t											t	t			t		

Species Name	Abbreviation	LHC-0	LHC-100	LHC-200	LHC-300	LHC-400	LHC-500	LHC-570	LHC-652	EOC-0	EOC-100	EOC-197	PC-0	PC-100	PC-200	PC-300	PC-400	PC-500	PC-600	PC-700
Epilobium spp.	Epi spp																			
Equisetum arvense	Equ arv	t		5									1		t			2		
Equisetum hyemale	Equ hym																	3		
Equisetum laevigatum	Equ lae																			
Erigeron formosissimus	Eri for																			
Erigeron speciosus	Eri spe																			
Erigeron spp.	Eri spp																			
Eupatorium maculatum	Eup mac																			
Fragaria spp.	Fra ame		t	t				t	t	t		t				t	t	t	t	
Galium septentrionale	Gal sep						t			t		t	t			t		t		
Galium triflorum	Gal tri	t	t	t		t	t	t	t				t	t			t	t	t	t
Geranium richardsonii	Ger ric			t	t	t	t		t	t	t		1 t			t	t	t		
Geum macrophyllum	Geu mac		t			t	t											t		
Glyceria striata	Gly str		2										t	t	t			t		
Goodyera oblongifolia	Goo obl											t								
Heracleum sphondylium	Her sph	t		2 t			5	1	2	2	3	1	3		6	3	4	2	3	2
Heterotheca villosa	Het vill											t								
Heuchera bracteata	Heu bra																			
Hydrophyllum fendleri	Hyd fen			t		t	t					t				t	t		t	t
Jamesia americana	Jam ame		2 2	2		7	3								2	t				t
Juncus longistylis	Jun lon																			
Juniperus communis	Jun com							t	t			t								
Juniperus scopulorum	Jun sco																			
Lactuca canadensis	Lac can																			
Lactuca serriola	Lac ser																			
Ligusticum porteri	Lig por							4		t										
Limnorchis hyperborea	Lim hyp																			
Limnorchis spp.	Lim spp																			
Listera convallarioides	Lis con	t	t	t									t	t	t			t		
Lonicera involucrata	Lon invo		t		5	2	3			t		1			t			2		
Luzula parviflora	Luz par						t													
Lysimachia vulgaris	Lys vul																			
Mahonia repens	Mah rep	t		t	t	t	t	t	t	t	t	t	t	t	t		t			
Maianthemum amplexicaule	Mia amp	t	t	t			t	t	t		t		t	t	t			t		t
Maianthemum stellatum	Mia ste		t		t	t	t	t		t			t	t			t	t		

Species Name	Abbreviation	LHC-0	LHC-100	LHC-200	LHC-300	LHC-400	LHC-500	LHC-570	LHC-652	EOC-0	EOC-100	EOC-197	PC-0	PC-100	PC-200	PC-300	PC-400	PC-500	PC-600	PC-700
Medicago lupulina	Med lup																			
Mentha arvensis	Men arv																			
Mertensia lanceolata	Mer lan								t			t								
Monarda fistulosa	Mon fis					t	t	t	t	t	t	t			t		t			
Muhlenbergia racemosa	Muh rac																			
Orthilia secunda	Oro sec						t													
Oryzopsis asperifolia	Ory asp						t													
Osmorhiza chilensis	Osm chi	t	t	t	t	t	t	t	t	t	1	t	t	t		t	t		t	t
Osmorhiza depauperata	Osm dep	t	t			t		t	t		t	t	t		t	t			t	
Oxalis dillenii	Oxa dil																			
Panicum spp.	Pan spp.																			
Parthenocissus inserta	Par ins																			
Phleum pratense	Phl pra			t																
Physocarpus opuliferous	Phy opu	t		3		t	t								t	t				
Picea pungens	Pic pun																			
Pinus contorta	Pin cor																			
Pinus ponderosa	Pin pon	6	13			13		20		12	6	8		14	2	6	9	7		
Plantago major	Pla maj																			
Poa compressa	Poa com									t										
Poa nervosa	Poa ner																			
Poa pratensis	Poa pra																			
Poa spp.	Poa spp																			
Polypodium amorphum	Pol amo																			
Populus angustifolia	Pop ang																			
Populus tremuloides	Pop tre	t							t	t			1					2		
Prunella vulgaris	Pru vul		t						t					t				t		
Prunus virginiana	Pru vir							t	t			1								
Pseudotsuga menziesii	Pse men	15	9	4		27		13	25	35	6	23	31	21	11	2	6	16		8
Pseudocymopterus montanus	Pse mon																			
Pteridium aquilinum	Ptr aqu	2	t	t	16	4		4		58	6	t	37	16	10	29	3	5	2	
Pyrola chlorantha	Pyr chl																			
Pyrola rotundifolia	Pyr rot	t	t						t				t	t	t			t		
Quercus gambelii	Que gam																			
Ranunculus acriformis	Ran acr																			
Ranunculus maconii	Ran mac																			

Species Name	Abbreviation	LHC-0	LHC-100	LHC-200	LHC-300	LHC-400	LHC-500	LHC-570	LHC-652	EOC-0	EOC-100	EOC-197	PC-0	PC-100	PC-200	PC-300	PC-400	PC-500	PC-600	PC-700
Ribes aureum	Rib aur															t				
Ribes cereum	Rib cer																			
Ribes inerme	Rib ine													t			t			
Rosa woodsii	Ros woo		t	t		t				t		2	t	t		1 t		t		t
Rubus deliciosus	Rub del	t	1	3		4	t	t	t	t	t	3	t		t	t	2	7	t	9
Rubus idaeus	Rub ide			1		t	t	t		t		t	t	t				2		t
Rubus parviflorus	Rub par																			
Rubus pubescens	rub pub																			
Rudbeckia ampla	Rud amp		5	7	1	t		7	1	4	2		3	2	2	3	2	4	3	4
Salix bebbiana	Sal beb																	t		
Salix exigua	Salix exi																			
Salix monticola	Sal mon																			
Sambucus canadensis	Sam can																t	t		
Sanicula marilandica	San mar			t			t	t	t			t	t	t	t			t	t	t
Sedum lanceolatum	Sed lan																			
Senecio sp.	Sen spp																			
Smilax lasioneuron	Smi las																			
Solidago canadensis	Sol can																			
Solidago missouriensis	Sol mis																			
Solidago spathulata	Sol spa							4												
Sorbus scopulina	Sor sco		2				t								9					8
Stellaria jamesiana	Ste jam																			
Stenactis (Erigeron) strigosus	Ste str																			
Streptopus amplexiflorus	Str fas		5 3	t					t		t		2	2	8	t		5		
Symphoricarpos albus	sym alb			t		t	t			t	t	t	t	t		t	t		t	t
Taraxacum officinale	Tar off	t	t				t	t					t						t	t
Thalictrum fendleri	Tha fen																			
Thermopsis divaricarpa	The div													t			t			
Thlaspi spp.	Tha spp																			
Toxicodendron rydbergii	Tox ryd						t													
Trifolium pratense	Tri pra																			
Trifolium repens	Tri rep																			
Trifolium spp.	Tri spp																			

Species Name	**Abbreviation**	**LHC-0**	**LHC-100**	**LHC-200**	**LHC-300**	**LHC-400**	**LHC-500**	**LHC-570**	**LHC-652**	**EOC-0**	**EOC-100**	**EOC-197**	**PC-0**	**PC-100**	**PC-200**	**PC-300**	**PC-400**	**PC-500**	**PC-600**	**PC-700**
Turritius glabra	Tur gla										t							t		
Urtica gracilis	Urt gra																			
Verbascum thapsus	Ver tha									t										
Verbena hastata	Ver has					t		t												
Veronica americana	*Ver ame*												*t*					*t*		
Veronica peregrina	*Ver per*																			
Viola rydbergii	*Vio ryd*																			
Viola scopulorum	*Vio sco*	*t*	*t*		*t*	*t*		*t*	*t*	*t*	*t*	*t*	*t*	*t*	*t*	*t*	*t*		*t*	*t*
Vitus riparia	*Vit rip*					*t*		*t*									*t*		*t*	*t*
Unknowns																				
Tight grass	*Tight grass(EOC197)*																			
Tiny grass	*Tiny grass*											*t*								
Small Grass	*Small Grass (still unknown)*							*t*				*t*	*t*							
Grass 2	Grass 2 (still unknown)																			
Total Cover	**Total Cover**	49	61	80	27	114	64	114	125	119	103	86	139	115	98	115	111	145	107	129

Species Name	**Abbreviation**	**GSC-0 (1)**	**GSC-108 (2)**	**GSC-220 (3)**	**GSC-320**	**GSC-445 (4)**	**GSC-545**	**GSC-635 (5)**	**GSC-735**	**GSC-835**	**GSC-935**	**GSC-1025 (7)**
Acer glabrum	Ace gla		10 3	t		4	12	t		18 28	43	20
Acetosella vulgaris	Ace vul											
Achillea millefolium	Ach mil	t	t	t		t		t				t
Aconitum columbianum	Aco col	t	t	t		t		t				t
Actaea rubra	Act rub	t	t	t	t	t		t				t
Agrostis exerata	Agr exa	t	t	t		t		t				t
Agrostis gigantea	Agr gig	t	t	t		t		t				t
Agrostis scabra	Agr sca	t	t	t	t	t		t		t		t
Aletes acaulis	Ale aca	t	t	t		t		t				t
Amelanchier alnifolia	Ame aln											
Anaphalis margaritacea	Ana mar	t	t	t		t		t				t
Anemone cylindrica	Ane cyl											
Angelica ampla	Ang amp											
Antennaria spp.	Ant spp	t	t	t		t		t		t		t
Antennaria parviflora	Ant par											
Antennaria rosea	Ant ros	t	t	t		t		t				t
Apocynum androsaemifolium	Apo and	t	t	t		t		2				t
Aquilegia coerulea	Aqu coe	t	t	t	t	t		t		t		t
Aralia nudicaulis	Ara nud	t	t	t		1 t		3 t		4	t	t
Arctostaphylos uvi-ursi	Arc uvi											
Arnica cordifolia	Arn cor	t	t	t		t		t		t		t
Artemisia ludoviciana	Art lud	t	t	t		t		t				t
Aster foliaceous	Ast fol											
Aster laevis	Ast lae	t	t	t		t	t	t		t		t
Aster porteri	Ast por											
Aster spp.	Ast spp				t							
Asteraceae	Asteraceae											
Athyrium filix-femina	Ath fil		4 15	t	t	t		5				t
Betula fontinalis	Bet fon		15 65	55	33	10	45	75	29	32	34	7
Betula papyrifera	Bet pap											
Botrypus virginianus	Bot vir	t	t	t		t		t				t
Bromopsis lanatipes	Bro lan	t	t	t	t	t		t		t		t
Bromopsis pubescens	Bro pub	t	t	t		t		t				t
Calamagrostis canadensis	Cal can	t	t	t		t		t				t

Species Name	Abbreviation	GSC-0 (1)	GSC-108 (2)	GSC-220 (3)	GSC-320	GSC-445 (4)	GSC-545	GSC-635 (5)	GSC-735	GSC-835	GSC-935	GSC-1025 (7)
Calamagrostis stricta	Cal str											
Campanula rotundifolia	Cam rot	t	t	t		t		t				t
Carex deweyana	Car dew	t	t	t		3 t		4 t		3 5	4	5
Carex disperma	Car dis	t	t	t		t		t				t
Carex geyeri	Car gey	t	t	t		t		t				t
Carex hasseyi	Car has	t	t	t		t		t				t
Carex limnophila	Car lim				t							
Carex microptera	Car mic	t	t	t		t		t				t
Carex spp.	Car spp	t	t	t	t	t		t				t
Cerastium fontanum	Cer fon	t	t	t		t		t				t
Cerastium nutans	Cer nut											
Chamerion angustifolium	Cha ang	t	t	t		t		t				t
Chimaphila umbellata	Chi umb											
Circaea alpina	Cir alp	15	20	10	3	5	2	5	t	t		3
Cirsium arvense	Cir arv	t	t	t		t		t	t			t
Cirsium spp.	Cir spp	t	t	t		t		t				t
Clematis ligusticifolia	Cle lig											
Conioselinum scopulorum	Con sco				t		t			t		
Cornus stolonifera/Swida sericea	Cor sto	t	t	8		30	17	3	4	13	37	t
Corylus cornuta	Cor cor	t	t	15		t	t	35				27
Crunocallis chamissoi	Cru cha	t	t	t		t		t				t
Cryptogramma acrostichoides	Cry acr	t	t	t		t		t				t
Cylactis pubescens	Cyl pub				t		t					
Cynoglossum officinale	Cyn off	t	t	t		t		t				t
Cystopteris fragilis	Cys fra	t	t	t	t	t		t				t
Dactylis glomerata	Dac glo											
Danthonia spicata	Dan spi	t	t	t		t		t				t
Deschampsia cespitosa	Des ces											
Disporum trachycarpum	Dis tra											
Dodecatheon pulchellum	Dod pul	t	t	t		t		t		t		t
Drymocallis fissa	Dry fis											
Dryopteris filix-mas	Dry fil	t	t	t		1 t	3	t	t			t

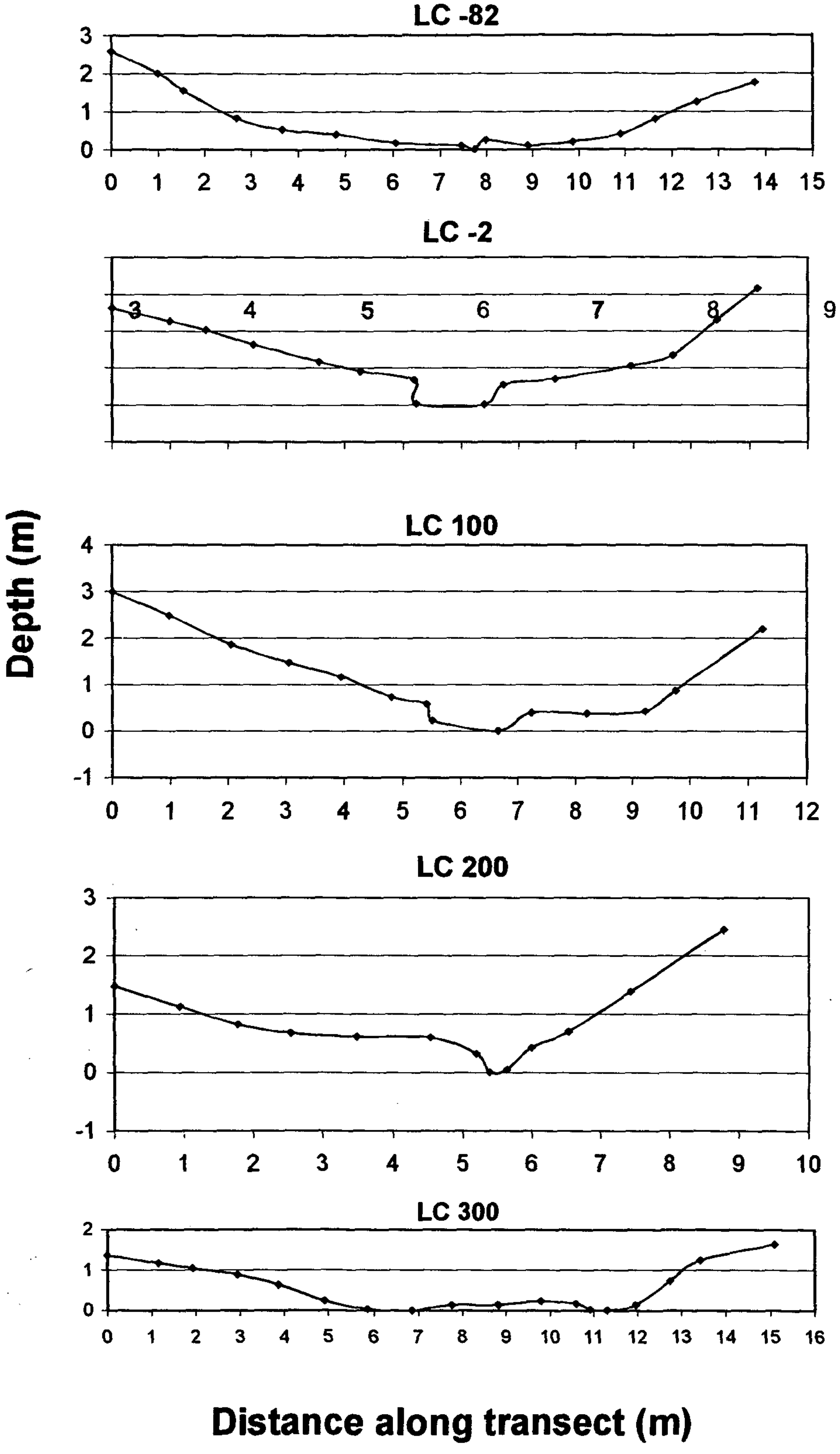
Species Name	Abbreviation	GSC-0 (1)	GSC-108 (2)	GSC-220 (3)	GSC-320	GSC-445 (4)	GSC-545	GSC-635 (5)	GSC-735	GSC-835	GSC-935	GSC-1025 (7)
Elymus canadensis	Ely can	t	t	t		t		t				t
Elymus glaucus	Ely gla	t	t	t		t	t	t	t	t		t
Elymus trachycaulus	Ely tra											
Epilobium ciliatum	Epi cil									t		
Epilobium hornemannii	Epi hor	t	t	t		t	t	t	t		t	t
Epilobium spp.	Epi spp											
Equisetum arvense	Equ arv	t	t	t	t	t		t				t
Equisetum hyemale	Equ hym	t	t	t		t	5	7				t
Equisetum laevigatum	Equ lae	t	t	t		t		t				t
Erigeron formosissimus	Eri for											
Erigeron speciosus	Eri spe	t	t	t		t		t				t
Erigeron spp.	Eri spp	t	t	t		t		t				t
Eupatorium maculatum	Eup mac	t	t	t		t		t				t
Fragaria spp.	Fra ame	t	t	t	t	t		t	t	t		t
Galium septentrionale	Gal sep	t	t	t		t		t				3
Galium triflorum	Gal tri	t	t	t	t	t		t		t	t	t
Geranium richardsonii	Ger ric	t	t	t	t	t	t	t	t	t		t
Geum macrophyllum	Geu mac	t	t	t		t		t	t	t		t
Glyceria striata	Gly str	t	t	t	t	4		t	t	t		t
Goodyera oblongifolia	Goo obl	t	t	t		t		t				t
Heracleum sphondylium	Her sph	2	t	12	4	7	t	t	3			t
Heterotheca villosa	Het vill											
Heuchera bracteata	Heu bra	t	t	t		t		t				t
Hydrophyllum fendleri	Hyd fen	t	t	t		t		t			t	t
Jamesia americana	Jam ame	t	t	2	16	3	27	25	2	16		10
Juncus longistylis	Jun lon											
Juniperus communis	Jun com	t	t	t	2	t		t		t		t
Juniperus scopulorum	Jun sco	t	t	t		t		t				8
Lactuca canadensis	Lac can	t	t	t		t		t		t		t
Lactuca serriola	Lac ser	t	t	t		t		t				t
Ligusticum porteri	Lig por	t	t	t		t		t				t
Limnorchis hyperborea	Lim hyp	t	t	t		t		t				t
Limnorchis spp.	Lim spp				t							
Listera convallarioides	Lis con	t	2	t	t	t		t				t
Lonicera involucrata	Lon invo	t	t	2	2	5	4	t	2		t	t
Luzula parviflora	Luz par											

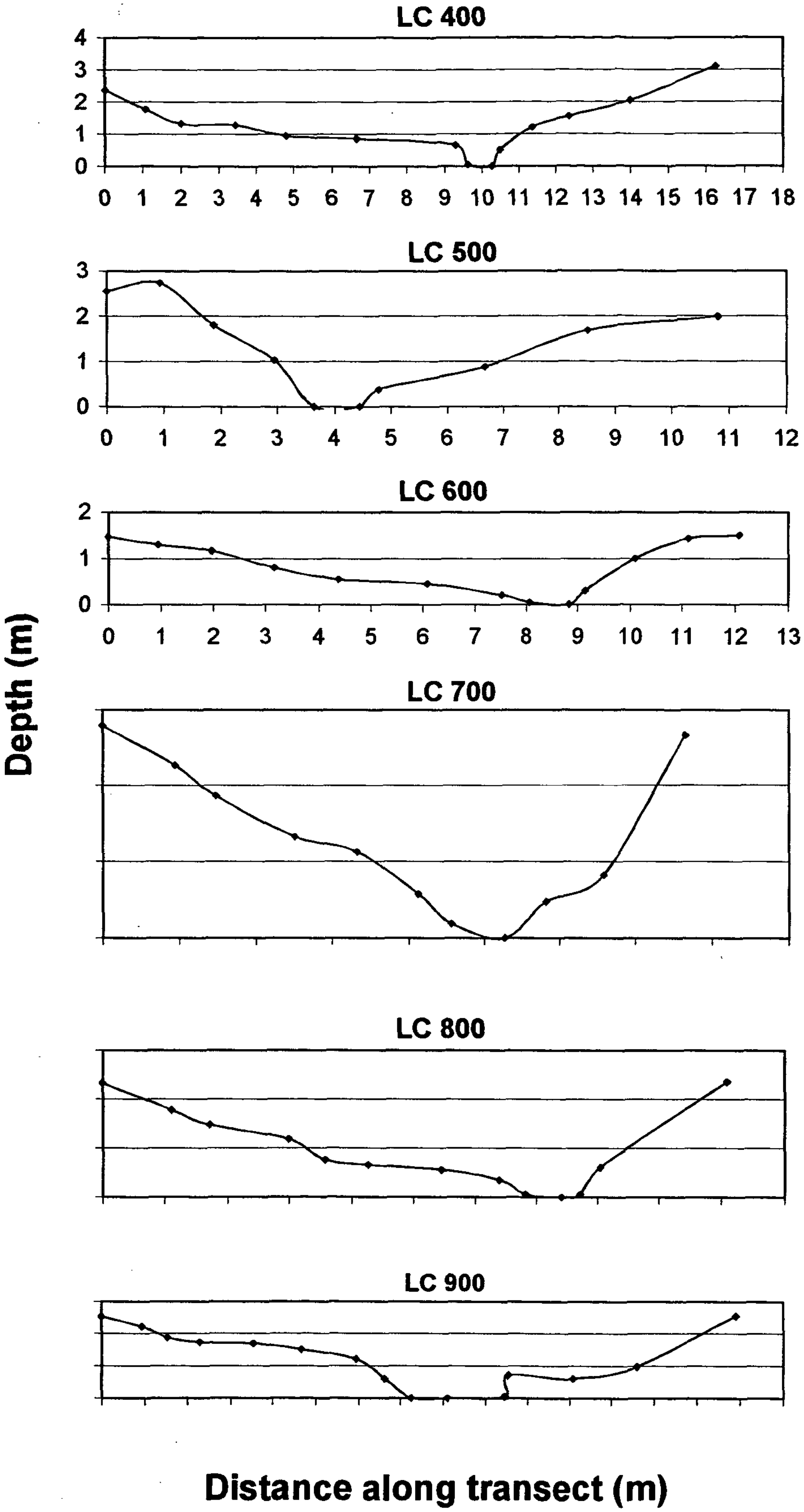
Species Name	Abbreviation	GSC-0 (1)	GSC-108 (2)	GSC-220 (3)	GSC-320	GSC-445 (4)	GSC-545	GSC-635 (5)	GSC-735	GSC-835	GSC-935	GSC-1025 (7)
Lysimachia vulgaris	Lys vul											
Mahonia repens	Mah rep	t	t	t		t		t		t	t	t
Maianthemum amplexicaule	Mia amp	t	t	t	t	t		t		t		t
Maianthemum stellatum	Mia ste	t	t	t	t	t		t	t			t
Medicago lupulina	Med lup											
Mentha arvensis	Men arv	t	t	t	t	t	t	t	t	t	t	t
Mertensia lanceolata	Mer lan											
Monarda fistulosa	Mon fis	t	t	t		t		t	t		t	t
Muhlenbergia racemosa	Muh rac	t	t	t		t		t				t
Orthilia secunda	Oro sec											
Oryzopsis asperifolia	Ory asp											
Osmorhiza chilensis	Osm chi								t	t	t	
Osmorhiza depauperata	Osm dep	t	t	t	t	t		t	t			t
Oxalis dillenii	Oxa dil	t	t	t		t		t				t
Panicum spp.	Pan spp.											
Parthenocissus inserta	Par ins	t	t	t		t		t				t
Phleum pratense	Phl pra											
Physocarpus opuliferous	Phy opu	t	t	t	2	4	9	7		t		3
Picea pungens	Pic pun	t	t	t		t		t				t
Pinus contorta	Pin cor	t	t	t		t		t				t
Pinus ponderosa	Pin pon	t	t	2		t	3	t		8		4
Plantago major	Pla maj	t	t	t		t		t				t
Poa compressa	Poa com	t	t	t		t		t				t
Poa nervosa	Poa ner											
Poa pratensis	Poa pra											
Poa spp.	Poa spp											
Polypodium amorphum	Pol amo	t	t	t		t		t				t
Populus angustifolia	Pop ang											
Populus tremuloides	Pop tre	15	t	t		t		2				t
Prunella vulgaris	Pru vul	t	t	t		t		t		t		t
Prunus virginiana	Pru vir	t	t	t	t	t	t	t			t	t
Pseudotsuga menziesii	Pse men	2	5	t	10	t	2	4	8	9	14	15
Pseudocymopterus montanus	Pse mon	t	t	t		t		t				t
Pteridium aquilinum	Ptr aqu	6	5	4	7	35		t	25	t	15	5
Pyrola chlorantha	Pyr chl	t	t	t		t		t				t

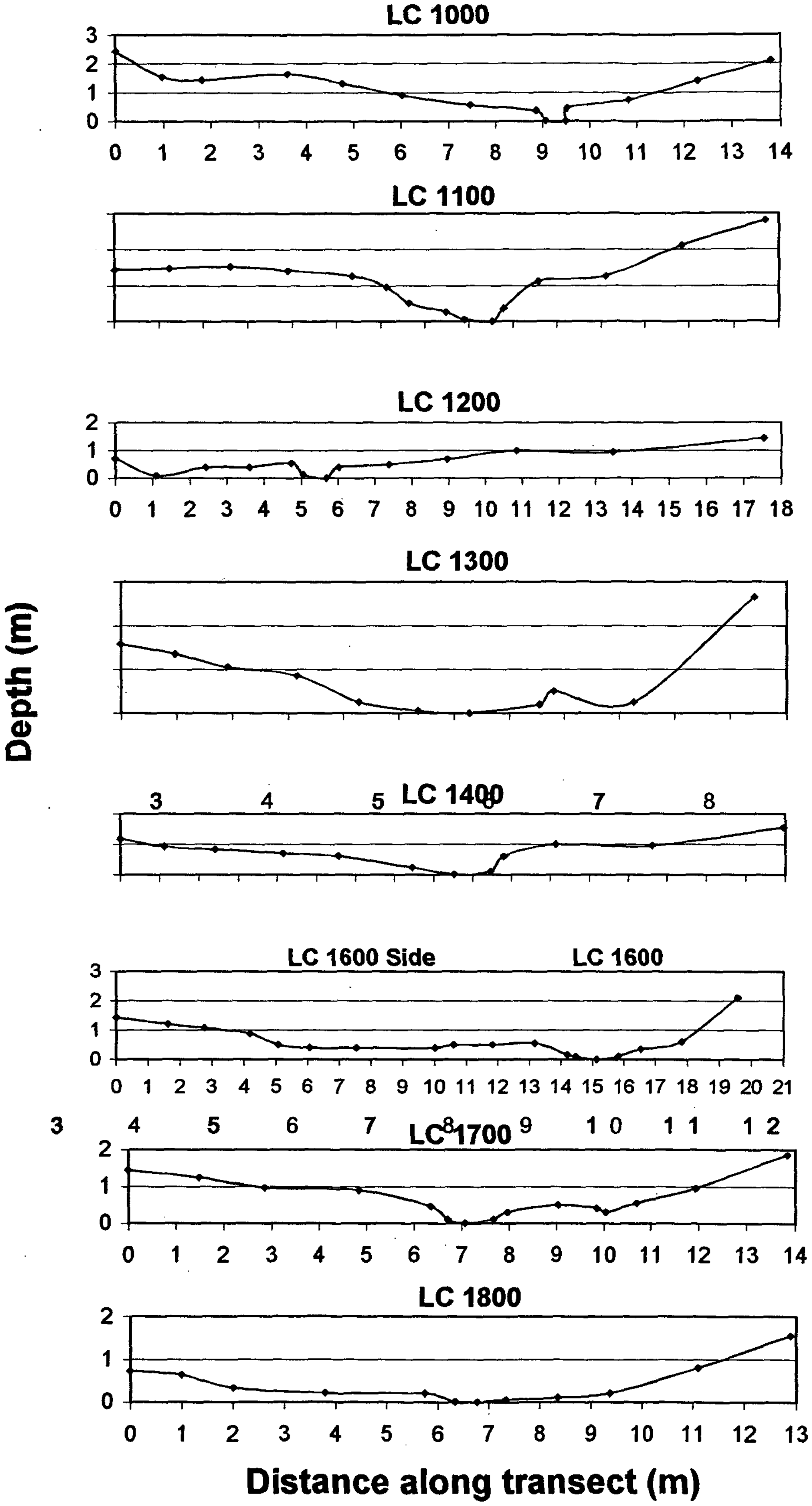
Species Name	Abbreviation	GSC-0 (1)	GSC-108 (2)	GSC-220 (3)	GSC-320	GSC-445 (4)	GSC-545	GSC-635 (5)	GSC-735	GSC-835	GSC-935	GSC-1025 (7)
Pyrola rotundifolia	Pyr rot	t	t	t	t	t		t				t
Quercus gambelii	Que gam											
Ranunculus acriformis	Ran acr											
Ranunculus maconii	Ran mac	t	t	t		t		t				t
Ribes aureum	Rib aur											
Ribes cereum	Rib cer											
Ribes inerme	Rib ine	t	t	t		t		t				t
Rosa woodsii	Ros woo	t	t	t	t	t	t	t	t	t		t
Rubus deliciosus	Rub del	t	t	t		t		t				t
Rubus idaeus	Rub ide	t	t	t		t		t	t			t
Rubus parviflorus	Rub par	3	t	t		t		t				t
Rubus pubescens	rub pub	t	t	t		t		t				t
Rudbeckia ampla	Rud amp	t	t	t		3	3	5	6	4	t	2
Salix bebbiana	Sal beb	t	t	t	t	6	t	t				t
Salix exigua	Salix exi											
Salix monticola	Sal mon											
Sambucus canadensis	Sam can		t									
Sanicula marilandica	San mar	t	t	t	t	t		t	t	t	t	t
Sedum lanceolatum	Sed lan	t	t	t		t		t				t
Senecio sp.	Sen spp											
Smilax lasioneuron	Smi las	3	t	t		t		t				t
Solidago canadensis	Sol can	t	t	t		t		t				t
Solidago missouriensis	Sol mis										t	
Solidago spathulata	Sol spa				1							
Sorbus scopulina	Sor sco	t	t	t		t		t				t
Stellaria jamesiana	Ste jam											
Stenactis (Erigeron) strigosus	Ste str									t		
Streptopus amplexiflorus	Str fas	t	2	2	t	t		t				t
Symphoricarpos albus	sym alb	t	t	t		t		t	t	t	t	2
Taraxacum officinale	Tar off	t	t	t		t		t			t	t
Thalictrum fendleri	Tha fen											
Thermopsis divaricarpa	The div											
Thlaspi spp.	Tha spp	t	t	t		t		t				t
Toxicodendron	Tox ryd											

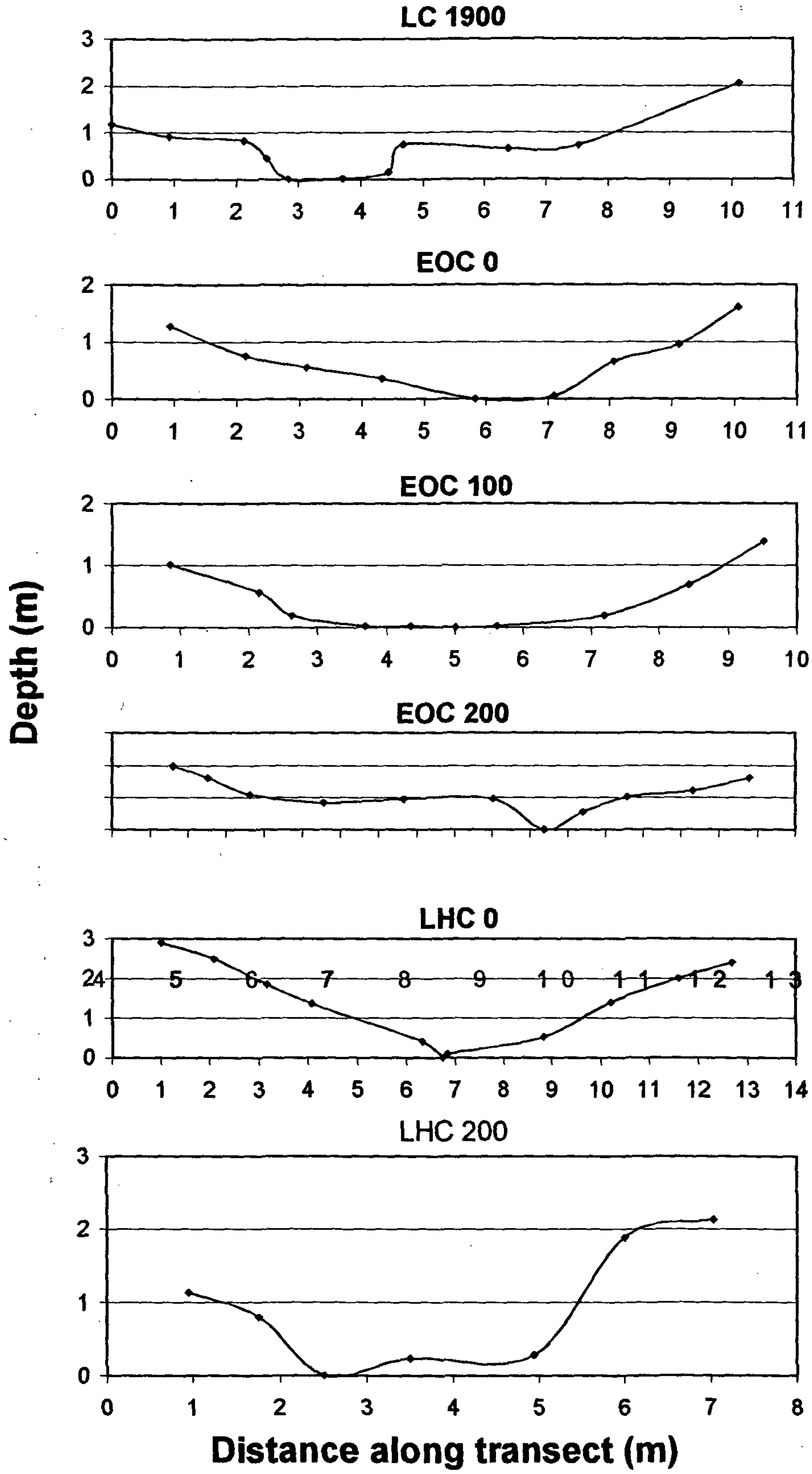
Species Name	**Abbreviation**	**GSC-0 (1)**	**GSC-108 (2)**	**GSC-220 (3)**	**GSC-320**	**GSC-445 (4)**	**GSC-545**	**GSC-635 (5)**	**GSC-735**	**GSC-835**	**GSC-935**	**GSC-1025 (7)**
rydbergii												
Trifolium pratense	Tri pra											
Trifolium repens	Tri rep											
Trifolium spp.	Tri spp	t	t	t		t		t				t
Turritius glabra	Tur gla								t			
Urtica gracilis	Urt gra	t	t	t		t		t				t
Verbascum thapsus	Ver tha											
Verbena hastata	*Ver has*											
Veronica americana	*Ver ame*	*t*	*t*	*t*		*t*		*t*				*t*
Veronica peregrina	*Ver per*											
Viola rydbergii	*Vio ryd*	*3*	*t*	*t*		*2*		*t*				*3*
Viola scopulorum	*Vio sco*	*t*	*t*	*t*	*t*	*t*	*t*	*t*	*t*	*t*	*t*	*t*
Vitus riparia	*Vit rip*											
Unknowns												
Tight grass	*Tight grass*											
Tiny grass	*Tiny grass*											
Small Grass	*Small Grass*											
Grass 2	*Grass 2*											
Total Cover	***Total Cover***	*78*	*117*	*112*	*85*	*118*	*138*	*175*	*98*	*119*	*147*	*117*

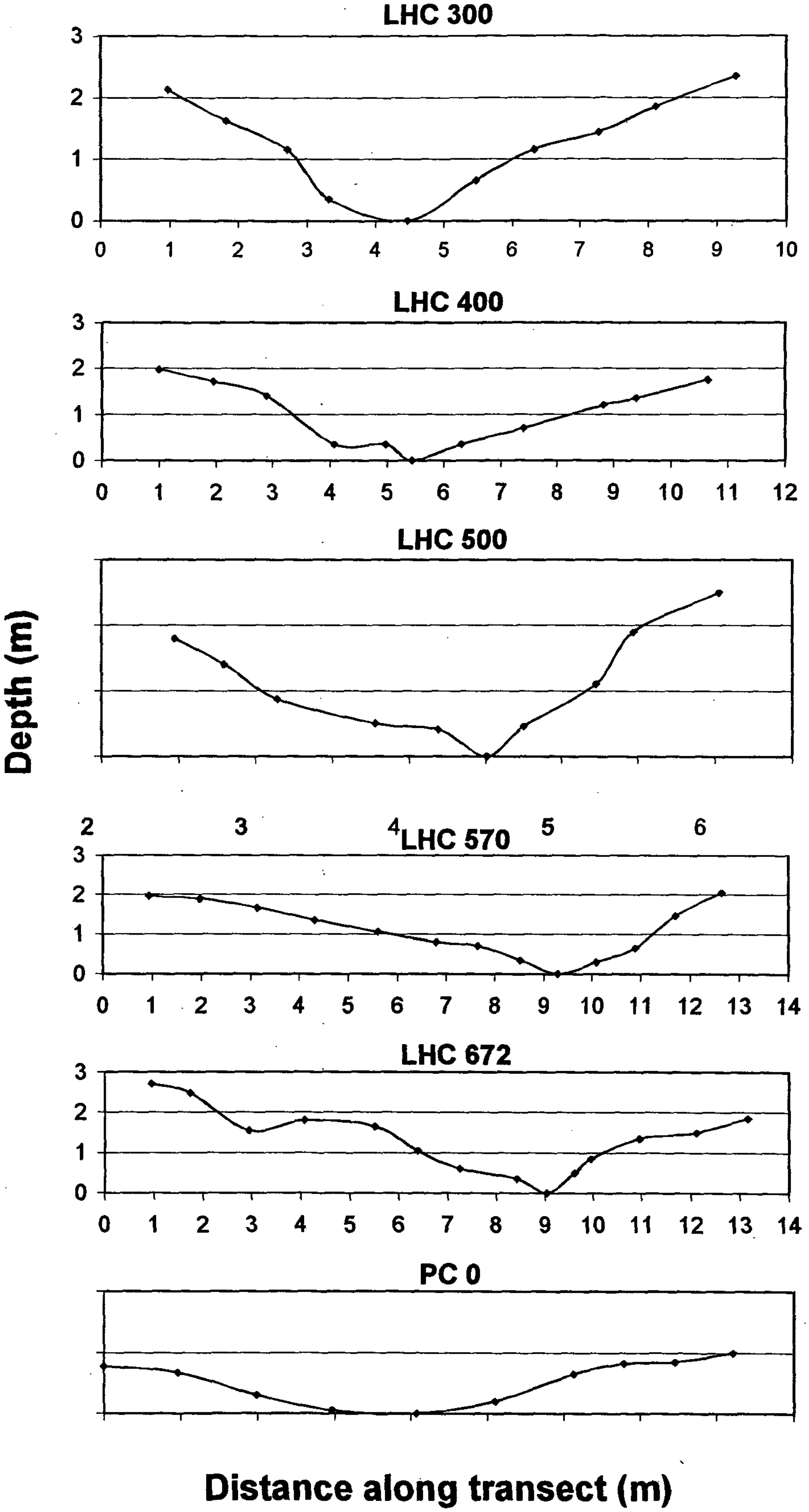
Appendix 2
Channel cross-sections

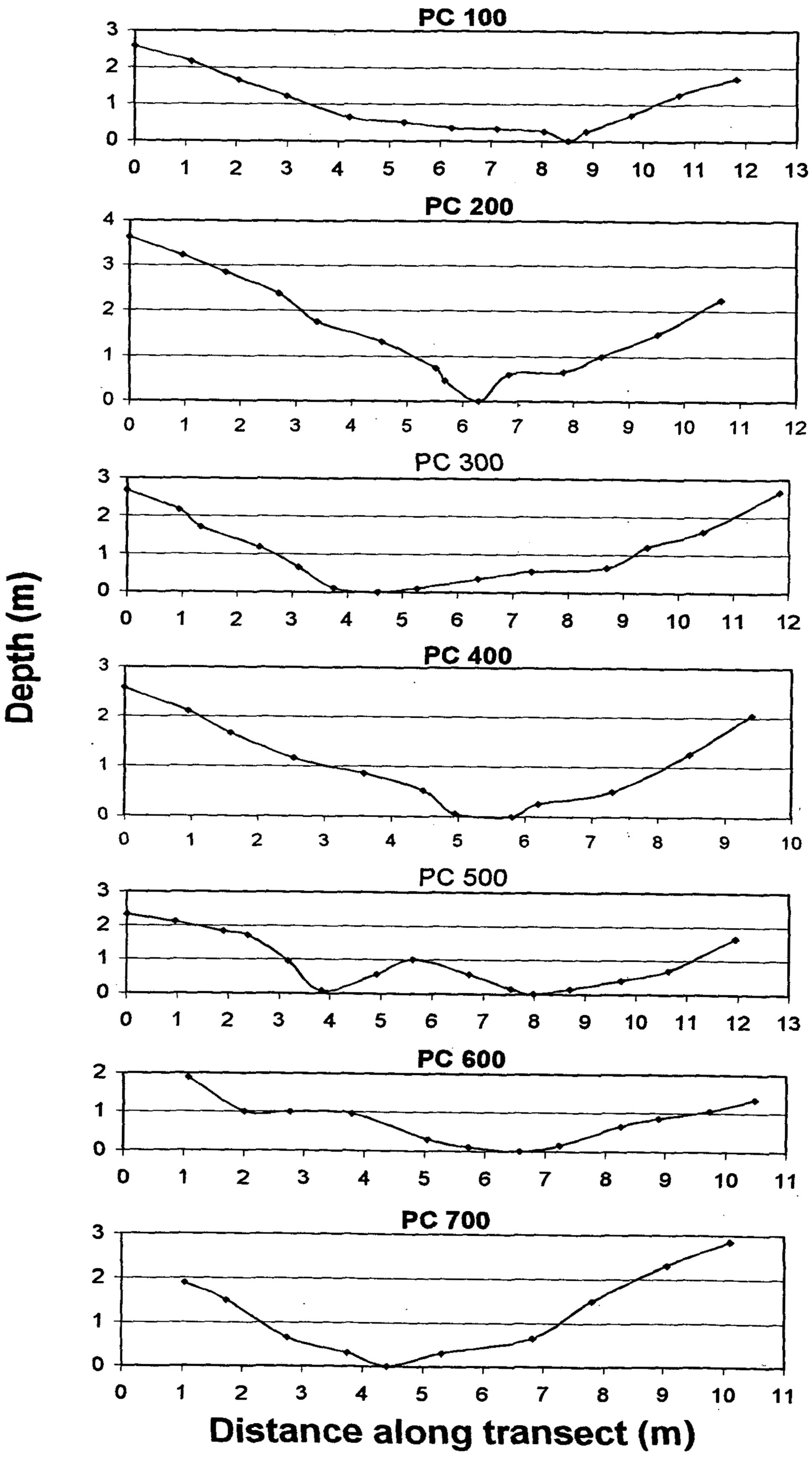



LC 400
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
LC 500
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12
LC 600
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13
LC 700
LC 800
LC 900
Depth (m)
Distance along transect (m)


LC 1000
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
LC 1100
LC 1200
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
LC 1300
Depth (m)
3 4 5 LC 1400 6 7 8
LC 1600 Side
LC 1600
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
3 4 5 6 7 LC 1700 8 9 1 0 1 1 1 2
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
LC 1800
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Distance along transect (m)


LC 1900
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11
EOC 0
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11
EOC 100
2
1
0
0 1 2 3 4 5 6 7 8 9 10
EOC 200
LHC 0
3
24 5 6 7 8 9 1 0 1 1 1 2 1 3
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
LHC 200
3
2
1
0
0 1 2 3 4 5 6 7 8
Depth (m)
Distance along transect (m)


LHC 300
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10
LHC 400
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12
LHC 500
2 3 4 5 6
LHC 570
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
LHC 672
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
PC 0
Depth (m)
Distance along transect (m)


PC 100
PC 200
PC 300
PC 400
PC 500
PC 600
PC 700
Depth (m)
Distance along transect (m)
0
1
2
3
4
5
6
7
8
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