Physical and Chemical Characteristics of Riparian Soils: Two Third-Order Streams in the Western Cascades of Oregon

by

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Abstract approved:

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Phillip Sollins

Study objectives were to survey and compare physical and chemical characteristics of soils within two third-order montane riparian ecosystems: a 500-year old Douglas-fir (Pseudotsuga menziesii) forest at Mack Creek, and a mature red alder (Alnus rubra) forest occupying a 35-year old clearcut at Quartz Creek, both near Blue River, Oregon, USA. Geomorphic surfaces and plant communities were mapped within each area. Principal components analysis and discriminant analysis served to group observations and reveal structure within the data. The first two principal components represented organic content and particle-

size characteristics at both sites. Discriminant analysis verified that virtually all sampling points were correctly classified. Dominant variables accounting for separation among sampling points were sodium fluoride pH and mineralizable ammonium at 15-30 cm depth at Mack Creek, and geomorphic surface at Quartz Creek. The vigor of the multivariate statistics indicated that plausible soil types were identified in a highly heterogeneous riparian area despite a small sample size. Sampling points plotted on the first two principal components and labeled by geomorphic surface or plant community were clearly clustered. Higher values of mean total carbon, nitrogen, CEC, and fine-earth content (Mack Creek only) were associated generally with soil types derived from older and/or aggrading geomorphic surfaces. Nitrate levels were higher in the alluvial samples at Quartz Creek than at Mack Creek, as indicated by both KCl-extraction and ion-exchange resin. Streamwater nitrate concentrations, however, were 5.7 times greater in Mack Creek than in Quartz Creek. The Quartz Creek alluvial soils may have been influenced strongly by alder-associated nitrogen fixation. The Mack Creek alluvial soils contained more organic matter, perhaps reflecting more time for soil development since disturbance. Site differences may reflect differences in soil development associated with geomorphic surface (and variation in parent material as determined by geomorphic processes), with plant community, and with time since disturbance.

"In the complexities of contemporary existence the specialist who is trained but uneducated, technically skilled but culturally incompetent, is a menace."

D.B. Truman, Dean
Columbia College

Dedication: To Oregon,

and all I have found here.

<u>retrospection</u> <u>as</u> <u>forward</u> <u>motion</u>

mountains.   rivers.
     earth shapers.
earth and atmosphere,
  lovers, passionately embraced.
if the peaks of the Cascades
  be a shoulder,
the fir and the hemlock
  soft down;
then the saguaros of Sonora
  are sweat,
glistening on a stomach
  desert taut, desert hard.
so the stream soothes the breathless
  surface,
the soil cloaks and comforts,
  'til thereupon
the softest of green light
  weds the wettest of dew,
and the soul of a place
  becomes part of your life.

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Kudos to each and every fellow student, for your unfailing support. That is what it is all about, and I will remember each and every one of you.

Thanks also to Steve Wondzell for reviewing this manuscript.

Thank you Theo, for reminding me that I do this for a reason and with a purpose.

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Chapter 1

INTRODUCTION

Forests and fisheries are two of the three most important industries in the State of Oregon, and among the major industries for the whole Pacific Northwest, including Canada. Understanding the mechanisms that contribute to sustained yields of both these natural resources is therefore of considerable economic importance to the region. Riparian ecosystems associated with third-order streams are the junction between two highly productive systems, an interface that may well be critically important to aquatic habitats, and one that offers unusual opportunity to study terrestrial habitats because of the complexity of the system.

Although considerable work has described soils associated with a variety of northwestern forest types, little work has been done in riparian ecosystems. The work presented here characterizes soils associated with two third-order streams in the western Oregon Cascades. In this region, third-order streams drain watersheds of approximately 100 to 1000 hectares. Their narrow valley floors are composed of the active channel, gravel bars, floodplain, and terrace surfaces, all generated primarily by deposition of sediment from the main channel. Soils on these geomorphic surfaces are generally immature and increase in age and degree of development with increasing elevation above the channel. An additional important parent material is the mixed alluvium/colluvium that is deposited as fans at the mouth of tributaries. Fan surfaces vary greatly in age (Swanson and James, 1975). Thus, third-order montane riparian ecosystems are established on geomorphic surfaces with soils of various origins and ages. Vegetation patterns follow geomorphic surfaces, at least to some extent. These two factors, geomorphic surface and plant community, are integral to soil formation and consequently to soil physical and chemical characteristics.

Soils of riparian ecosystems associated with third-order streams are formed under the extremely dynamic influences of mass flow on steep slopes, erosion and deposition along the main channel, and erosion or deposition involved in fan formation at mouths of tributaries.

Additionally, surface erosion, subsurface hydrological activity and nutrient redistribution, and soil mixing resulting from windthrow influence riparian soil development. Fans develop at the confluence of tributaries and the third-order channel as a result of deposition by debris flows and alluvium. Debris flow deposits contain alluvium and toeslope colluvium. Parent materials derived from main-channel bedload are more stream-rounded and sorted by size than parent materials derived from tributary streams, which in turn are more rounded and sorted than parent materials derived from debris flow deposits. The resulting pattern of soils on the landscape is complex and highly heterogeneous.

This study is a first effort to characterize and compare the soils of two third-order montane riparian ecosystems: an old-growth Douglas-fir (*Pseudotsuga menziesii*) forest at Mack Creek, and a mature red alder (*Alnus rubra*) forest occupying a 35-year old clearcut at Quartz Creek. Both research sites are spatially complex. A variety of erosional and depositional events, differing in date, duration, and intensity, has resulted in the formation of extremely heterogeneous soils. The intent was to sample a wide range of soil types, thus achieving a broad characterization of the sites.

I. Objectives:

Specific objectives were:

A. To describe and contrast physical and chemical characteristics of two third-order montane riparian soil systems.

1. To describe and contrast patterns of soil carbon accumulation within and between sites. Carbon content was expected to be greatest in colluvial samples and least in alluvial samples.

2. To identify variables correlated with nitrogen (N) availability at the two sites. Nitrogen availability was expected to correlate with variables associated with soil development (such as carbon accumulation) at Mack Creek, and with variables associated with symbiotic N-fixation at Quartz Creek.

B. To develop a preliminary classification of riparian soils in the study area that might provide insight into relationships between soil fertility and geomorphic and vegetational characteristics.

Chapter 2

METHODS AND MATERIALS

I. Study Sites

The two research sites are located at Blue River, Oregon, near the western crest of the Cascade Mountains, approximately 80 km east of Eugene, Oregon (Figure 2-1). Both sites are riparian ecosystems and border third-order streams.

The Quartz Creek site is in the *Tsuga heterophylla* zone, and the Mack Creek site is in the *T. heterophylla* transition zone (Franklin and Dyrness, 1973). The surrounding slopes are generally steep, in some cases greater than 100%. Bedrock is of volcanic origin, and the climate is mesic to moist. Mean annual precipitation of the region is 227.6 cm, with a monthly low of 1.5 cm occurring in July during the hot-dry summer, and a monthly high of 39.6 cm occurring in December primarily as snow (F. Bierlmaier, personal communication, 26 year summary of precipitation at Watershed #2, H.J. Andrews Experimental Forest). Mean monthly maximum and minimum air temperatures at Mack

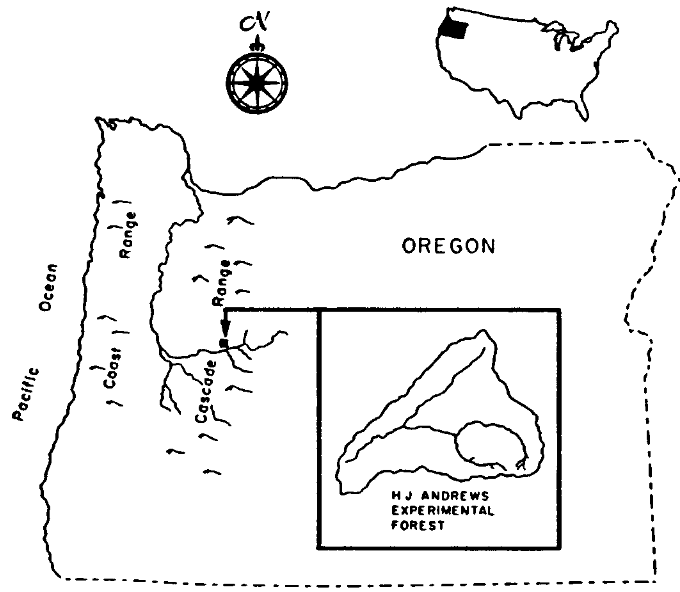


Figure 2-1. Location of the study sites.

Creek, based on 10 years of meteorological data, indicate a high temperature of 20.3 ^{o}C in July and a low of 0.4 ^{o}C in January (Bierlmaier and McKee, in press). At Quartz Creek, 4 years of data indicate a temperature maximum of 21.4 ^{o}C in August and a minimum of -0.4 ^{o}C in December (Bierlmaier and McKee, in press). The Mack Creek site is at 800 m elevation, within the H.J. Andrews Experimental Forest, and the Quartz Creek site is at 500 m, on the Blue River District of the Willamette National Forest.

The Mack Creek site is characterized by a very steep slope (80-100%) on one side of the channel, and an old colluvial fan on the other. Both ephemeral and persistent debris dams, particularly a large log jam established some 100 years or more ago, have strongly influenced both main-channel width and the position and permanence of gravel bars. The dominant vegetation on the site is a 500-year-old stand composed of Douglas-fir (<u>Pseudotsuga</u> <u>menziesii</u>), intermixed with young western hemlock (<u>Tsuga</u> <u>heterophylla</u>), and western red cedar (<u>Thuja</u> <u>plicata</u>) (Teensma, 1987).

The geology of the vicinity is Tertiary and Quarternary volcanic rocks (Peck et al., 1964; Swanson and James, 1975; Sherrod and Smith, 1989). Valley floor bedrock is 17-25 million year old tuff breccia, lapilli tuff, and tuff composed of pyroxene andesite and less abundant basalt and dacite. The surrounding ridges and slopes are primarily younger lava flows of basaltic andesite, olivine basalt, and pyroxene andesite with interbedded pyroclastic and volcanic-sedimentary rocks. The soils of Mack Creek have previously been classified as belonging to the Carpenter Series (Stephens, 1962; Sherrod and Smith, 1989).

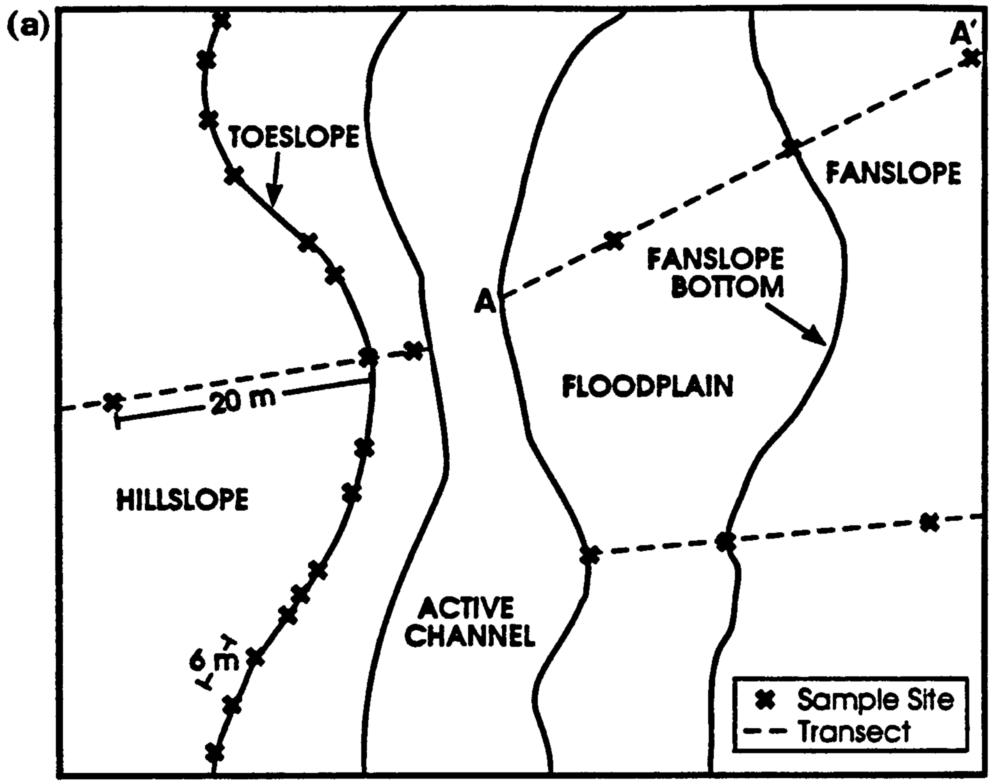
Riparian soils of nearby Lookout Creek have been classified as Fluventic Hapludolls (floodplain), Fluventic Dystrochrepts (stream terrace) and Fluventic Eutrochrepts (alluvial-colluvial fans) (R. Brown, 1975). Further, soils of the H.J. Andrews reference stands from similar elevations, geomorphic surfaces, and plant communities have been classified as primarily Typic Dystrochrepts, but may also be Entic Dystrandepts or Andic Dystrochrepts (Brown and Parsons, 1973).

The Quartz Creek valley floor is dominated by both colluvial and alluvial fans and was heavily disturbed by tractor logging about 35 years ago. Vegetation is predominantly red alder (*Alnus rubra*), with minor components of cascara (*Rhamnus purshiana*) and western hemlock. Fans at Quartz Creek vary considerably in age and dominant process of formation. The surface of the low-gradient alluvial fan (fine, sorted material) on the east side of the creek is deeply incised by its tributary stream, so sediment no longer accumulates on the fan surface. Consequently, this fan surface is older than the comparatively steep colluvial fan (coarse, poorly sorted material) on the west side where the tributary stream has not incised the fan (F. Swanson, personal communication). A log jam at the bend in the main channel has caused channel constriction and accelerated erosion through cutting of the banks on both sides of the main channel, eroding toes of fans and thereby expanding the fanslopes.

The bedrock of the western Cascades is predominantly Eocene to Pliocene volcanics, predominantly hydrothermally altered clastics of andesitic, dacitic, and rhyodacitic composition (Swanson and James, 1975).

II. Experimental Design and Field Sampling Methods

Initial reconnaissance of the two sites suggested three general geomorphic zones within each system: hillslope or fanslope (colluvium), toeslope or fanslope bottom, and stream-influenced (alluvium). These zones defined the strata from which samples were collected. Fifteen transects were established on either side of the main channel and, where possible, within the mapped study reaches (Figure 2-2). Thus, the experimental design used was a 2-way factorial design with 2 replications:



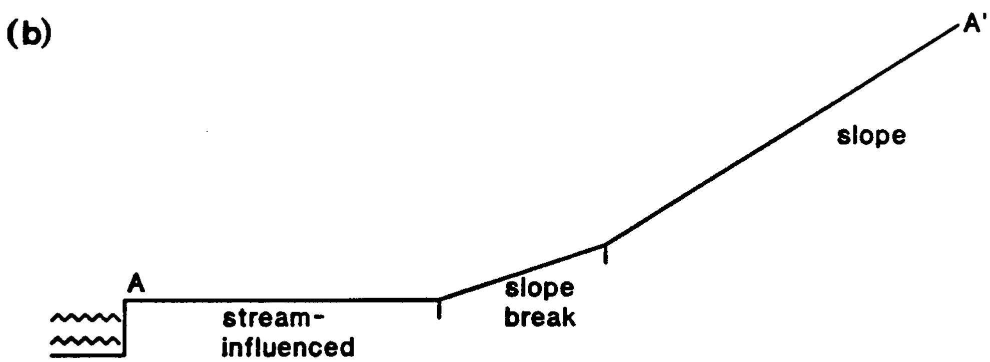


Figure 2-2. Schematic representation of zones and sampling transect layout. (a) hypothetical stream reach; (b) cross-section of a slope profile.

Factor 1	=	geomorphic stratum
Factor 2	=	sample depth (0-15 cm and 15-30 cm)
Replicates	=	either side of the stream (reps = 2)

Sampling point selection was partly systematic and partly random. Toeslope or fanslope bottom (slope break) sampling points were first located systematically at 6-m intervals. The distance between sampling points was altered where obstacles prevented sampling. Transects perpendicular to the slope break were then established between sampling points at the toeslope or fanslope bottom and at the edge of the stream. Alluvial sampling points were situated as close to the stream bank as possible, wherever gravel and boulders would permit digging. Hillslope or fanslope sampling points were located approximately 20 m above the toeslope/fanslope bottom sampling point of each transect, and adjusted up- or downslope to avoid obstacles (Figures 2-3 and 2-4). A total of 90 potential sampling points were identified at each site.

A subset of sampling points was selected for soil analyses. Within each stratum, sampling points with "confounding" features such as buried logs, extreme rockiness, logging compaction, windthrown soil, etc. were discarded. Five sampling points in each stratum on each side of the

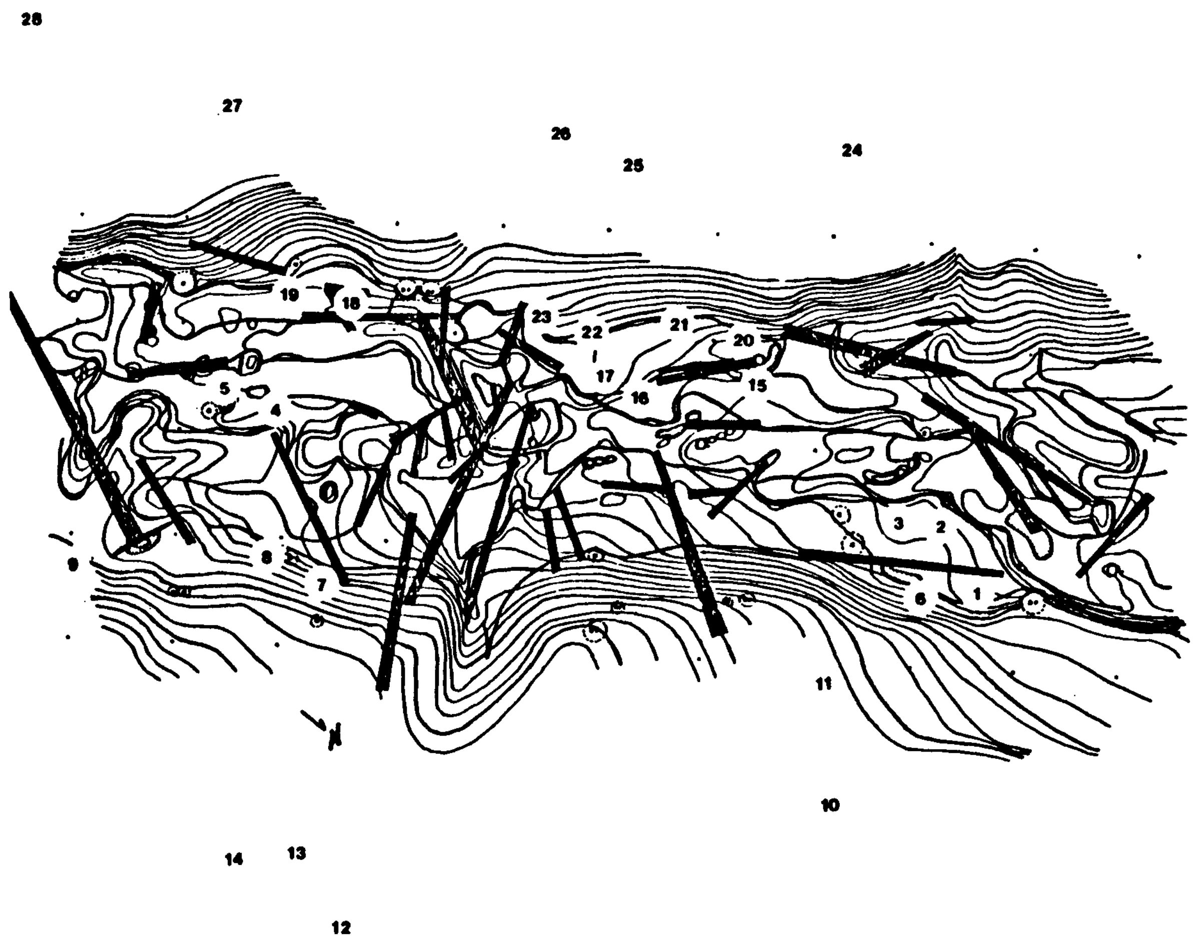


Figure 2-3. Sampling points at Mack Creek.

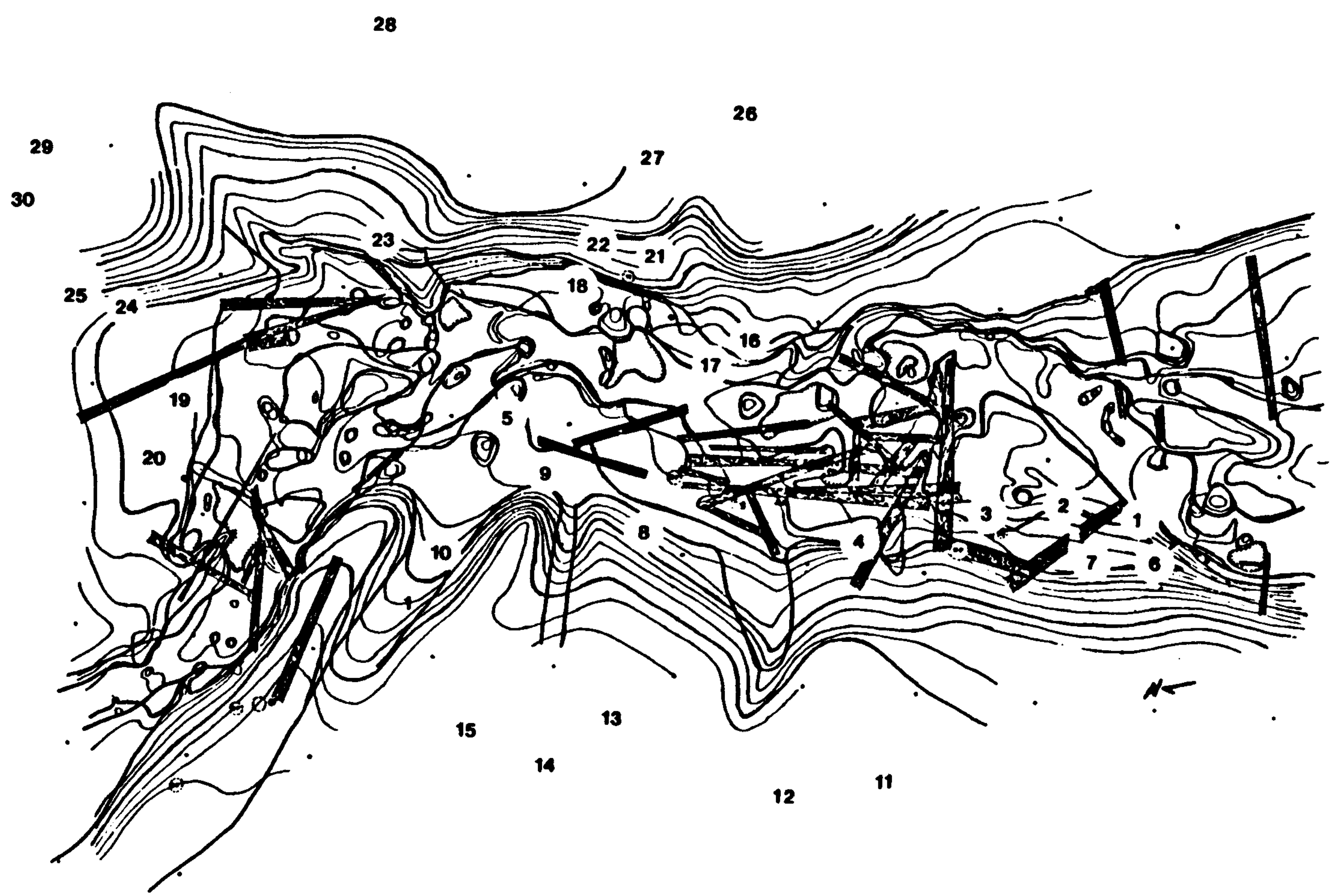


Figure 2-4. Sampling points at Quartz Creek.

stream were selected randomly from the remaining points. The final soil sampling scheme included 10 sampling points per geomorphic zone, or 30 sampling points per site. Plots (1.5 m^2) were established around each sampling point, with the bulk of the plot uphill of the soil pit, in order to prevent disturbance by other researchers working at the sites.

Soil pits were dug to a depth of 60 cm or more in the fall of 1983. Pits were sampled systematically at fixed depths, 0-15 and 15-30 cm, because horizonation was extremely variable and inconsistent, and at times weakly developed. Bulk samples (2-3 kg) were collected, and stone content of each pit was estimated visually. All samples were stored field moist at 5 ^{o}C until analyzed. I measured slope immediately above the soil pit rather than below because I expected this measurement to be a better indicator of erosion at the soil pit.

Eight plant communities within, and directly adjacent to, each 1.5 m^2 plot were identified, with the assistance of Art McKee, using the key of Campbell & Franklin (1979). These communities were subsequently combined into four categories of inferred similar disturbance frequency, again with the assistance of Art McKee. A code of "1" was given to unstable, frequently disturbed communities, and a code of "4" to the least disturbed communities.

Group #	Plant communities
1	Invasive small herb Pioneer *Tolmiea menziesii*
2	*Rubus spectabilis*/*Ribes bracteosum*
3	*Oplopanax horridum* *Polystichum munitum*/*Blechnum spicant*
4	Mixed-fern, large herb *Acer circinatum* *Vaccinium alaskaense*/*Vaccinium parvifolium*

III. Laboratory Methods

After manual removal of cobbles and large chunks of wood from the bulk soil samples, subsamples were air-dried only as necessary to permit sieving (4 mm and 2 mm). The 2 mm sieving was assisted by physical disruption of aggregates with a metal spatula. All discernible charcoal fragments and small chunks of wood were removed prior to 2 mm sieving. Parallel moisture analyses were conducted for each chemical analysis, and all values were expressed per gram dry weight of < 2 mm (fine earth) soil.

Subsamples for carbon and nitrogen analyses were oven dried at 95-100 ^{o}C for 24 hours, and ground to pass a 60 mesh (0.25 mm) screen. Total carbon (C) was determined by dry combustion (LECO 12 automatic analyzer). Every fifth subsample was replicated, and variability among replicates averaged 0.13% of the mean.

Total nitrogen (N) and phosphorus (P) were determined by micro-Kjeldahl digestion with subsequent ammonium and ortho-P analysis by autoanalyzer (Technicon method number 334-74A/A). The accuracy of the Technicon was 0.1 ppm N). A selenium/hydrated copper sulfate catalyst was used, and every tenth subsample was replicated. Kjeldahl-phosphorus measures neither available-P nor total-P, but something intermediate. This value is useful for soil classification and as a clustering variable in multivariate analysis, but is not validly used to explain or correlate with other nutrient cycling variables.

Soil pH values in distilled water (1:2 soil:water), and in sodium fluoride (NaF) (1:25 soil:NaF) (after Fieldes & Perrot, 1966) were determined with a Beckman model 3500 digital pH meter with a glass electrode on bulk soil subsamples. Subsamples were adjusted for percent fine earth fraction so that they contained about 10 g of < 2 mm soil for the pH in water, and 1 g of < 2 mm soil for the pH in NaF.

Sodium fluoride (NaF) pH was measured because it has been shown to be linearly correlated with amorphous aluminum oxide, which in turn is a predictor of phosphorus retention in the soil (Alvarado, 1982). NaF has been noted to react with humus-bound aluminum, allophane-like constituents, imogolite, and poorly crystalline layer silicates (Mizota and Wada, 1980). Soils with a NaF pH larger than 10.2 have an amorphous clay mineralogy.

Cation exchange capacity (CEC) of the fine earth fraction of 0-15 cm samples was determined by the ammonium acetate method (Chapman, 1982) on bulk soil subsamples that had been stored at room temperature for 1 year prior to analysis.

Mineralizable soil nitrogen was measured by anaerobic incubation using the 7 day, 40 ^{o}C method (Keeney and Bremner, 1966; Keeney, 1982) on duplicate, unsieved, 35 g fresh subsamples from which only large stones and organic debris had been removed; extractions (1 N KCl) and incubations (H_2O, extracted in 2 N KCl) were begun within 24 hours of field sampling. VWR medium quantitative filters were rinsed prior to decanting to remove traces of ammonium in the filters. Dry weight of the < 2 mm fraction was determined after extraction. Anaerobic incubations of this type are a measure of microbial biomass, and not of actual nitrogen mineralization (Myrold, 1988).

Particle size-class distribution (Mack Creek 0-15 cm samples only) was determined by a modified pipette method (Gee and Bauder, 1987). Fractions included clay, silt (2-5 μm, 5-20 μm, and 20-45 μm), sand (0.045-.105 mm, 0.105-.25 mm, 0.25-.5 mm, 0.5-1.0 mm, and 1.0-2.0 mm) and sand-sized organic matter. Dispersion was by shaking in water so as to simulate the action of a stream on whole soil; samples were not pretreated to remove carbonates, soluble salts, iron oxides or organic matter.

Samples were first separated into < 45 μm and > 45 μm subsamples. Previous determination of the proportion of fine earth in the bulk soil of each sample provided an estimate of the quantity of bulk soil needed for reliable particle-size analysis. Each bulk soil sample was shaken overnight in distilled water, sieved (2 mm) and washed repeatedly with forced air and distilled water. The < 2mm slurry was passed through a 45-μm sieve fitted to a 600 ml beaker and washed on a shaker. Each sample was washed repeatedly until the < 45-μm suspension was nearly clear, and the suspensions collected in a common container. Suspension volume was subsequently reduced by centrifugation.

Size-class fractions were obtained as follows: Each > 45-μm subsample was oven-dried at 100 ^{o}C for 24 hours and sand-sized organic matter combusted with 30% hydrogen peroxide. The sand fraction was then oven-dried, and weight of the sand-sized organic organic matter fraction calculated by subtraction. Sand fractions were shaken through a series of sieves, oven-dried, and then weighed. Silt and clay fraction masses were determined by repeated sedimentation of the < 45-μm suspension. The mass of the mineral particles in < 45-μm suspension that was not removed during pipetting was determined by oven-drying at 100 ^{o}C for 24 hours. Total dry weight of the fine earth subsample was calculated by summation of the individual measurements. Coefficients of variation for each particle-size class averaged 2.22 to 4.82 percent.

Seasonal changes in solution nutrient availability were estimated with ion-exchange resin bags (J.T. Baker #M614 mixed-bed resins). Spring and fall were chosen as sampling periods because wet soils permit nutrient movement, and because soil microflora are active during these periods. Bags were placed 15 cm below the soil surface, perpendicular to the slope and 10-15 cm from the soil pit edge, using a straight-blade hoedad. Spring bags containing 3 tablespoons of resin were placed as soon as snowmelt and ground thaw permitted access to the sites. Fall bags containing 4 tablespoons of resin were placed at the end of the summer hot-dry period, just as the fall rains were beginning, and retrieved prior to the first major fall storm. One tablespoon of resin was estimated to be capable of retaining the nutrients in 6-12 liters of concentrated solution. Resins remained in the ground for 10 weeks, were subsequently extracted in KCl at room temperature for 24 hours, and were analyzed for nitrate, ammonium, and orthophosphorus.

A complete list of the variables measured is given in the Appendix, Table A-1.

IV. Statistical Analyses

The frequency distribution of each variable, by site (Mack Creek or Quartz Creek) and depth (0-15 or 15-30 cm), was tested for departures from normality based on values for skewness and kurtosis (Bowman & Shenton, 1975). Non-normal distributions were scanned for potential outliers. I deleted only those observations that appeared to be highly unusual or singular, the result of measurement or procedural error, or due to excessive charcoal content.

The data for two entire soil pits at Mack Creek were deleted; each such pit was the sole representative of a soil profile. The data from a total of 28 soil pits from Mack Creek, and of 30 from Quartz Creek, were included in the final data set. On occasion, missing observations or deleted outliers caused the working data set to be one or two observations smaller.

Statistical transformations were applied to distributions that remained non-normal after outliers had been removed. Since the arcsine ($\sin^{-1}$) transformation ($p' = \arcsin \sqrt{p}$), which is especially appropriate to percentages and proportions, did not normalize any of the distributions, Poisson (square root) and inverse transformations were tried next, and the best of the two was used. Quartz Creek extractable nitrate, at both depths, required the square-root transformation, as did 15-30 cm depth Kjeldahl-phosphorus at Mack Creek. Further, 15-30 cm C, N and P at Quartz Creek needed the inverse transformation. As each variable was now normally distributed, the entire data set was assumed to be multivariate normally distributed (Dillon and Goldstein, 1984).

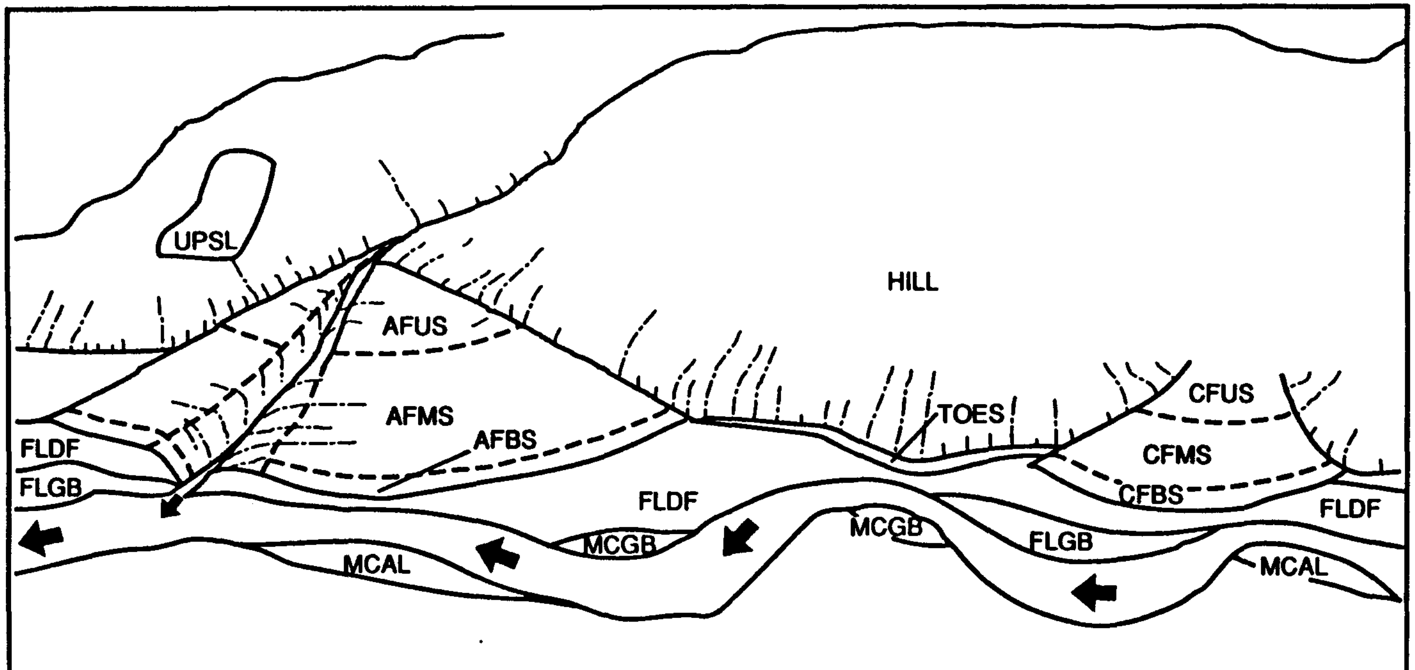
As the factorial design did not adequately block the study sites into meaningful units, and since the mean total carbon ranking was internally consistent between sites and depths, a completely randomized design was used for analysis of variance. This design is one of statistical convenience, especially useful given the exploratory nature of the study. Analysis of variance and correlation analysis were performed on the transformed, outlier-deleted data sets.

V. Mapping of Geomorphic Surfaces

Analysis of variance yielded little useful information, most likely because the experimental design was too simplistic for such a highly variable system. I therefore investigated whether sampling points corresponded, at least roughly, with identifiable geomorphic surfaces. High-resolution topographic maps (1 m contours drawn from a 10 x 10 m grid), available for both sites, were used to classify and map geomorphic surfaces along with visible features such as channels, slope breaks, areas of active erosion or deposition, unusually high groundwater tables, rock outcrops, surface boulders resulting from debris flows, and human disturbance. Fred Swanson assisted in the identification of geomorphic surfaces.

Twenty-one different surfaces were identified initially, then simplified and combined into eight categories based on probable time since disturbance, slope position, differences between alluvium and colluvium, etc., again with the assistance of Fred Swanson. An idealized arrangement of the various geomorphic surfaces in a third-order riparian zone is given in Figure 2-5.

I first mapped all surfaces other than fans. Alluvial surfaces included main- and side-channel summer base flow, floodplains, debris flows, and gravel bars. Main-channel alluvial surfaces were those that were reworked annually during major winter storms, while main-channel gravel bars were surfaces that were reworked only during unusually high main-channel flow. Floodplain gravel bars were somewhat less accessible (hence more stable) gravel deposits resulting from main- or side-channel deposition. Debris flows were distinguished by the presence of surface boulders. Side-channel alluvium and debris flows were



MCAL - Main-channel alluvium	AFUS - Alluvial fan, upper slope
MCGB - Main-channel gravel bar	CFUS - Colluvial fan, upper slope
FLGB - Floodplain gravel bar	UPSL - Upland slump
FLDF - Floodplain/debris flow	AFBS - Alluvial fan, bottom slope
AFMS - Alluvial fan, mid-slope	CFBS - Colluvial fan, bottom slope
CFMS - Colluvial fan, mid-slope	TOES - Toeslope
HILL - Hillslope	

Figure 2-5. Idealized arrangement of geomorphic surfaces in a third-order riparian zone, showing upland features as well.

actually fans, and were so classified. I next mapped visible upland features including distinct slope breaks, slumps, seeps, terraces and rock outcrops. Surfaces classified as hillslopes consisted of long, continuous, steep slopes, and the zone of accumulation at the base of these hillslopes was classified as a toeslope.

Fans were then mapped. Alluvial fans, originating from periodic bedload deposition from side channels, consisted of layers of sandy deposits, whereas colluvial fans resulted from debris flows composed of coarser-textured colluvium and tributary-derived alluvium. Fans were distinguished primarily on the basis of slope position and gradient. Upper fans were generally low gradient slopes (approximately 5-8^{o}), and fanslopes were shorter slopes below the upper fan where slopes had steepened due to streambank erosion within the main channel. Finally, fan slope-bottoms occurred at the base of fanslopes, and were zones of accumulation similar to toeslopes.

Disturbance features such as roads, skid roads, landings, log decks, and windthrow were also mapped, but were not included in the coding categories since they were not sampled.

The geomorphic surfaces of each category are listed below, and are represented graphically for each site (Figures 2-6 and 2-7). The most recently (e.g. annually)

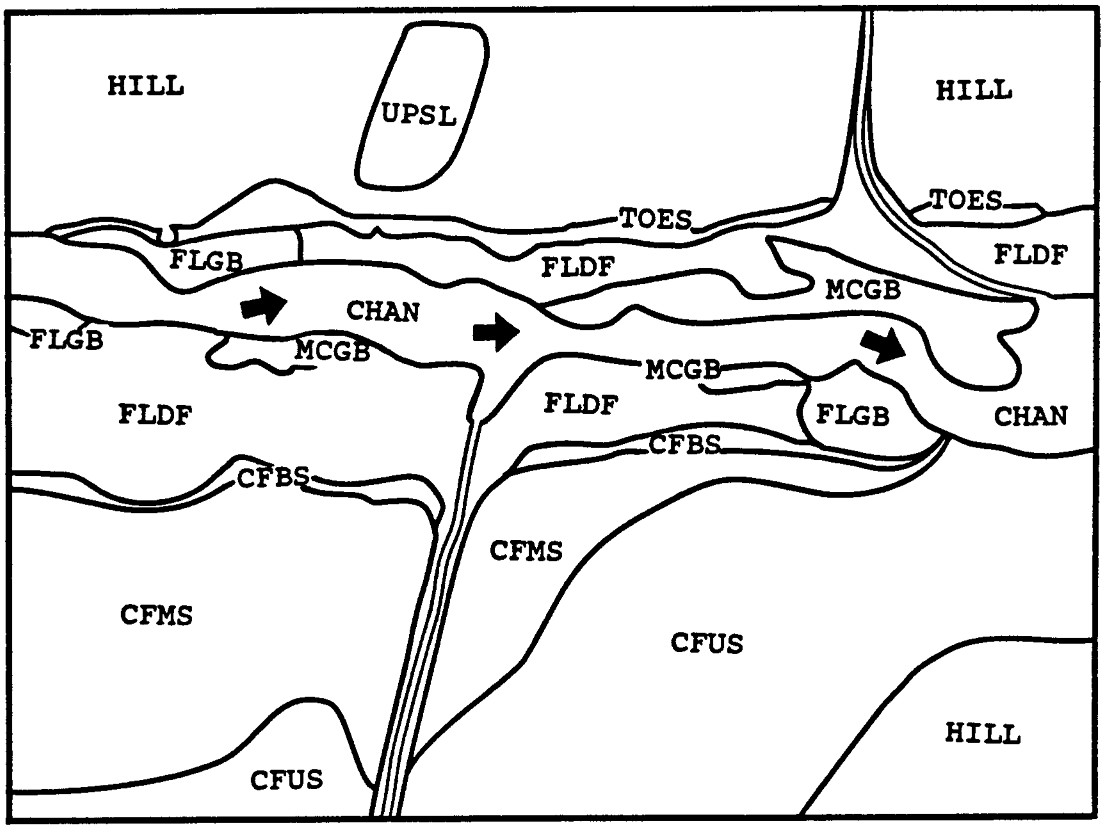


Figure 2-6. Map of geomorphic surfaces at Mack Creek. Key indicates surfaces of similar geomorphic "stability".

"Stability" Code	KEY TO GEOMORPHIC SURFACES	
	CHAN	Main- and side-channels
2	MCGB	Main-channel gravel bar
3	FLGB	Floodplain gravel bar
	FLDF	Floodplain/debris flow
4	CFMS	Colluvial fan, mid-slope
5	HILL	Hillslope
6	CFUS	Colluvial fan, upper slope
	UPSL	Upland slump
7	CFBS	Colluvial fan, bottom slope
8	TOES	Toeslope

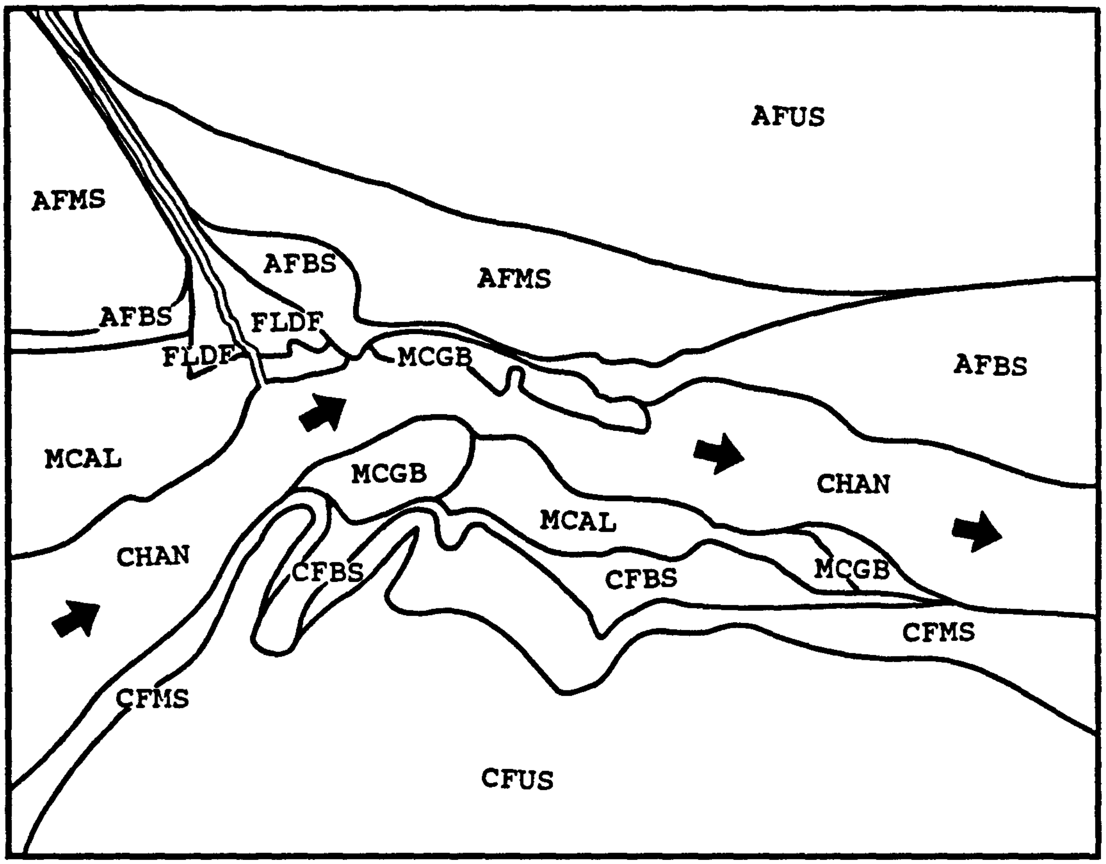


Figure 2-7. Map of geomorphic surfaces at Quartz Creek. Key indicates surfaces of similar geomorphic "stability".

"Stability" Code	KEY TO GEOMORPHIC SURFACES	
	CHAN	Main- and side-channels
1	MCAL	Main-channel alluvium
2	MCGB	Main-channel gravel bar
3	FLDF	Floodplain/debris flow
4	AFMS	Alluvial fan, mid-slope
	CFMS	Colluvial fan, mid-slope
6	AFUS	Alluvial fan, upper slope
	CFUS	Colluvial fan, upper slope
7	AFBS	Alluvial fan, bottom slope
	CFBS	Colluvial fan, bottom slope

disturbed surfaces were coded "1", and the most stable surfaces were coded "8". In this way, geomorphic surfaces of similar stability were treated as a group during subsequent analyses.

Group #	Geomorphic surfaces
1	Main-channel alluvium
2	Main-channel gravel bar
3	Floodplain gravel bar Floodplain/debris flow
4	Alluvial fan, mid-fanslope Colluvial fan, mid-fanslope
5	Hillslope
6	Alluvial fan, upper fanslope Colluvial fan, upper fanslope Upland slump
7	Alluvial fan, bottom slope (break below fanslope) Colluvial fan, bottom slope (" ")
8	Toeslope (break below hillslope)

Chapter 3

INITIAL RESULTS AND SITE COMPARISONS

The first set of data analyses, including analysis of variance, was conducted on the sampling points grouped according to the initial strata of the experimental design. At either site, most of the among-strata comparisons were confusing. Between-site comparisons were even more difficult to interpret. This was initially surprising. The lack of interpretable results suggested strongly that the experimental design did not reveal patterns that might reasonably be expected in the data.

In an effort to simply characterize and compare the two sites, I first took a reductionist approach to the data and lumped all the sampling points, regardless of geomorphic stratum. This resulted in average site values for each "homogeneous" riparian vegetation type.

Soil profiles of the two sites differed in degree of horizonation. Both the 0-15 and the 15-30 cm depth samples at Quartz Creek consisted almost entirely of A-horizon material, with a minor component of B-horizon material (somewhat more in the 15-30 cm samples). The 0-

15 cm samples were mostly A1 material, and the 15-30 cm samples were mostly A2 material. More horizonation was evident at Mack Creek. The 0-15 cm samples at this site included A1-horizon material but it was not dominant. Because horizons were generally thin, many of the 0-15 cm samples at Mack Creek spanned two or three horizons, ranging from AO to C. Variable horizonation at this site was especially obvious in the 15-30 cm samples, which were equally likely to be primarily A-, B-, or C-horizon material. Thus, the 15-30 cm depth data at Mack Creek may reflect differences in soil development, and this profile depth may be important when comparing the two soils.

I. Comparison of Sites

The grand means (average site values) of each variable were compared between sites and by depth with a t-test (Table 3-1). Standard errors were nearly always $\leq$ 10% of the mean.

Comparisons that were significantly different were mostly as expected. Quartz Creek samples were more coarse-textured and nutrient-depleted, with the exception of abundant nitrate, presumably associated with symbiotic N-fixation by alder. Quartz Creek 0-15-cm samples were more acidic and had less fine earth, mineralized ammonium, and cation exchange capacity than samples from the same

Table 3-1 -- Mean values of soil chemical and physical characteristics, by site and sampling depth. Standard errors in parentheses. Significant differences between sites for a given depth, as determined by the Student's t-test, are indicated by asterisks.

	Site/Depth			
	Mack Creek		Quartz Creek	
Variable	0-15 cm	15-30 cm	0-15 cm	15-30 cm
n	28	28	30	30
Total carbon (%)	7.87 (0.52)	4.74 (0.47)	7.76 (0.65)	1.21 *** (0.02)
Total nitrogen (N_t) (%)	0.32 (0.02)	0.21 (0.02)	0.30 (0.02)	0.06 *** (0.03)
Kjeldahl-phosphorus (%)	0.14 (0.01)	0.35 (0.01)	0.11 *** (0.01)	0.12 *** (0.01)
C/N	24.60 (0.74)	22.19 (0.66)	25.73 (0.84)	25.24 ** (1.06)
CEC (cmol(+)/kg)	38.57 (1.75)	- -	29.93 ** (1.77)	- -
pH	5.61 (0.08)	5.92 (0.08)	5.51 (0.12)	5.76 * (0.10)
NaF pH	10.62 (0.07)	10.43 (0.08)	9.71 *** (0.09)	10.23 (0.08)
Extractable nitrate (mg/kg)	0.20 (0.08)	0.21 (0.10)	2.91 *** (0.31)	2.08 *** (0.27)

Table 3-1 (continued)

	Site/Depth			
	Mack Creek		Quartz Creek	
Variable	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Mineralized ammonium (mg/kg)	111.13 (7.51)	56.90 (5.65)	69.61 ** (9.46)	46.33 (6.40)
Mineralized ammonium + extractable nitrate (N_m) (mg/kg)	108.73 (7.38)	55.32 (5.57)	76.89 (10.29)	50.00 (6.38)
Proportion of nitrogen mineralized (N_m/N_t)	3.41 (0.17)	2.64 (0.16)	2.70 (0.34)	2.33 (0.29)
Fine-earth (< 2 mm) (%)@	65.80 (3.82)	56.38 (3.86)	50.02 *** (2.88)	46.80 (2.33)
Coarse fragments (> 4 mm)(%)@	23.00 (3.17)	30.43 (3.07)	34.45 ** (2.84)	37.07 (2.20)
Sand content (%)#	48.54 (2.27)	- -	- -	- -
Silt content (%)#	31.99 (1.61)	- -	- -	- -
Clay content (%)#	13.76 (1.19)	- -	- -	- -

@ percent of the bulk soil.
# percent of the fine-earth (< 2 mm soil).
Signficantly different comparisons at the 0.01, 0.05, and 0.10 levels are indicated by ***, **, and *, respectively.

depth at Mack Creek. The 15-30-cm samples at Quartz Creek had lower values for carbon, nitrogen, and NaF pH, and a higher C/N ratio than did samples from the same depth at Mack Creek. Kjeldahl-phosphorus was lower for both depths at Quartz Creek than it was at Mack Creek. Extractable nitrate values were greater for both depths at Quartz Creek than for the same depths at Mack Creek, and the 0-15 cm depth at Quartz Creek was coarser than the same depth at Mack Creek.

A brief interpretation of the values found at Quartz Creek might be that the relatively recent tractor-logging, wildfire, and (possibly) broadcast burning at Quartz Creek may have contributed to the loss of fine soil particles in the upper soil profile, to a decrease in carbon and nitrogen in the lower soil depths, and to a decrease in phosphorus content at both depths.

II. Comparison with Similar Sites

In order to evaluate the reasonableness of the average site values, the relevant literature was searched for sites similar in location, vegetation, and climate to the study sites (Table 3-2). Soil chemical and physical properties from these sites were then compared to values for Mack and Quartz Creeks (Table 3-3). Seven similar old-growth sites were found, all of which were on the H.J.

Table 3-2 -- Location, vegetation, climate and soils of sites similar to the study sites at Mack and Quartz Creeks. Information in parentheses is inferred from elsewhere in the table.

Site #	Location	Vegetation Type	Stand Age (yr)	Elev-ation (m)	Mean Annual Precipi-tation (cm)	Mean Annual Temper-ature (^{o}C)	Soil Type	Reference
1	H.J. Andrews Experimental Forest, McRae Creek, Blue River, Oregon	Conifer	350-550	850	215	8	Andic Haplumbrept	Sollins et al. (1984)
2	H.J. Andrews Exp. For., Reference stand #2	_Tsuga heterophylla_	> 300	490	mesic/warm		Typic Dystrochrept	McKnabb et al. (1986)
3	H.J. Andrews Exp. For., Reference stand #7	_T. heterophylla_	> 300	460	moist/warm		Dystric Eutrochrept	" " " "
4	H.J. Andrews Exp. For., Reference stand #2	_T. heterophylla_	(> 300)	480-500	(mesic/warm)		Typic Dystrochrept	Brown & Parsons (1973)
5	H.J. Andrews Exp. For., Reference stand #7	_T. heterophylla_	(> 300)	450-470	(moist/warm)		Dystric Eutrochrept	" " "
6	H.J. Andrews Exp. For., Reference stand #9	_T. heterophylla_	450	435-465	240	8	Typic Dystrochrept	" " "
7	H.J. Andrews Exp. For., Reference stand #15	_T. heterophylla_	450	680-720	mesic/warm		Typic Dystrochrept	" " "

Table 3-2 (continued)

Site #	Location	Vegetation Type	Stand Age (yr)	Elevation (m)	Mean Annual Precipitation (cm)	Mean Annual Temperature (°C)	Soil Type	Reference
8	H.J. Andrews Exp. For., Lookout Creek, Alluvial floodplain	Conifer	-	440	mesic	-	Fluventic Hapludoll	Brown (1975)
9	H.J. Andrews Exp. For., Lookout Creek, Fluvial terrace	Conifer	-	450	mesic	-	Fluventic Dystrochrept	" "
10	H.J. Andrews Exp. For., Lookout Creek, Alluvial fan	Conifer	-	450	mesic	-	Fluventic Dystrochrept	" "
11	Cascade Head Exp. For., Widow Creek Otis, Oregon	*Alnus rubra*	30	275	240	10	Typic Dystrandept	Franklin et al. (1968)
12	Skykomish, Washington	*A. rubra*	23	35	120	mild	Dystric Xerochrept	Binkley (1983)
13	Mt. Benson, Nanaimo, British Columbia	*A. rubra*	23	510	200	cool	Typic Haplorthod	" "

Table 3-3 -- Properties[#] of fine (< 2 mm) whole soil at similar sites compared to the study sites. Standard errors in parentheses.

Site #	Vegetation Type	Sample Depth (cm)	n	pH	Total Carbon (%)	Total Nitrogen (%)	C:N ratio	CEC	Mineralized Ammonium (mg/kg)	Proportion of Nitrogen Mineralized (N_m/N_t)	Sand (%)	Silt (%)	Clay (%)
1	Conifer	0-15	14	-	4.3 (0.4)	0.16 (0.01)	26.0 (1.4)	-	26 (4)	1.54 (0.20)	-	-	-
2	TSHE	0-15	10	-	3.5	0.18	19.1	-	34.3	1.90*	-	-	-
3	TSHE	0-15	10	-	3.8	0.20	18.9	-	40.6	2.05*	-	-	-
4**	TSHE	0-15	1	5.45	4.7[1]	0.16	29.4*	22.5	-	-	29.7	47.3	23.0
		15-33	1	5.55	2.1[1]	0.10	21.0*	20.8	-	-	-	-	-
5**	TSHE	0-23	1	5.5	5.4[1]	0.20	27.0*	31.4	-	-	29.1	46.4	24.5
		23-32	1	5.6	2.9[1]	0.11	26.4*	27.1	-	-	-	-	-
6**	TSHE	0-18	1	5.25	9.7[1]	0.17	57.1*	27.6	-	-	37.8	41.7	20.5
		18-41	1	5.4	3.2[1]	0.11	29.1*	20.4	-	-	33.5	42.2	24.3
7**	TSHE	0-21	1	5.65	9.9[1]	0.26	38.1*	21.7	-	-	43.9	45.6	10.5
		21-36	1	5.8	4.3[1]	0.29	14.8*	18.8	-	-	-	-	-
Mack Creek	PSME/TSHE	0-15	28	5.61 (0.08)	7.87 (0.52)	0.32 (0.02)	24.6 (0.7)	38.6 (1.8)	111.1 (7.5)	3.41 (0.17)	48.54 (2.27)	31.99 (1.61)	13.76 (1.19)
		15-30	28	5.92 (0.08)	4.74 (0.47)	0.21 (0.02)	22.2 (0.7)	-	56.9 (5.7)	2.64 (0.16)	-	-	-

Table 3-3 (continued)

Site #	Vegetation Type	Sample Depth (cm)	n	pH	Total Carbon (%)	Total Nitrogen (%)	C:N ratio	CEC	Mineralized Ammonium (mg/kg)	Proportion of Nitrogen Mineralized (N_m/N_t)	Sand (%)	Silt (%)	Clay (%)
8**	Conifer	0-16	1	5.4	7.0[1]	0.15	26	28.2	-	-	59.8	28.4	11.8
		16-39	1	5.4	2.5[1]	0.10	15	18.8	-	-	70.8	23.6	5.6
9**	Conifer	0-11	1	5.5	5.3[1]	0.16	19	23.2	-	-	62.6	31.4	6.0
		11-36	1	5.6	3.7[1]	0.13	17	21.2	-	-	72.9	23.8	3.3
10**	Conifer	0-19	1	5.4	5.0[1]	0.12	25	29.1	-	-	48.5	36.5	15.0
		19-46	1	5.2	2.9[1]	0.09	18	28.8	-	-	44.9	40.4	14.7
Quartz Creek	ALRU	0-15	30	5.51 (0.12)	7.76 (0.65)	0.30 (0.02)	25.7 (0.8)	29.93 (1.77)	69.6 (9.5)	2.70 (0.34)	-	-	-
		15-30	30	5.76 (0.10)	1.21 (0.02)	0.06 (0.03)	25.2 (1.1)	-	46.3 (6.4)	2.33 (0.29)	-	-	-
11***	ALRU	0-14	3	4.8	20.2[1]	0.60	20	50.4	-	-	-	-	-
12	ALRU	0-10	10	4.1	4.72[1]	0.29	16.3*	-	61	2.1*	-	-	-
		10-20	5	4.6	5.03[1]	0.25	20.1*	-	29	1.2*	-	-	-
		20-35	5	4.5	2.85[1]	0.16	17.8*	-	8	0.5*	-	-	-
13	ALRU	0-10	10	4.4	3.92[1]	0.19	20.6*	-	77	4.1*	-	-	-
		10-20	5	4.9	2.13[1]	0.11	19.4*	-	52	4.7*	-	-	-
		20-35	5	5.0	1.52[1]	0.08	19.0*	-	48	6.0*	-	-	-

identical or similar methods, except where noted.
* value calculated.
** sampled by soil profile. Where n > 1, mean values are given.
*** sampled by soil profile. Values weighted and calculated by profile depth.
1 Walkley-Black estimate of soil organic matter.

TSHE = <u>Tsuga heterophylla</u>
PSME = <u>Pseudotsuga menziesii</u>
ALRU = <u>Alnus rubra</u>

Andrews Experimental Forest and apparently in "upland" positions. Three alluvial sites were found, again on the H.J. Andrews at Lookout Creek (a fourth-order stream; Mack Creek flows into Lookout Creek). Only three alder sites were found, none of which were in the immediate vicinity. The soils of the "comparable" alder sites have formed from parent materials that are different from those of Quartz Creek.

Overall, values for properties at Mack and Quartz Creeks were very similar to those found by other workers at similar sites. At Mack Creek, values for total carbon and nitrogen, CEC, mineralized ammonium and proportion of nitrogen mineralized were somewhat higher than the values given for both the old-growth and alluvial sites. This is not surprising, since sampling at Mack Creek included toeslopes, soils that were likely to be rich in carbon and nitrogen relative to the upland or alluvial soils of the comparison sites. Quartz Creek values were very similar to the comparison sites, with the exception of pH which was slightly less acidic, perhaps reflecting differences in parent materials.

I concluded that the values for properties at Mack and Quartz Creeks found in this study were reasonable. In order to uncover information that might be obscured in the data because of an overly simplistic experimental design, I next used a multivariate approach to data evaluation and interpretation. This approach, and subsequent site-characterizations and interpretations are presented in the following chapters.

Chapter 4

SOIL VARIATION ALONG A GEOMORPHIC STABILITY GRADIENT: A MULTIVARIATE APPROACH TO RIPARIAN SITE DESCRIPTION

I. Introduction

Since the results of the site-to-site comparisons described in Chapter 3 yielded only minimal insight while raising many questions, I used statistical techniques to group similar observations. I hoped to find some inherent structure within the data that would reflect differences between soils developing on geomorphic surfaces of different parent material and frequency of disturbance.

I expected different geomorphic surfaces to differ in soil properties. Within each major surface type are subtypes that reflect the influences of parent material, time, degree of weathering and disturbance history. Aggrading surfaces include benches (with very long periods of formation), toeslopes (continuous deposition), and live fans (periodic deposition, sometimes intensely by debris flows). The upper surfaces of incised fans are of rather gentle slope and so are relatively stable over very long periods. Geomorphic surfaces experiencing substantial erosion include fanslopes (continuous erosion), floodplains (periodic erosional deposition), steep hillslopes (chronic, low-intensity erosion), and the main channel (frequent, intense events).

Since riparian zones include many types of surfaces, analysis of within- and between-observation interactions, among the variables measured, could both help to order these extremely heterogeneous systems and to suggest patterns within the landscape. In turn, order and pattern might provide the basis for interpreting soil physical and chemical characteristics, and hence differences in soil types and site productivity. Two descriptive techniques, principal component analysis and discriminant analysis, were used first. Both techniques help reduce the number of variables in a data set, as well as find linear combinations that identify groupings within the data that reflect relationships among variables.

Norris (1972) proposed that "all soil survey work is based on multivariate concepts since the surveyor recognizes the importance of the covariation of soil properties". Principal components analysis has been applied to a variety of soil studies. It has been used to characterize wetland soils across vegetation zones of different depth to water table (Richardson and Bigler, 1984), wetland paddy soils of southeast Asia (Kyuma & Kawaguchi, 1973), as an ordination method to explain soil variation (Norris, 1971; 1972), to investigate sequential variation in soil enzyme activity across a climosequence (Ross et al., 1975), and as an agglomerative numerical taxonomic method to describe local variation (Edmonds et al., 1985).

In the above studies, one objective was always to determine the similarity between individuals, and hence the difference among groups of individuals, an objective to which principal components analysis is well suited. Norris (1971) has noted that since soil properties do not vary independently, soil variation can be characterized by relatively few properties. Ross et al. (1975) found that while stepwise multiple regression did not yield interpretable results with regard to distribution patterns of soil enzyme activities, principal components analysis lent considerable insight, effectively and logically grouping a rather arbitrary set of enzyme and respiratory activities. The plane described by the first two principal components is the best two-dimensional summary of the n-dimensional space, and typically accounts for 50-60% of the variance within a data set (Norris, 1971).

Webster and Burrough (1974) suggested that "a classification that groups soil properties or sampling sites on measured properties relating to soil use as well as visible morphological properties is likely to have more practical value than one based on visible morphology alone." Williams (1983) further suggests that "when the structure of data is unknown at the time it is collected, exploratory methods are often both necessary and informative. In the absence of statistical reliability, any perceived patterns are at best suggestive, and should be regarded as preliminary." In keeping with these considerations, descriptive discriminant analysis was used in this study to explore data of unknown structure and to suggest a preliminary classification with some practical value.

Like principal components analysis, discriminant analysis has been used in the investigation of diverse studies regarding soils and geology/geomorphology. Webster and Burrough (1974) used the method to evaluate the effectiveness of soil classification by soil survey in Berkshire and Oxfordshire, England, while Henderson and Ragg (1980) used discriminant analysis to determine the discriminatory value of soil properties in gley soils of the Scottish lowlands and to separate soil taxonomic units. The method has also been used to evaluate the degree of pedogenesis of sandy, quartz-rich soils at a beach ridge and dune complex along Lake Michigan, to determine which are the pedogenic variables of best discriminatory value, and to classify sample locations into different radiocarbon age groups (Berg, 1980). Paton and Little (1974) used discriminant analysis to separate stratigraphic units of valley-fill materials in southeastern Queensland, Australia. Pavlik and Hole (1977) used the method to discriminate between two moraine surfaces in southeastern Wisconsin, while Crum and Rust (1986) used discriminant analysis to differentiate among island and non-island glacial drifts with regard to stratigraphy, properties of parent materials, and populations of parent materials.

Henderson and Ragg (1980) concluded that discriminant analysis separates soil taxonomic units relatively well. Webster and Burrough (1974) further noted that allocation of soil profiles to groups by discriminant analysis resulted in classification of soils to taxonomic units that was far better than classification by soil survey alone. Berg (1980) concluded that discriminant analysis effectively evaluated subtle differences in soil formation, and that morphological features do not adequately differentiate radiocarbon age groups because the rate of morphological change approaches zero as soils approach maturity.

The remainder of this chapter discusses the application of principal components and discriminant analysis to the data collected in this study. The data were normalized and standardized before performing either statistical technique.

II. Statistical Methods

A. Principal Component Analysis

Principal component analysis (PCA) is both a data reduction method and a method of transforming a set of variables into a new set of composite variables, or principal components, that are mutually orthogonal. The initial variable set should ideally contain variables that are known to differ among classes or types. The first principal component is the best summary of linear relationships within the data; subsequent components consist of the linear combinations of variables that account for the residual variance after the effect of previous components is removed from the data. In this study, principal components analysis (SAS Institute, 1985) was used to select the set of variables that most strongly contribute to structure within the data and to provide an initial picture of this structure.

Thirty-one independent (primary) variables (Table 4-1), which were known to be of importance in distinguishing among soils, were selected from the measured and calcu-

Table 4-1 -- List of primary variables used in principal components analysis for both sites. Values are for both the 0-15 cm and 15-30 cm depths, except where noted.

Total carbon
Total nitrogen (N_t)
Kjeldahl-phosphorus
C/N ratio
Cation exchange capacity (CEC)(0-15 cm depth only)
pH
Sodium fluoride (NaF) pH
KCl-extractable nitrate (NO_3^-)
Mineralized ammonium (NH_4^+)
Net mineralized ammonium + extractable nitrate (N_m)
Proportion of nitrogen mineralized (N_m/N_t)
Fine-earth fraction of the bulk soil
Coarse fragment fraction of the bulk soil
Slope
Geomorphic surface
Plant community
Sand content of the fine-earth*
Silt " " " " "
Clay " " " " "

* Mack Creek 0-15 cm depth only

lated variables (Table A-1). Variables for both the 0-15 and 15-30 cm depths were included so that each observation (sampling point) was oriented in eigenspace on the basis of the most important variables throughout the sampled portion of the soil profile. Successive PCA runs were conducted for each site, and variables with low coefficients removed until the ratio of observations to variables was $\geq$ 2:1.

For each site, all reasonable combinations of observations were grouped visually by proximity among observations and by apparent 'planar' orientation in the two-dimensional representation of eigenspace given by plotting principal component 1 against principal component 2.

B. Discriminant Analysis

Discriminant analysis (DA) distinguishes among two or more groups of observations by forming linear combinations (discriminant functions) of the variables that maximize the separation of the groups. Again, the variables used should measure characteristics by which the groups are expected to differ.

The validity of the groups that resulted from PCA was evaluated by stepwise discriminant analysis (BMDP, 1985), and the percent of observations correctly classified was assessed by a jackknife procedure. The jackknife procedure removes each observation from its group, one at a time, and evaluates whether the observation has been correctly classified. It does so by reclassifying the observation according to the remaining observations in each group. Pairs of variables with correlation coefficients of 0.80 or better were assumed to be collinear. Of these pairs, the variable with the least discriminating power was deleted, thus preventing statistical error associated with multicollinearity. The variables of all final DA runs met the statistical criterion of equality of variance.

The best DA runs were chosen on the basis of several criteria:

(1) percent correct jackknife classification,

(2) greatest numerical value of the eigenvalues of the discriminant functions (a measure of the relative importance of the discriminant function),

(3) value of Wilk's Lambda (a measure of among-group discrimination), and

(4) values of the canonical correlations of the discriminant functions (a measure of relatedness between the discriminant function and the group variable).

'Incorrectly classified' observations were checked against the raw data means of the stepwise variables for both the group into which PCA placed the observation and for the group into which DA suggested the observation should be placed. On the basis of these comparisons, no reallocations were justifiable. Because confidence in the integrity of a group increases with the number of observations included in that group, the small number of samples is as likely a cause of the error in classification as any other factor.

The vector of each attribute (stepwise discriminate variable) was plotted by calculating a set of coordinates based on the coefficients of the canonical variables and the univariate F-statistic of each variable selected in the final stepwise procedure (Dillon and Goldstein, 1984). Canonical discriminate analysis (SAS Institute, 1985) was used to generate these F-statistics.

C. Analysis of Variance

Analysis of variance (ANOVA) was performed on mean values for the groups distinguished by DA. Analysis of variance was asked to 'order' means, and the 'ranking' corresponding to mean total carbon was used retrospectively to order the groups defined by the multivariate statistics.

Since the comparisons were made on "unplanned" groups (i.e. groups that were not defined before the field work was conducted), an F-test could not be used to compare the means. Instead, unplanned (a posteriori) multiple comparisons were made. These tests are rather insensitive to differences between individual means or within small subsets. Thus they are conservative tests, designed to control bias due to experimental error and hence type I error.

Conservative tests were used to compare groups within and between sites so that subsequent interpretations could be made with confidence. Within a site, means were contrasted by the Scheffé method, which is the most powerful of the tests of unplanned contrasts among means which are designed to evaluate all possible contrasts. The Scheffé method is powerful when both the number of groups and the degrees of freedom of the standard deviation are small, and when most coefficients of linear comparison are non-zero. Between sites, soils on similar geomorphic surfaces were compared by the Tukey-Kramer method, which is the most powerful unplanned pairwise comparison when sample sizes are slightly unequal.

III. Results

A. Principal Components Analysis

For each site, principal components with both large eigenvalues ($\geq$ 1.00) and high percent explained variance, i.e. meaningful components, were retained (Table 4-2): there were three such components at Mack Creek and four at Quartz Creek. These components explained 81% of the within- and among-observation variance at Mack Creek, and 84% at Quartz Creek. The first two components (or axes) explained 62% and 63% of the variance at Mack and Quartz Creeks, respectively. These high proportions, and the very large eigenvalues for the first two principal components, indicated that the planes represented by these components described well the distribution of the sampling points relative to one another.

For each site, plots of the sampling points on the pair of axes principal component 1 vs. principal component 2 revealed three to four generally well separated groups (Figures 4-1 and 4-2). Of the Mack Creek groups, only the sampling points in group 1 corresponded closely with the alluvial soil stratum in the initial sampling scheme. The sampling points in group 2 represented soils developed on hillslope colluvium on one side of the stream, derived from an old debris flow. The geomorphic surfaces

Table 4-2 -- Results and summary statistics of principal components analysis.

Site	Principal Component #	Eigenvalue	Percent Explained Variance	
			Proportion	Cumulative
Mack Creek				
	1	4.87	0.37	0.37
	2	3.19	0.25	0.62
	3	2.42	0.19	0.81
Quartz Creek				
	1	4.79	0.32	0.32
	2	4.65	0.31	0.63
	3	2.10	0.14	0.77
	4	1.04	0.07	0.84

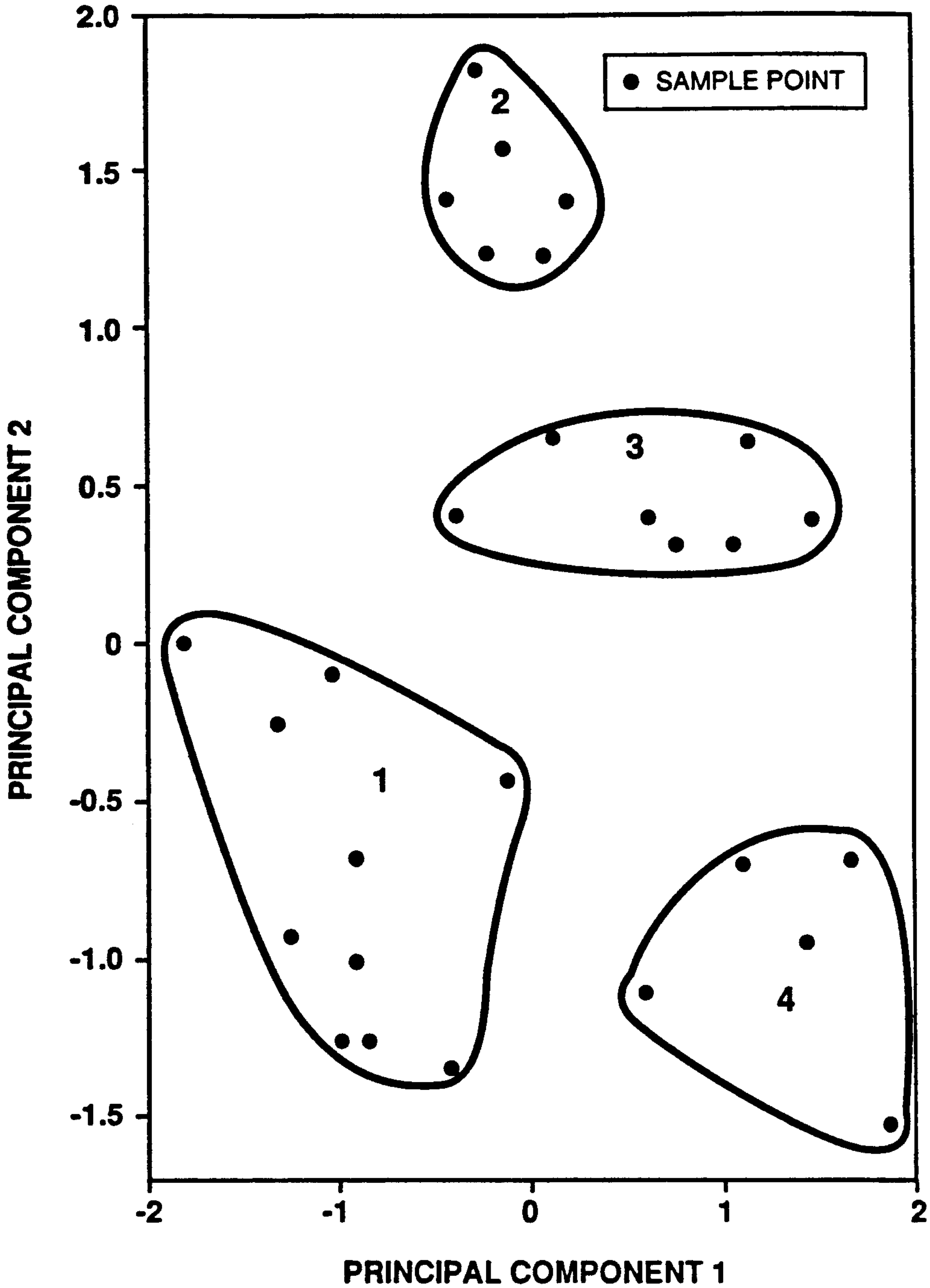


Figure 4-1. Mack Creek observations plotted on the first two principal components and grouped according to apparent planar orientation.

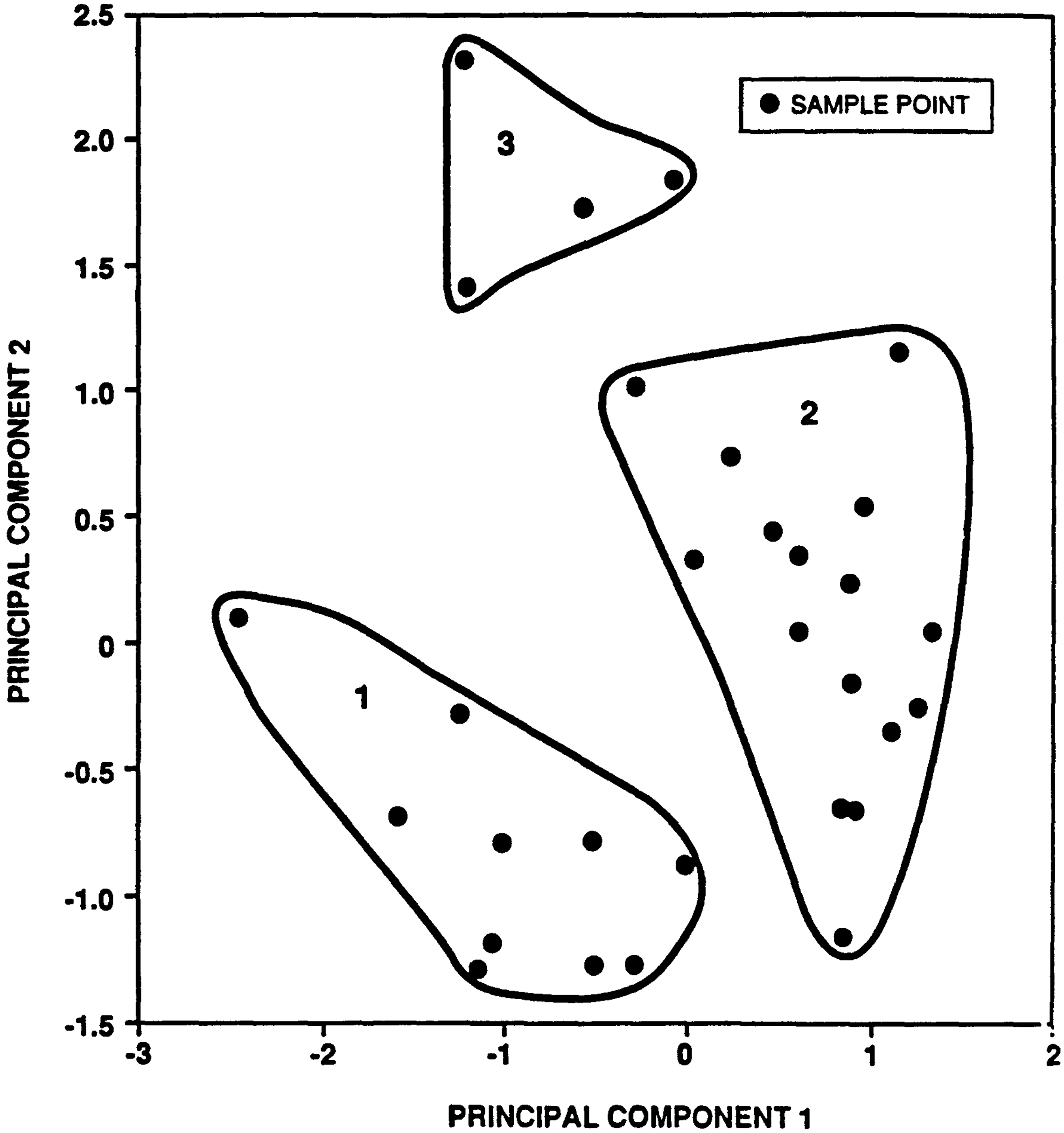


Figure 4-2. Quartz Creek observations plotted on the first two principal components and grouped according to apparent planar orientation.

associated with the sampling points in the remaining two groups bore little similarity to those of the original sampling strata.

At Mack Creek, 10 of the sampling points in group 1 fell within main-channel and floodplain alluvium, and one was on a hillslope. Five plant communities occurred on these geomorphic surfaces. Five of six sampling points in group 2 were on upper and mid colluvial fans, and one was on a hillslope. The _Vaccinium alaskaense/V. parvifolium_ plant community dominated on four of these surfaces. Group 3 includes sampling points on hillslopes, toeslopes, colluvial fan slope-bottoms and upland slumps; four were occupied by the _Polystichum munitum/Blechnum spicant_ plant community. Finally, three of the five sampling points in group 4 were on colluvial fan slope-bottoms, one was on a toeslope, and one was on a floodplain debris-flow deposit (unusually nutrient-rich alluvium). Four plant communities were found on these surfaces. It may be that, because of differences in the extent of erosion, hillslope soils share attributes with alluvium, colluvial fans, or other geomorphic surfaces.

As at Mack Creek, only the alluvial sampling points at Quartz Creek tended to group together into a class similar to one used in the original sampling scheme. Sixty percent of these main channel and floodplain surfaces were occupied by the invasive small herb plant community. The sampling points in group 2 represented a mixture of upper-, mid- and lower-slope alluvial and colluvial fans, 63% of which were occupied by the *P. munitum/B. spicant* plant community. The upper colluvial fan sampling points of group 3 occurred entirely on one side of the stream, as did the colluvial-fan/debris-flow sampling points of group 4 at Mack Creek. Group 3 was occupied by *P. munitum/B. spicant*. (Only one upper colluvial fan sampling point was not found in group 3, and DA suggested that it should be reclassified from group 2 to group 3.) Thus, at both sites there was evidence that soils developing upon similar geomorphic surfaces grouped together.

The coefficients of the retained principal components are given in Table 4-3. Where appropriate, variables for each PCA run were grouped by the soil depth interval with which they were associated. In this way, components that are a function of a process occurring over one depth interval only could be seen relative to components that represent a process occurring throughout the profile.

Variables that strongly influence the eigenvector of a given principal component have coefficients with large absolute values. The sign of the coefficient indicates the direction (slope) of the individual variable with regard to the overall component (eigenvector). The

Table 4-3 -- Coefficients of normalized PCA variables. Coefficients used for interpretation of components are indicated by an asterisk (*).

Site/Variables	Component # 1	2	3	4
MACK CREEK				
0-15 cm depth				
Mineralized NH_4^+	0.62	-0.45	0.46	
Total carbon	0.81 *	-0.11	0.29	
NaF pH	0.19	0.80 *	-0.37	
Coarse fragments#	-0.66	0.22	0.61 *	
Sand content@	0.07	-0.71 *	-0.66 *	
Silt content@	-0.17	0.27	0.84 *	
Clay content@	-0.21	0.87 *	0.15	
15-30 cm depth				
Mineralized NH_4^+	0.74 *	-0.31	0.45	
Total carbon	0.87 *	-0.10	0.29	
NaF pH	0.53	0.70 *	-0.18	
Fine-earth#	0.82 *	0.08	-0.32	
Geomorphic surface	0.83 *	0.23	0.07	
Plant community	0.57	0.56	-0.19	
QUARTZ CREEK				
0-15 cm depth				
Mineralized NH_4^+	-0.37	0.52	0.48	0.29
Total carbon	-0.01	0.90 *	-0.21	0.08
CEC	0.38	0.86 *	-0.09	0.10
Kjeldahl-phosphorus	0.47	0.41	0.58	0.22
pH	-0.50	-0.79 *	0.13	0.17
NaF pH	0.56	-0.24	0.45	0.33
Fine-earth#	0.55	-0.61	-0.26	0.44 *
Coarse fragments#	-0.51	0.69	0.16	-0.42 *
15-30 cm depth				
Mineralized NH_4^+	-0.69 *	0.28	0.31	0.42 *
Total carbon	0.44	-0.36	0.64 *	-0.39 *
pH	-0.66	-0.60	0.28	0.00
NaF pH	0.49	0.05	0.73 *	-0.16
Fine-earth#	0.89 *	-0.13	-0.14	-0.04
Coarse fragments#	-0.81 *	0.31	0.11	0.11
Geomorphic surface	0.61	0.67	-0.09	0.13

\# percent of the bulk soil.
@ percent of the fine-earth.

processes described by the eigenvector of a principal component can sometimes be inferred from careful evaluation of the variables with large coefficients. The processes can be identified with greater confidence if the coefficients of all the variables used in interpretation are of high absolute value. Further, a variable is more strongly implicated if the coefficients of that variable are large for only one component, or, in the case where the coefficients of a variable are large for two components, the coefficients are of opposite sign. For most of the components, the most important variables were all from the same soil depth.

Most of the principal components described lent themselves to plausible interpretations (Tables 4-2 and 4-3). When selecting variables for interpretation, the relatedness of the variables to one another is an important consideration. All variables with coefficients larger than 0.70 (absolute value) were used for interpretation. If fewer than three variables resulted from this selection, the cutoff point was lowered until three or more meaningfully related variables were selected. The next most important variable was (generally) less significant by a value of 0.08 to 0.10. Because relatedness among variables was not clear for some components, some interpretations were unclear. In all cases the coefficients identified met the necessary conditions for strong implication of processes.

For components 1 and 2 at each site, the variables with coefficients of large absolute value were reviewed for relevance to interpretation of the component. The raw data for sampling points at the extremes and mid-points of both axes were reviewed in order to verify that the sign of a coefficient corresponded with the distribution of real data. In this way, the validity of the sign of individual variables was checked, assuring correct use of each variable in interpretation of the component. Because the data were not plotted on the axes for components 3 and 4, the raw data were not evaluated for these components. However, since these components accounted for considerably less variance in the data, and since any interpretation of components other than components 1 and 2 was restricted to fewer possibilities (since components are orthogonal and interpretations had already been made for components 1 and 2), I felt reasonably confident in my interpretations of components 3 and 4.

Proposed interpretations of the components are listed below:

Mack Creek:

Component 1 -- Soil development (indicated by carbon content, fine earth content, and mineralized ammonium) throughout the profile, especially at 15-30 cm depth, and geomorphic surface. Strongly implicated.

Component 2 -- Amorphous aluminum (indicated by NaF pH) throughout the profile, especially at 0-15 cm depth, and clay content at 0-15 cm depth. Strongly implicated.

Component 3 -- No clear interpretation.

Quartz Creek:

Component 1 -- The negative effect of fine earth particle content on nitrogen mineralization at 15-30 cm depth (perhaps caused by reduced aeration associated with silt and clay particles), and the positive effect of coarse fragments. Strongly implicated.

Component 2 -- Carbon content and CEC at 0-15 cm depth. Strongly implicated.

Component 3 -- Amorphous aluminum (indicated by NaF pH) and carbon content at 15-30 cm depth. Moderately implicated.

Component 4 -- No clear interpretation.

Geomorphic surface and/or plant community appeared to be at least secondary factors in the first two components at both sites.

B. Discriminant Analysis

The validity of the groups revealed by PCA was evaluated by stepwise DA. I propose that these groups represent soil types. A danger of a small data set is that weak statistical differentiation among observations may result in imprecise groupings. Although this might have been expected with these data, particularly in view of the small number of observations in some of the proposed soil types, the results of DA strongly indicated that the soil types were different (Table 4-4). Despite the small number of observations, the jackknife procedure verified that sampling points were correctly placed in the groups proposed by PCA, 100% of the time at Mack Creek and 96.7% of the time at Quartz Creek. The large eigenvalues for the first two canonical variables at each site indicated that 98.2% of the separation among sampling points was explained at Mack Creek, and that 100% of the separation was accounted for at Quartz Creek. Further, the very small values for Wilk's Lambda, a measure of among-group

Table 4-4 -- Results and summary statistics of stepwise discriminant analysis. Data standardized and normalized.

Site	Stepwise discriminant analysis variables	% Correct classification[1]	Final Wilk's Lambda	Eigenvalue of the canonical variable[2]	Cumulative proportion of total dispersion[3]	Canonical correlation	Coefficients for canonical variables 1	Coefficients for canonical variables 2	Approximate F-statistic
Mack Creek									
	15-30 cm depth NaF pH	100.0	0.006	12.28	59.6 %	0.96	1.22	-1.19	22.2
	" " " min. NH_4^+			7.95	98.2 %	0.94	0.54	-1.05	21.2
	" " " fine-earth#			-[4]	-	-	1.50	-0.99	18.4
	0-15 cm depth NaF pH			-	-	-	0.33	1.85	17.4
	" " " clay content@			-	-	-	1.80	0.87	17.3
Quartz Creek									
	Geomorphic surface	96.7	0.019	13.62	84.3 %	0.97	1.46	-0.95	60.7
	0-15 cm depth NaF pH			2.54	100.0 %	0.85	1.66	-0.40	32.2
	" " " CEC			-	-	-	0.36	1.71	30.2
	15-30 cm depth min. NH_4^+			-	-	-	-0.45	0.90	30.7
	0-15 cm depth pH			-	-	-	-1.29	-0.35	28.5

\# Percent of the bulk soil. @ Percent of the fine-earth.

1 Correctly classified, jackknife proportion.

2 Characteristic root (a measure of variance) of the discriminate axis ($lambda_i \geq 1$).

3 Proportion of the canonical factor; $\simeq$ proportion of separation among observations due to the associated canonical variable.

4 Variable of discriminatory value, but with an eigenvalue that is numerically too small to report.

discrimination, indicated that the group centroids, hence proposed soil types, were distinctly different.

Discriminant analysis selected eight of the thirty-one PCA variables as the primary soil characteristics that differentiated among groups (Table 4-4). Of the variables selected, several appeared to help distinguish most among the grouped sampling points. At each site, two variables accounted for from 98% to 100% of the separation among the groups identified by PCA: NaF pH and mineralized ammonium at 15-30 cm depth at Mack Creek, and both geomorphic surface and NaF pH at 0-15 cm depth at Quartz Creek. Notably, both 0-15-cm-depth NaF pH and 15-30-cm-depth mineralized ammonium distinguished among groups at both sites. Other important variables were 0-15-cm-depth CEC, clay content of the fine earth fraction, and pH, 15-30-cm-depth NaF pH and fine earth fraction of the bulk soil, and geomorphic surface.

The orientation of the soil types in discriminant space is shown with the vectors of the discriminate variables (Figures 4-3 and 4-4). The univariate F-statistic used in calculating these vectors is a weighting factor that determines the length of the vector. The length of each vector indicates the relative importance of the variable in discriminating among groups. Vectors that pass through the center of a group identify the variables

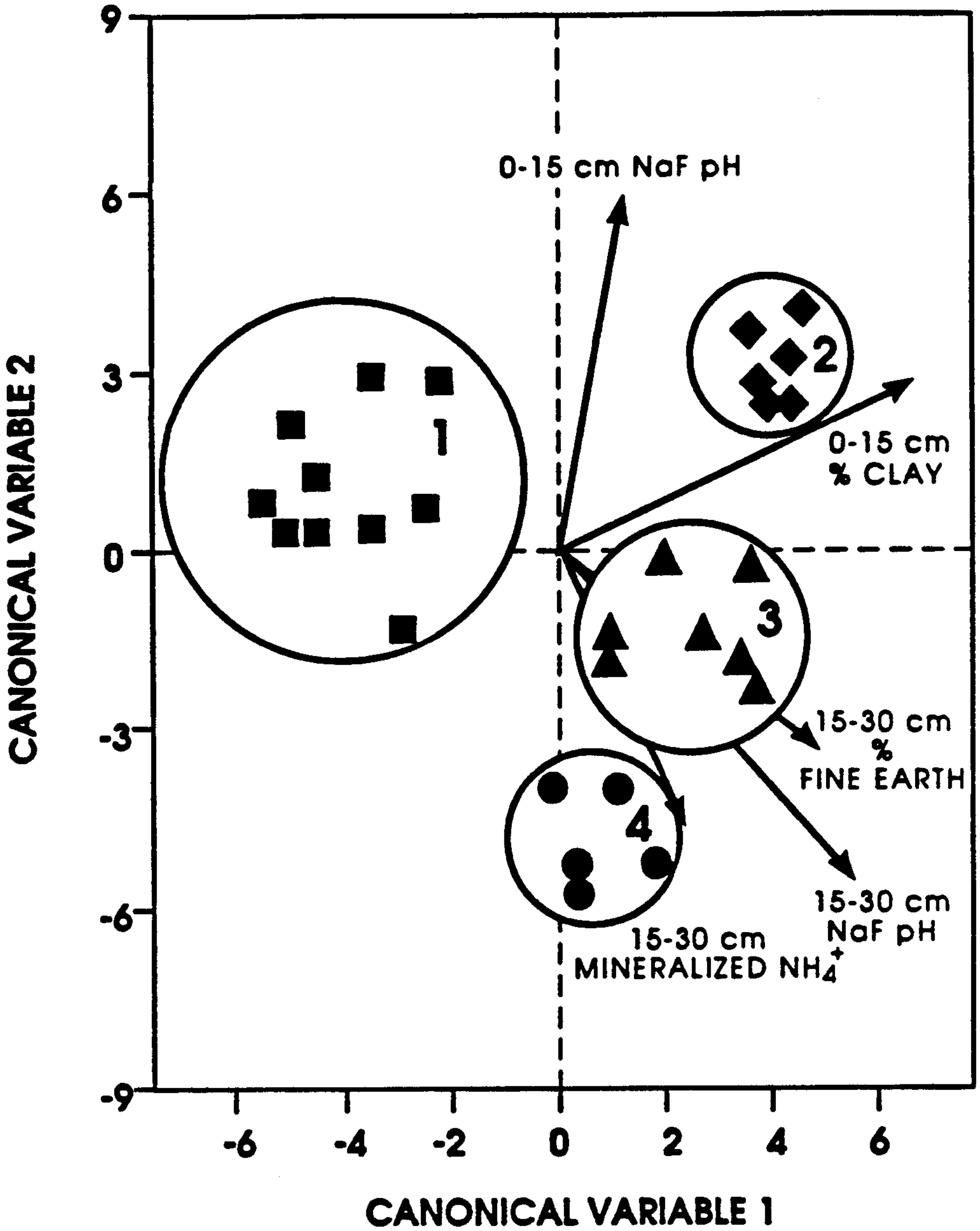


Figure 4-3. Proposed soil types at Mack Creek plotted in relation to the first two discriminant axes, and vectors of the discriminating variables. Circles indicate 95% confidence limits. Vector lengths have been reduced by a factor of five for pictorial representation.

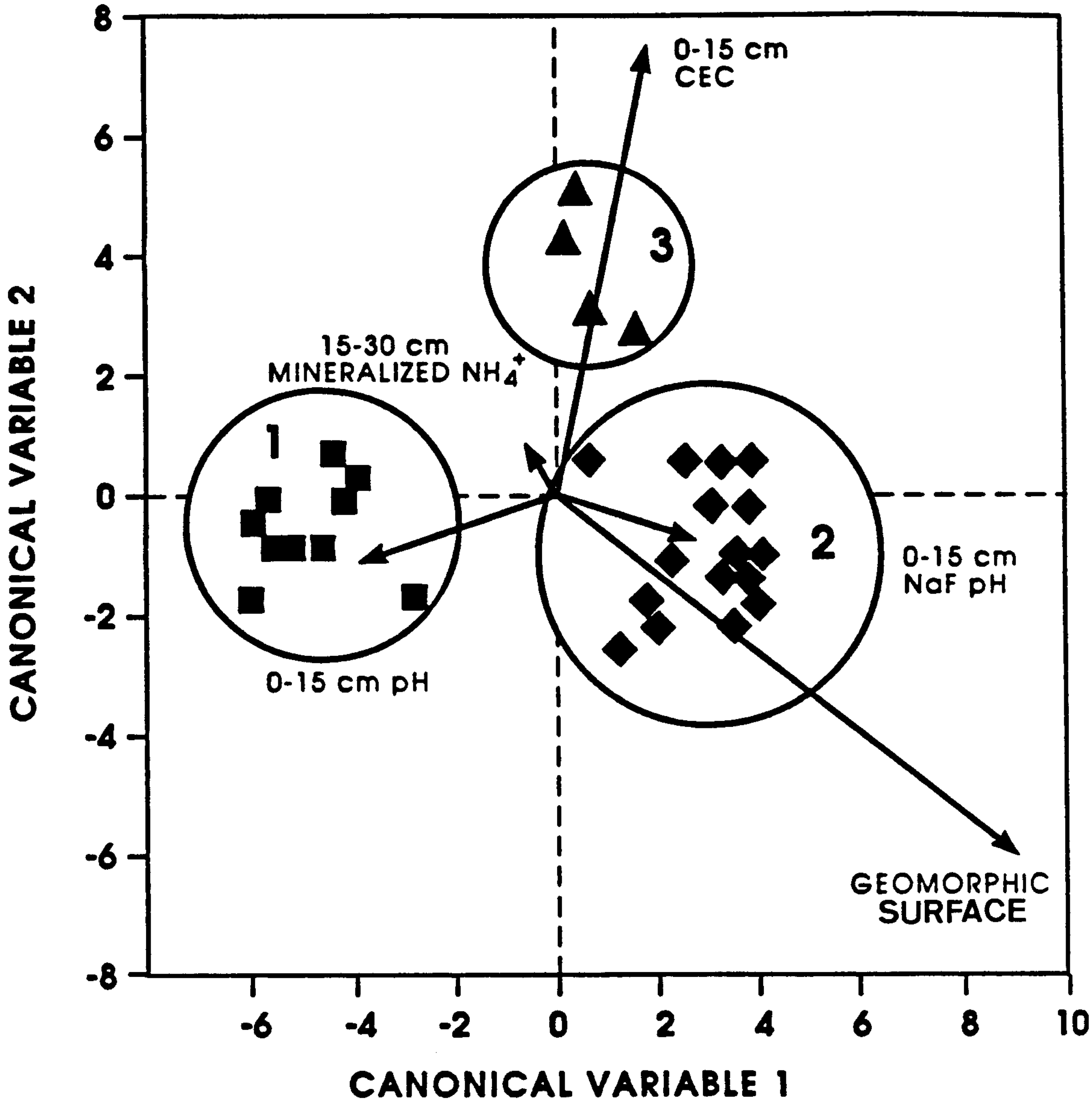


Figure 4-4. Proposed soil types at Quartz Creek plotted in relation to the first two discriminant axes, and vectors of the discriminating variables. Circles indicate 95% confidence limits. Vector lengths have been reduced by a factor of ten for pictorial representation.

that are most important in separating that group from other groups. Vectors passing near a group provide information of lesser importance in separating two adjacent groups. Vectors that radiate from the origin in the opposite direction from a group indicate variables that are strongly separating other groups from the first.

Vectors of the attributes can be used to identify the variables that best distinguish among soil types (Dillon and Goldstein, 1984). At Mack Creek, amorphous aluminum content (as indicated by NaF pH) at 0-15- and 15-30-cm-depths and clay content of the fine earth fraction at 0-15-cm-depth were similar in their discriminating value, as were 15-30-cm-depth mineralized ammonium and fine earth. The former set of variables discriminated better than the latter. Soil types 2, 3, and 4 were separated from soil type 1 because of amorphous aluminum (indicated by NaF pH), types 3 and 4 were separated from type 2 because of quantities of ammonium mineralized in the 15-30 cm samples, and so on.

At Quartz Creek, the influence of individual variables was even clearer. The importance of the differentiating variables, from most to least, was: geomorphic surface, CEC at 0-15-cm-depth, 0-15-cm-depth pH, amorphous aluminum (as indicated by NaF pH) at 0-15-cm-depth, and 15-30-cm-depth mineralized ammonium. Geomorphic surface was quite clearly the most important differentiating variable at this site, as demonstrated by both the length of the vector and the proportion of the separation among observations for which it accounted. Geomorphic surface strongly separated soil type 2 from types 1 and 3, while 0-15-cm-depth pH and CEC differentiated between soil types 1 and 3.

C. Analysis of Variance

Analysis of variance was used first to rank the soil types proposed by PCA and evaluated by DA. Carbon was chosen as the ranking variable because of the well-known relationships between soil carbon and other soil characteristics, thus providing a conceptual framework when interpreting results. Further, carbon content was expected to be lower in soils on "relatively unstable" geomorphic surfaces influenced by fluvial activity, erosion, or other processes that remove organic matter and fine mineral particles, and to have accumulated in soils on "stable" geomorphic surfaces. Thus, the final soil type designation corresponded with increasing mean total carbon, i.e. soil type 1 had the lowest carbon content, and type 4 the highest.

Analysis of variance was used subsequently to compare means among soil types at each site, and also to compare soils of similar geomorphic surfaces between the two sites. Between sites, only the alluvial soils could be validly compared since the majority of sampling points in group 1 from each site were on alluvial surfaces. All other groups were mixtures of sampling points from several geomorphic surfaces, or were composed of sampling points from geomorphic surfaces that were not comparable. The results of these comparisons are discussed in Chapter 5.

IV. Discussion

A. Spatial Statistics

Together, the first two principal components explained 62 and 63% of the variance in the data at Mack and Quartz Creek. In a study of eleven beechwoods and one farmland in Gloucestershire, Norris (1972) found the first two principal components explained 53% of the variance in an analysis of 85 variables from 410 soil profiles that had been weighted toward the surface horizons in which the rate of change was expected to be the greatest. Richardson and Bigler (1984) found that the first two principal components explained 64% of the variance in wetland prairie potholes of North Dakota, while Ross et al. (1975) found 80% of the variance in tussock grasslands to be explained by the first two principal components.

The variance explained at both Mack Creek and Quartz Creek appears to be in line with that found by other investigators.

Edmonds et al. (1985) found that variables commonly used to describe soil profiles yield PCA coefficient loadings within components that are so low in value that it is not possible to distinguish the variables of importance. Norris (1971), however, determined that percent clay, total cations and field texture of surface soils are very good classification variables. Norris (1972) suggested that the first two principal components represent soil development/parent material and plant community. In their studies of two different wetland soil systems, both Richardson and Bigler (1984) and Kyuma and Kawaguchi (1973) found the first three principal components to be related to mobile cation distribution, organic matter distribution, and sedimentation (particle-size distribution). Both investigators found electrical conductivity, Mg^{2+}, and Na^{+} to be the most important variables contributing to the first principal component, and thus the variables explaining observable differences in wetland soils. Richardson and Bigler (1984) concluded that the variables most useful in characterization of wetland soils were electrical conductivity, soil organic carbon, calcium carbonate equivalent, and clay content.

The assumption that the groups suggested by PCA in this study are different is supported by the very high proportion of correctly classified observations (100% at Mack Creek, and 96.7% at Quartz Creek) when these groups were evaluated by DA. These proportions are somewhat higher than those reported by Crum and Rust (1986) who found that discriminant analysis correctly classified observations 88-96% of the time into previously determined classes based on field morphology.

My intent was to identify patterns and structural features within the data in order to narrow the focus and to point to profitable areas for further study. I propose that the final classification suggested by DA represents distinguishable soil types within a site.

Considerable internal structure within the data is to be expected at Mack Creek, the old-growth site, because of the very long time since catastrophic disturbance and the geomorphic complexity of the site, and consequent differences in soil development. The extent of horizonation, particularly of the A-horizons, which commonly reached to depths of 30-36 cm, was evidence of in-place soil development.

The vectors derived from DA suggested that amorphous aluminum (indicated by NaF pH) and clay content of the soils were the dominant variables distinguishing among soil types at Mack Creek. Sodium fluoride pH was notably uncorrelated with total carbon at either depth at this site. However, this may be due to the ubiquitous and variable presence of charcoal in these samples. Thus, variables associated with soil weathering may be the important ones contributing to the observed structure within the data at Mack Creek.

The degree to which sampling points could be grouped at Quartz Creek was surprisingly high. I expected this site to be relatively homogeneous because of soil mixing and compaction during the recent logging. Quartz Creek is a fan-dominated valley floor with <u>Alnus</u> <u>rubra</u> as the dominant overstory species. While the variable origins and ages of the fans should lead to stratification among soils, the ubiquity of the red alder should exert a homogenizing influence on certain soil properties. Discriminant analysis suggested that a class of phenomena different from those at Mack Creek contributed to the data structure at Quartz Creek. At Quartz Creek, soil types separated strongly on the basis of either geomorphic surface (soil type 2), CEC (soil type 3), or pH of the 0-15 cm depth (soil type 1). Thus, differences in soil chemistry (particularly organic matter and microbial processes associated with N-mineralization at this site) and geomorphology seemed to be the important variables at Quartz Creek.

The very high proportion of total dispersion among observations explained, in this study, by the first two canonical variables (98.2 and 100%) is somewhat higher than that noted by other workers. Paton and Little (1974) found that the first two canonical variables explained 88% of the dispersion among soils developed on valley-fill materials. The variables of greatest importance were Mg, K, Fe, and Zr, while variables of secondary importance were Ti, Al, P, Mn, Zn, Na, Sr, Cop, Pb, coarse-sand, CEC, and K-content of clay. Berg (1980) found that the first two canonical variables, thickness of the A1 horizon and clay content in the B horizon, explained 92.3% of the dispersion among observations.

In other studies, Henderson and Ragg (1980) found the soil properties of best discriminating value to be depth to gleying and secondary lithology, while matrix value, texture, and prismatic structure were of secondary value. Henderson and Ragg further found that depth to significant gleying, matrix chroma of the B horizon, and organic matter content and color of the A horizon characterized differences in drainage among soils. Soils with similar drainage characteristics could be further differentiated by texture, structure, ped face chroma in the B horizon, and secondary lithology. Berg (1980) found soil properties related to landforms to be blocky structure, thickness and clay content in the B2 horizon, thickness and organic matter content in the A1 horizon, soil color in the A1 and A2 horizons, depth to bedrock, depth to mottling zone, and ratio of clay in the A1 and B2 horizons. Crum and Rust (1986) found silt and coarse fragment contents to be useful properties for distinguishing between soils derived from glacial drift materials. In another study of glacial materials, Barnhardt (1979) found clay in the A horizon and thickness of solum to be the most powerful variables discriminating among moraines of different ages.

Paton and Little (1974) found that particle sizes, and their associated minerals, discriminated among valley-fill materials better than did soil morphology. They found that clay maxima were explained by depositional cycles, and that minerals associated with clay were Ti, Mg and Al. The further found that minerals associated with silt were Fe, Zn, Mn, and Ni. Phosphorus behaved variably, associating with clay in two of the taxonomic units and with fine sand in another two units.

B. Relationships Between Soils, Geomorphic Surfaces and Plant Communities

In this study, sampling points with higher carbon contents corresponded roughly with the older and/or aggrading geomorphic surfaces at both sites. At Mack Creek, the trend toward more carbon-rich points proceeded from alluvium, to upper and mid colluvial fans, to sampling points from several hillslope surfaces, to fan slope-bottoms/toeslopes. This sequence corresponded roughly with expected geomorphic stability:

* at one end of the continuum were the annually disturbed, fluvially influenced surfaces (alluvium);

* at the other end of the continuum were the rarely disturbed surfaces at the base of hill- and fan-slopes which are areas of deposition well away from fluvial activity;

* intermediate to these surfaces were fans and hill-slopes. Sampling points on middle and upper colluvial fans may have been influenced more strongly by erosion than sampling points on hillslopes. However, at the present level of sampling and evaluation, these distinctions were unclear.

At Quartz Creek, carbon content increased from alluvium to mixed alluvial and colluvial fans to upper colluvial fans. The flatness of the upper colluvial fans, and the parent material from which these fans are derived, may account for the apparent abundance of organic matter in these soils.

Soil spatial variability at the two sites reflects their different histories. Mack Creek has experienced more than 500 years of erosion, deposition, pedogenesis and biomass accumulation since the last major disturbance, a large wildfire, and subsequent establishment of the current stand. Considerable microsite variation in organic matter accumulation is a likely result. Conversely, the recent logging at Quartz Creek probably mixed and compacted the soil, resulting in homogeneous soil conditions, a homogeneity that may have been augmented by the uniformity of the overstory species. At Quartz Creek, 50% of the understory is dominated by the secondary successional P. munitum/B. spicant community (Table 4-5). It was therefore not surprising to find fewer plant communities occurring on a similar number of geomorphic surfaces at Quartz Creek than at Mack Creek (i.e. greater plant community/geomorphic surface homogeneity at Quartz Creek).

Plant species distribution within riparian zones has been related to elevation above the stream (Nixon et al., 1977; Wharton et al., 1982; and Hupp, 1982, 1983). However, Harris (1986) found floodplain elevation to be only a gross indicator of species distribution.

Table 4-5 -- Correspondence between plant community and geomorphic surface.

		Proportion of Sampling Points (%)					
		Geomorphic Surface					
Site	Plant Community	1	2	3	4	5	6
Mack Creek	HERB (11)	MCGB (7)	FLGB (4)	-	-	-	-
	RUSP (14)	FLGB (11)	FLDF (4)	-	-	-	-
	OPHO (11)	MCGB (4)	TOES (4)	CFBS (4)	-	-	-
	POMU (21)	HILL (11)	TOES (7)	UPSL (4)	-	-	-
	FERN (4)	FLDF (4)	-	-	-	-	-
	ACCI (7)	FLDF (4)	CFMS (4)	-	-	-	-
	VAAL (32)	CFBS (14)	CFUS (8)	CFMS (8)	HILL (4)	-	-
Quartz Creek	HERB (20)	MCAL (13)	MCGB (7)	-	-	-	-
	TOME (7)	FLDF (7)	-	-	-	-	-
	RUSP (3)	FLDF (3)	-	-	-	-	-
	POMU (50)	CFUS (17)	AFBS (10)	CFBS (7)	AFUS (7)	AFMS (3)	MCAL (3)
	ACCI (17)	AFUS (7)	AFMS (7)	CFBS (3)	-	-	-
	VAAL (3)	CFBS (3)	-	-	-	-	-

KEY:

MCAL	Main-channel alluvium
MCGB	Main-channel gravel bar
FLGB	Floodplain gravel bar
FLDF	Floodplain debris flow
AFUS	Alluvial fan, upper slope
AFMS	Alluvial fan, mid-slope
AFBS	Alluvial fan, bottom slope
CFUS	Colluvial fan, upper slope
CFMS	Colluvial fan, mid-slope
CFBS	Colluvial fan, bottom slope
HILL	Hillslope
UPSL	Upland slump
TOES	Toeslope
HERB	Invasive small herb
TOME	Pioneer *Tolmeia menziesii*
RUSP	*Rubus spectabilis*/*Ribes bracteosum*
OPHO	*Oplopanax horridum*
POMU	*Polystichum munitum*/*Blechnum spicant*
FERN	Mixed-fern, large herb
ACCI	*Acer circinatum*
VAAL	*Vaccinium alaskaense*/*Vaccinium parvifolium*

Effects of flooding on riparian forest species distribution has been noted (Johnson et al., 1976; Teversham and Slaymaker, 1976; and Hupp, 1982). While certain riparian vegetation types may persist as "non-equilibrium" systems (White, 1979; Pickett, 1980) because of periodic flooding, other riparian vegetation types may be well adjusted to or maintained by flooding (Hupp, 1983). Relationships between frequency and intensity of stream inundation, geomorphic surface and vegetation distribution have also been observed (Yanosky, 1982; Hupp, 1983). Simon and Hupp (1987) found that peak rates of channel widening were strongly associated with sparsely vegetated surfaces, and that the oldest plants were found in the upper-most stream reaches where banks had been stripped of vegetation for some time.

Osterkamp and Hupp (1984) found that riparian geomorphic surfaces supported characteristic woody plant species, some of which were nearly surface-specific in distribution. Using binary discriminant analysis, they noted that geomorphic surface correlated more strongly with species distribution than did silt + clay content of the sediment.

Hupp and Osterkamp (1985) found fluvial landform to be more significantly correlated with riparian forest species distribution than was sediment size, and that, along high-energy streams, depth to saturated zone was secondary to fluvial landform in determining species distribution. While some species were surface-specific in distribution, others did not discriminate between two adjacent surfaces, even though both were absent from a third. They noted that inundation frequency and species susceptibility to flood damage varied with fluvial landform, and suggested that plant species distribution was influenced by differences in hydrogeomorphic processes acting on the various landforms. They concluded that distribution patterns of woody vegetation on observable fluvial landforms may be useful in the identification of particular hydrogeomorphic conditions. Similarly, Simon and Hupp (1987), using detrended correspondence analysis, observed that riparian plant species had distinct site preferences. They concluded that patterns of species distribution may be used to infer stream bank stability.

At both Mack and Quartz Creeks, several plant communities were clearly associated with specific geomorphic surfaces (Table 4-5). At Mack Creek, the invasive small herb, Rubus spectabilis/Ribes bracteosum, and mixed-fern/large herb plant communities were found only at alluvial sampling points. The P. munitum/B. spicant plant community was associated with slopes, slumps, and toeslopes of hillslopes, and the V. alaskaense/V. parvifolium community occurred primarily on colluvial fans. As expected, *Oplopanax horridum* occurred only on surfaces with high water tables, on the bottoms of fans and hillslopes and on main-channel alluvium. At Quartz Creek, the invasive small herb, *Tolmeia menziesii*, and *R. spectabilis*/*R. bracteosum* plant communities occurred only on alluvium, whereas the *Acer circinatum* and *V. alaskaense*/*V. parvifolium* communities preferred alluvial and colluvial fans, respectively. *P. munitum* showed no pattern with regard to geomorphic surfaces at this site. In general, these patterns are in keeping with the observations of Hupp and Osterkamp (1985).

When each sampling point in the groups determined by PCA was plotted on the first two principal components, and labeled by geomorphic surface or plant community, both surfaces and communities clustered clearly (Figures 4-5 and 4-6). Thus, from both this information, and that discussed earlier, it appeared that soil characteristics correlated well with geomorphic surfaces and plant communities. More importantly, this clustering of geomorphic surface or plant community was evident despite a small sample size.

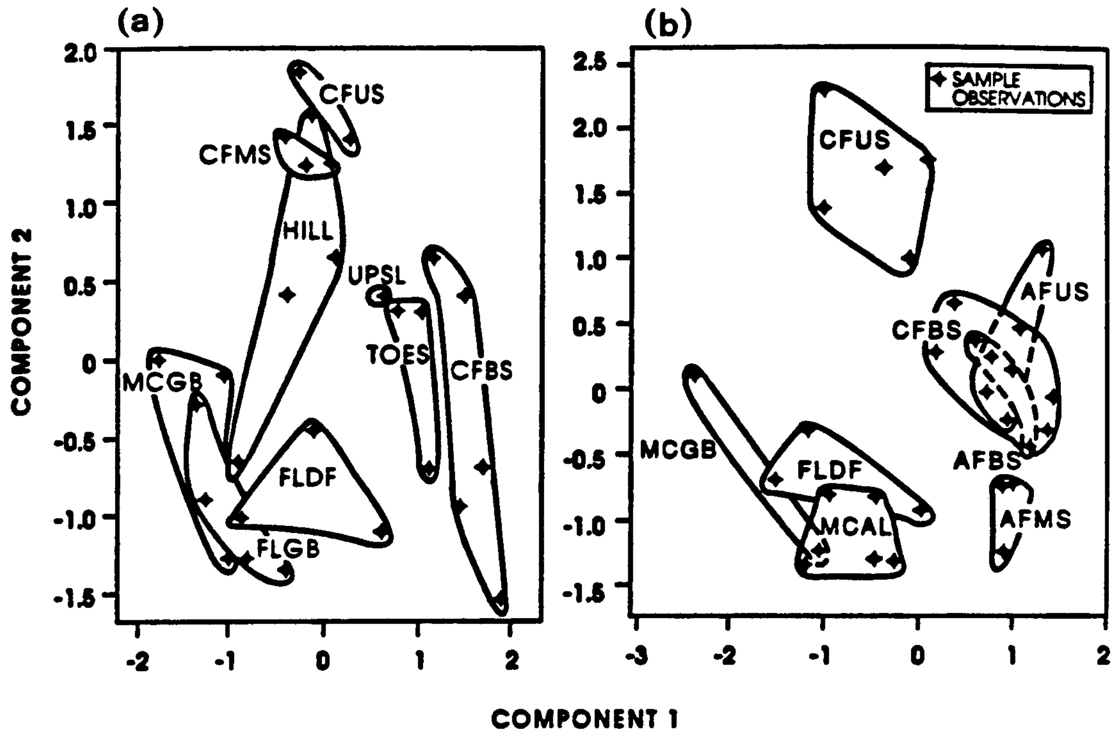


Figure 4-5. Observations at each site plotted on the axes defined by the first two principal components and labelled by geomorphic surface. (a) Mack Creek, (b) Quartz Creek. Code value used for each geomorphic surface is given in the key.

"Stability" Code	KEY TO GEOMORPHIC SURFACES	
1	MCAL	Main-channel alluvium
2	MCGB	Main-channel gravel bar
3	FLGB	Floodplain gravel bar
	FLDF	Floodplain/debris flow
4	AFMS	Alluvial fan, mid-slope
	CFMS	Colluvial fan, mid-slope
5	HILL	Hillslope
6	AFUS	Alluvial fan, upper slope
	CFUS	Colluvial fan, upper slope
	UPSL	Upland slump
7	AFBS	Alluvial fan, bottom slope
	CFBS	Colluvial fan, bottom slope
8	TOES	Toeslope

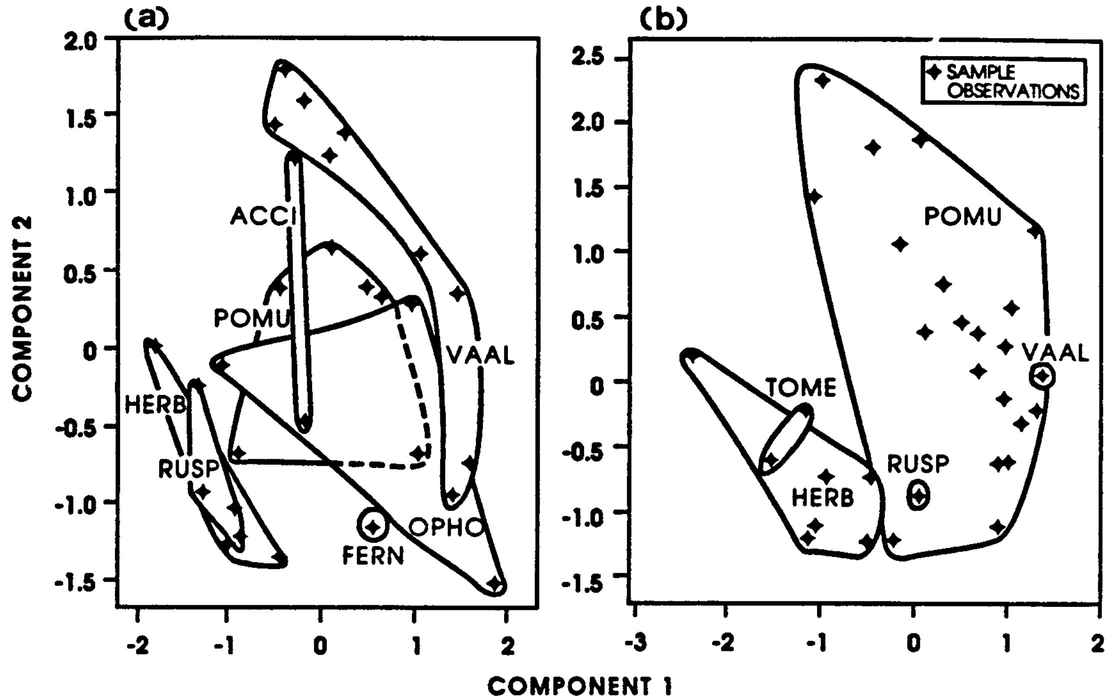


Figure 4-6. Observations at each site plotted on the axes defined by the first two principal components and labelled by plant community. (a) Mack Creek, (b) Quartz Creek. Plant community stability code value used for each community is given in the key.

"Stability" Code	KEY TO PLANT COMMUNITIES	
1	HERB	Invasive small herb
	TOME	Pioneer *Tolmiea menziesii*
2	RUSP	*Rubus spectabilis*/ *Ribes bracteosum*
3	OPHO	*Oplopanax horridum*
	POMU	*Polystichum munitum*
4	FERN	Mixed-fern, large herb
	ACCI	*Acer circinatum*
	VAAL	*Vaccinium alaskaense*/ *Vaccinium parvifolium*

V. Conclusions

Norris (1972) concluded that "classification groups and components serve as a definition of soil variation -- the first stage of the soil survey process." Norris further suggested that soil type distribution may be closely related to landform, and that soil maps may possibly be made from observation of landform. Edmonds et al. (1985) concluded that random pedologic diversity over short distances in some landscapes is not effectively described by the taxa of Soil Taxonomy, and that numerical taxonomy may be useful for aggregating similar soils into natural groupings, thus aiding in the identification of homogeneous mapping units.

In combination, the two multivariate techniques indicated substantial internal structure within the data. The vigor of the statistics indicated that PCA and DA identified plausible soil types in a highly heterogeneous riparian area despite a small sample size.

Principal components analysis identified a subset of variables that may be useful when describing riparian soils of the western Cascade region: geomorphic surface, total carbon, mineralized ammonium, fine earth and coarse fragment contents of the bulk soil, pH, CEC, amorphous aluminum (as implied by NaF pH), and sand and clay contents of the fine earth fraction. This subset is clearly preliminary; as sampling methods are refined, it is likely that the list of the "best" measurement variables will change.

Discriminant analysis proposed a set of eight differentiating variables, four of which were critical in distinguishing among samples from the sites studied: geomorphic surface, 0-15- and 15-30-cm-depth NaF pH, and 15-30-cm-depth mineralized ammonium. Only the first three are easily measured; the last is costly by comparison.

While the most carbon-rich soils are found at the bottom of slopes at Mack Creek, they occur on flat, upper fans at Quartz Creek. This suggests that maximum microbial activity and thus soil fertility in riparian zones may be associated with different geomorphic surfaces (i.e. fans, slopes) or plant communities at different sites.

The clustering of plant community or geomorphic surface with regard to soil characteristics might improve if soil sampling procedures were refined. Since observations clustered more tightly when arrayed by geomorphic surface than by plant community, geomorphic surface may be the more effective means of blocking when designing soil experiments in heterogeneous systems such as riparian zones.

The first two components at each site are, roughly, axes representing carbon accumulation and mineral weathering, both of which are important factors in soil development. Thus, the clustering of geomorphic surfaces on the first two principal components for each site confirms a relationship between geomorphology and soil development. This relationship may reflect two aspects of soil/geomorphology interactions: (1) variation in *in situ* soil development on different geomorphic surfaces, and (2) variation in parent material as determined by geomorphic processes, which in turn may be partially interpreted from landforms. In the following chapter, soil physical and chemical characteristics of the two sites are discussed with regard to this apparent relationship with geomorphic surface stability.

Chapter 5

PHYSICAL AND CHEMICAL CHARACTERISTICS OF RIPARIAN SOILS ALONG A GEOMORPHIC STABILITY GRADIENT

I. Introduction

As early as 1948, Morison et al. proposed that soil development was determined primarily by the effect of topography on water movement. They divided soils of a catena into three complexes: eluvial (geomorphic surfaces lose soil material), colluvial (surfaces both lose and gain material concurrently), and illuvial (surfaces gain material and flood). Morison et al. further noted that units of a soil type were occupied by plant communities of consistently similar floristic composition. Soils at Quartz and Mack Creeks are either colluvial or illuvial complexes, and, as has been shown, may occur as soil "types" correlated with plant community type.

Riparian geomorphic surfaces have been shown to vary considerably in particle-size distribution and depth to water table (Osterkamp and Hupp, 1984), and the importance of surface substrate to riparian species distribution has been noted (Sigafoos, 1976; Wolfe and Pittillo, 1977; Robertson et al, 1978; U.S. Fish and Wildlife Service, 1981). Hupp and Osterkamp (1985) suggested that woody vegetation distribution may be useful in the identification of hydrogeomorphic conditions. Simon and Hupp (1987) concluded that species distribution may indicate stream bank stability.

Osterkamp and Hupp (1984) noted that geomorphic surfaces near the channel were coarser in texture than depositional bars and terraces further from the channel. Hupp and Osterkamp (1985) found sediment size characteristics within a stream cross-section to be generally homogeneous for each geomorphic surface.

Few studies have investigated the relationships between riparian soil physical and chemical characteristics and above-ground productivity. Harris et al. (in press) have noted greater spatial variability in productivity of riparian forests growing on soils of fluvial terraces than on soils of alluvial fans. They suggest that differences in geomorphic process which form these surfaces, hydrological sorting (terraces) versus debris avalanche deposition (fans), explain the variation in forest productivity. Pastor et al. (1984) evaluated changes in net primary productivity (NPP) across a series of edaphic climax forests on Blackhawk Island (southern Wisconsin) and found NPP to be highly correlated with soil N-mineralization and silt + clay content. In another study, Johnston et al. (1984) found nitrate concentrations to be highest in the silt loam alluvial levees of glaciated wetlands in northeastern Wisconsin. They further noted that total P correlated strongly with increasing alluvial deposition of silt + clay.

This chapter discusses differences in the chemical and physical characteristics of the soils of the two sites with respect to a geomorphic stability gradient.

II. Results and Discussion

The groups proposed by principle components analysis (PCA) corresponded, at least roughly, with recognizable geomorphic surfaces. In the preceding chapter, I proposed that these groups were a first approximation of soil types, and they will be referred to as such from here on. As described in Chapter 4, the soil types listed below were ordered by increasing value of mean total carbon. Moreover, soils with higher carbon contents developed generally on older and/or aggrading geomorphic surfaces (see Chapter 2 and Figure 4-5):

Mack Creek: type 1 -- mostly channel and floodplain alluvium, type 2 -- mostly upper and middle fan colluvium,

type 3 -- mixture of hillslope, toeslope, upland slump and fan slope-bottom colluvium,

type 4 -- mixture of fan slope-bottom colluvium, toeslope, and some floodplain alluvium.

Quartz Creek: type 1 -- channel and floodplain alluvium,

type 2 -- mixed fan alluvium and colluvium,

type 3 -- upper fan colluvium.

The distribution of geomorphic surfaces and plant communities by soil type is given in Table 5-1. Further, the distribution of the soil sampling points at each site by soil type is depicted in Figures 5-1 and 5-2.

Presented next are the results of the analysis of variance described in Chapter 4, in which the above soil types were compared.

Table 5-1 -- Geomorphic surfaces and plant communities of each soil type.

			Proportion of Sampling Points/Soil Type (%)		
			Plant Community		
Site	Soil Type	Geomorphic Surface	1	2	3
Mack Creek	1	FLGB (40)	RUSP (30)	HERB (10)	-
		MCGB (30)	HERB (20)	OPHO (10)	-
		FLDF (20)	RUSP (10)	ACCI (10)	-
		HILL (10)	POMU (10)	-	-
	2	CFMS (50)	VAAL (33)	ACCI (17)	-
		CFUS (33)	VAAL (33)	-	-
		HILL (17)	POMU (17)	-	-
	3	HILL (29)	POMU (29)	-	-
		TOES (29)	POMU (14)	OPHO (14)	-
		CFBS (29)	VAAL (29)	-	-
		UPSL (14)	POMU (14)	-	-
	4	CFBS (60)	VAAL (40)	OPHO (20)	-
		TOES (20)	POMU (20)	-	-
		FLDF (20)	FERN (20)	-	-
Quartz Creek	1	MCAL (50)	HERB (40)	POMU (10)	-
		FLDF (30)	TOME (20)	RUSP (10)	-
		MCGB (20)	HERB (20)	-	-
	2	CFBS (31)	POMU (19)	VAAL (6)	ACCI (6)
		AFUS (25)	POMU (13)	ACCI (13)	-
		AFMS (19)	POMU (6)	ACCI (13)	-
		AFBS (19)	POMU (19)	-	-
		CFUS (6)	POMU (6)	-	-
	3	CFUS (100)	POMU (100)	-	-

<u>KEY</u>:

MCAL	Main-channel alluvium
MCGB	Main-channel gravel bar
FLGB	Floodplain gravel bar
FLDF	Floodplain debris flow
AFUS	Alluvial fan, upper slope
AFMS	Alluvial fan, mid-slope
AFBS	Alluvial fan, bottom slope
CFUS	Colluvial fan, upper slope
CFMS	Colluvial fan, mid-slope
CFBS	Colluvial fan, bottom slope
HILL	Hillslope
UPSL	Upland slump
TOES	Toeslope
HERB	Invasive small herb
TOME	Pioneer <u>Tolmeia</u> <u>menziesii</u>
RUSP	<u>Rubus</u> <u>spectabilis</u>/<u>Ribes</u> <u>bracteosum</u>
OPHO	<u>Oplopanax</u> <u>horridum</u>
POMU	<u>Polystichum</u> <u>munitum</u>/ <u>Blechnum</u> <u>spicant</u>
FERN	Mixed-fern, large herb
ACCI	<u>Acer</u> <u>circinatum</u>
VAAL	<u>Vaccinium</u> <u>alaskaense</u>/ <u>Vaccinium</u> <u>parvifolium</u>

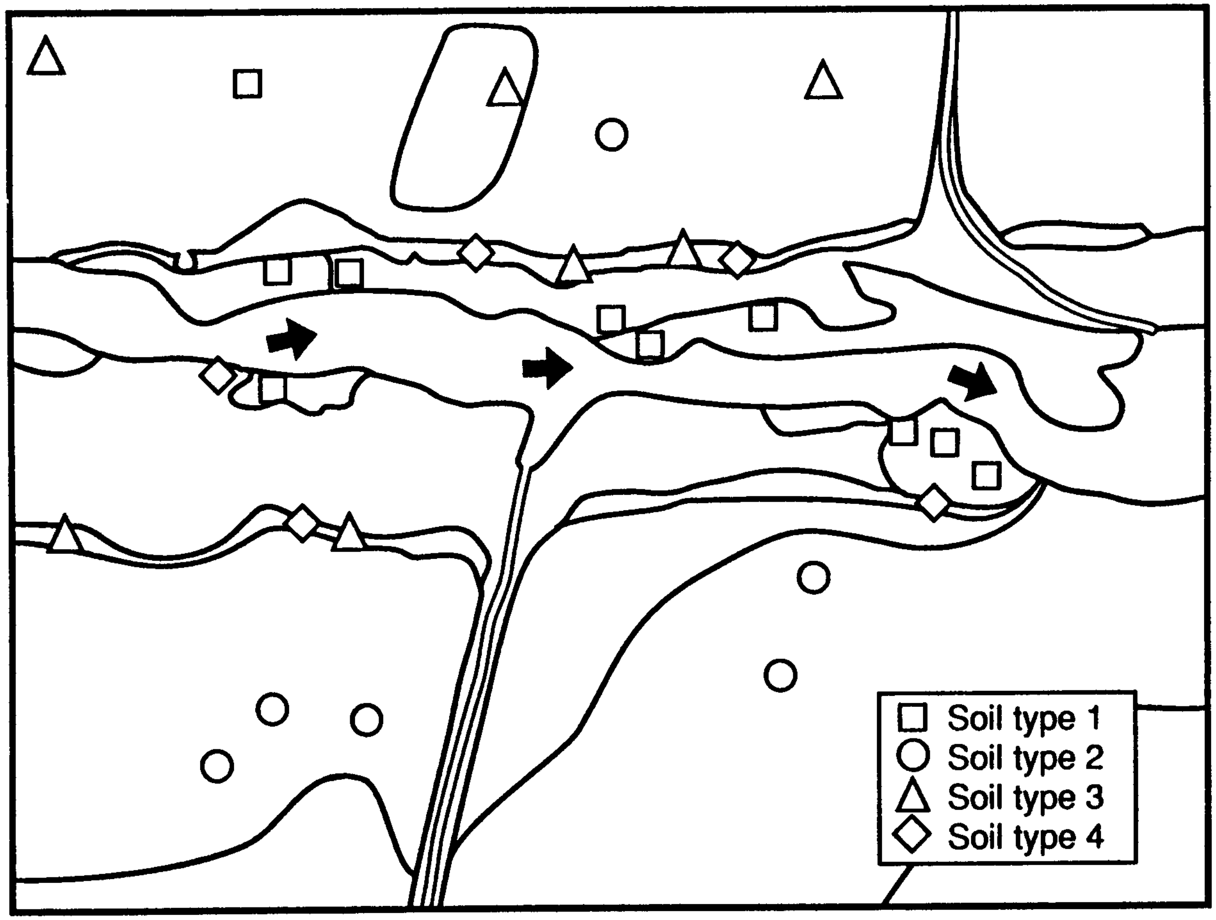


Figure 5-1. Distribution of soil types at Mack Creek relative to geomorphic surfaces and by soil pit location.

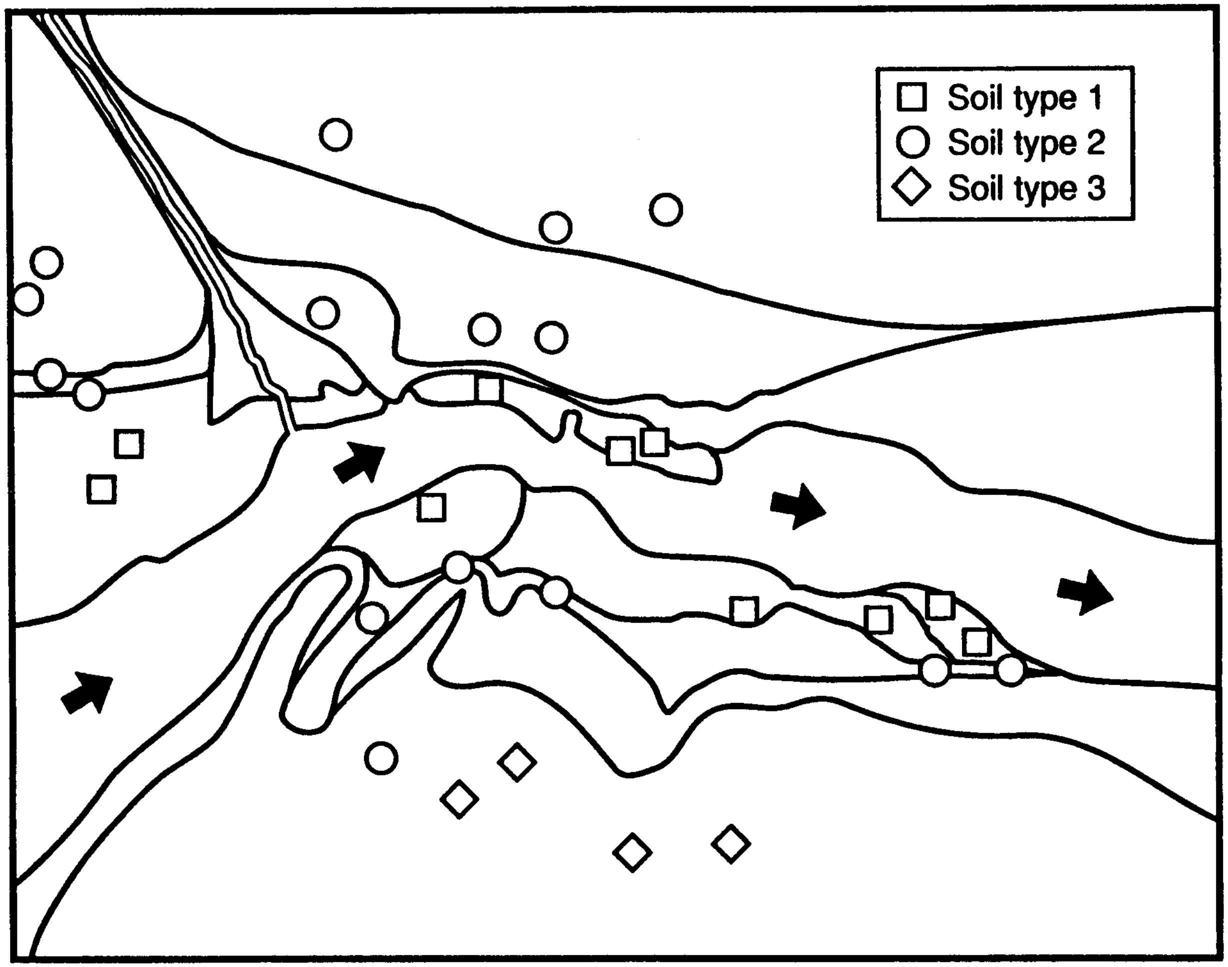


Figure 5-2. Distribution of soil types at Quartz Creek relative to geomorphic surfaces and by soil pit location.

A. Within-Site Contrasts -- Soil Chemistry

Means for soil types at 0-15 cm and 15-30 cm depths were compared (Tables 5-2 and 5-3). Standard errors were mostly $\leq$ 10% of the mean, even after the grouping of observations by the multivariate techniques. Grouping of observations did not increase the variance, but did simplify interpretation of the existing variation.

The most significant correlations are listed in Table 5-4. Less significant, but potentially interesting, correlations are presented throughout the text. Many of the correlations presented are not easily explained. Geomorphic surface and plant community were each variables in 32% of the significant correlations.

Both geomorphic surface and plant community were clearly linked to physical and chemical characteristics of the two sites. Assuming that geomorphic surface and plant community <u>should</u> have some relationship to soil characteristics, the large number of strong correlations with these variables suggests that the grouping and ordering of geomorphic surface and plant communities that was used in this study may be a good first effort.

Table 5-2 -- Soil chemical characteristics at 0-15 cm depth. Differences among soil types within a site as indicated by analysis of variance.

Variable (units)	Soil Type	Mack Creek Mean	Mack Creek s.e.		Quartz Creek Mean	Quartz Creek s.e.	
Total carbon (%)	1	6.0	0.6	a	5.4	0.5	a
	2	7.2	0.8	ab	7.7	0.8	a
	3	9.0	0.7	ab	13.7	1.4	b
	4	10.9	1.4	b			
Total nitrogen (N_t) (%)	1	0.24	0.03	a	0.22	0.02	a
	2	0.28	0.02	ab	0.31	0.02	b
	3	0.38	0.03	b	0.46	0.02	c
	4	0.42	0.04	b			
Kjeldahl-phosphorus (%)	1	0.12	0.01		0.08	0.00	a
	2	0.16	0.02		0.12	0.01	b
	3	0.15	0.01		0.12	0.01	b
	4	0.14	0.01				
C/N	1	23.5	1.1		26.1	1.5	
	2	25.8	2.1		24.5	1.1	
	3	24.0	0.9		29.8	1.6	
	4	25.9	2.4				
CEC (cmol(+)/kg)	1	30.8	1.9	a	19.5	1.1	a
	2	37.4	0.9	ab	32.9	1.4	b
	3	44.4	3.0	b	44.4	2.5	c
	4	47.4	4.3	b			
pH	1	5.96	0.13	a	6.24	0.09	a
	2	5.42	0.07	ab	5.23	0.11	b
	3	5.38	0.15	bc	4.78	0.16	b
	4	5.48	0.17	ac			

Table 5-2 (continued)

Variable (units)	Soil Type	Within-Site Comparison: Mack Creek Mean	s.e.		Quartz Creek Mean	s.e.	
NaF pH	1	10.38	0.06	a	9.40	0.05	a
	2	11.08	0.05	b	10.03	0.10	b
	3	10.73	0.12	bc	9.20	0.27	a
	4	10.36	0.06	ac			
Extractable nitrate (mg/kg)	1	0.40	0.16		2.16	0.26	a
	2	0.00	0.00		2.92	0.48	ab
	3	0.19	0.14		4.75	0.55	b
	4	0.00	0.00				
Exchangeable ammonium (mg/kg)	1	2.07	0.28	a	4.03	0.38	
	2	0.65	0.16	b	3.58	0.48	
	3	1.29	0.19	ab	5.83	0.55	
	4	1.48	0.30	ab			
Mineralized ammonium (mg/kg)	1	102.1	7.5	ab	68.1	8.1	a
	2	68.2	11.4	b	52.6	12.8	a
	3	133.1	7.9	ac	141.7	24.0	b
	4	150.0	20.4	c			
Net mineralized ammonium + extractable nitrate (N_m) (mg/kg)	1	97.6	7.2	ab	69.4	8.0	a
	2	67.6	11.3	b	61.0	13.8	a
	3	131.4	7.7	ac	159.4	26.8	b
	4	148.7	19.1	c			
Proportion of nitrogen mineralized (N_m/N_t)	1	3.9	0.2	a	3.6	0.6	
	2	2.4	0.4	b	1.9	0.4	
	3	3.5	0.2	ab	3.5	0.5	
	4	3.6	0.3	ab			

Values within a column followed by the same letter (or with no letter) are not statistically different at the 95 percent confidence level by Scheffé's test.

Table 5-3 -- Soil chemical characteristics at 15-30 cm depth. Differences among soil types within a site as indicated by analysis of variance.

		Within-Site Comparison					
		Mack Creek			Quartz Creek		
Variable (units)	Soil Type	Mean	s.e.		Mean	s.e.	
Total carbon (%)	1	2.9	0.5	a	1.2	0.0	
	2	3.4	0.4	a	1.2	0.0	
	3	6.5	0.8	b	1.1	0.0	
	4	7.7	0.5	b			
Total nitrogen (N_t) (%)	1	0.14	0.02	a	0.06	0.01	
	2	0.15	0.01	a	0.06	0.01	
	3	0.28	0.03	b	0.05	0.01	
	4	0.32	0.01	b			
Kjeldahl-phosphorus (%)	1	0.35	0.01		0.13	0.00	
	2	0.31	0.02		0.11	0.01	
	3	0.35	0.01		0.10	0.01	
	4	0.38	0.02				
C/N	1	20.4	1.2		25.7	2.0	
	2	22.2	1.6		23.9	1.4	
	3	23.2	0.9		29.3	1.8	
	4	24.4	1.2				
pH	1	6.38	0.09	a	6.41	0.11	a
	2	5.58	0.07	b	5.47	0.09	b
	3	5.63	0.14	b	5.34	0.07	b
	4	5.82	0.11	b			
NaF pH	1	10.00	0.08	a	9.94	0.09	a
	2	10.81	0.04	b	10.43	0.12	b
	3	10.73	0.07	bc	10.11	0.17	ab
	4	10.40	0.14	c			

Table 5-3 (continued)

Variable (units)	Soil Type	Within-Site Comparison Mack Creek Mean	s.e.		Quartz Creek Mean	s.e.	
Extractable nitrate (mg/kg)	1	0.45	0.23		1.90	0.37	
	2	0.00	0.00		1.98	0.42	
	3	0.00	0.00		2.96	0.49	
	4	0.26	0.26				
Exchangeable ammonium (mg/kg)	1	3.14	1.09		1.76	0.13	
	2	0.17	0.06		1.43	0.11	
	3	0.77	0.18		1.78	0.11	
	4	2.44	1.08				
Mineralized ammonium (mg/kg)	1	40.5	6.3	a	58.9	8.0	a
	2	28.4	5.5	a	28.1	7.2	b
	3	79.0	6.4	b	87.7	18.1	a
	4	93.1	4.5	b			
Net mineralized ammonium + extractable nitrate (N_m) (mg/kg)	1	37.8	5.7	a	60.4	8.1	ab
	2	28.2	5.6	a	32.5	7.1	a
	3	78.2	6.4	b	94.0	17.1	b
	4	90.9	4.5	b			
Proportion of nitrogen mineralized (N_m/N_t)	1	2.8	0.2		3.1	0.5	
	2	1.8	0.3		1.7	0.4	
	3	3.0	0.3		3.0	0.1	
	4	2.9	0.2				

Values within a column followed by the same letter (or with no letter) are not statistically different at the 95 percent confidence level by Scheffé's test.

Table 5-4 -- Significant correlations.

Site	Depth (cm)	Variables	Significance Level	Correlation Coefficient
Mack Creek	0-15	CEC * geomorphic surface	p < .0001	r = 0.683
		CEC * sand-sized organic matter#	"	r = -0.673
		(silt + clay) content# * coarse fragments@	"	r = 0.670
		mineralized ammonium * CEC	"	r = 0.668
		silt content# * coarse fragments@	p < .0015	r = 0.573
		sodium fluoride pH * plant community	p < .0020	r = 0.559
		sand content# * fine-earth@	p < .0022	r = 0.554
		sand-sized OM# * geomorphic surface	p < .0027	r = 0.545
		exchangeable ammonium * plant community	"	r = -0.545
		sand content# * uphill slope	p < .0053	r = -0.512
		silt content# * extractable nitrate	p < .0055	r = 0.519
		clay content# * NaF pH	p < .0082	r = 0.490
	15-30	moisture content@ * geomorphic surface	p < .0001	r = 0.684
		fine-earth@ * geomorphic surface	"	r = 0.677
		fine-earth@ * plant community	p < .0005	r = 0.614
		sodium fluoride pH * geomorphic surface	p < .0008	r = 0.596
		sodium fluoride pH * plant community	p < .0010	r = 0.589
		moisture content@ * plant community	p < .0013	r = 0.579
Quartz Creek	0-15	CEC * geomorphic surface	p < .0001	r = 0.804
		CEC * plant community	p < .0003	r = 0.610
		moisture content@ * geomorphic surface	p < .0006	r = 0.593
		extractable nitrate * CEC	p < .0031	r = 0.522
	15-30	exchangeable ammonium * sodium fluoride pH	p < .0001	r = -0.656
		mineralized ammonium * coarse fragments@	p < .0002	r = 0.626
		fine-earth@ * plant community	p < .0006	r = 0.588

percent of the fine-earth (< 2 mm soil).   @ percent of the bulk soil.

1. Total carbon, total nitrogen, cation exchange capacity and pH

In general, soil type 'order' corresponded with increasing total carbon. Both total nitrogen and cation exchange capacity (CEC) increased with increasing carbon content of the soil, whereas pH generally decreased. However, the carbon and nitrogen trends did not hold for the Quartz Creek 15-30 cm samples in that all of the 15-30 cm depth samples at Quartz Creek were roughly similar with respect to carbon and nitrogen.

The differences in carbon and nitrogen contents among soil types for both depths at Mack Creek, and for the 0-15 cm depth at Quartz Creek, were striking and suggested that the groups proposed by principal components were strongly defined. These strong groupings imply that the correlations presented throughout this chapter are real, even though they may be difficult to interpret. It may be that a third "common" factor would better explain each correlate pair and the processes involved.

Not surprisingly, total carbon and nitrogen differed most between the 0-15-cm-depth alluvial samples (type 1 at both sites), and the 0-15-cm-depth slope-bottom (type 4 at Mack Creek) and upper colluvial fan (type 3 at Quartz Creek) samples. The latter two soils tend to be found on nearly flat surfaces where organic matter was more likely to accumulate. At both sites, the 0-15 cm samples contained more carbon and nitrogen than the 15-30 cm samples.

Soil pH, for both sample depths at the two sites, was higher than that (5.2-5.6) commonly found on upland (non-riparian) soils of the H.J. Andrews (Brown, 1975; Brown & Parsons, 1973). Most notably, the channel and floodplain samples ranged from pH 6.0 - 6.4.

Overall, for these variables, the 15-30 cm samples at both sites were more homogeneous than the 0-15 cm samples, especially at Quartz Creek. Further, 0-15 cm samples at Quartz Creek were <u>less</u> homogeneous than those of Mack Creek, particularly total nitrogen and CEC, possibly reflecting rapid, differential development of topsoils in a secondary successional <u>Alnus</u> <u>rubra</u> community.

The characteristics of the 0-15 cm samples at Quartz Creek correlated particularly well with geomorphic surface, as demonstrated by the significant differences among surface soil nitrogen and CEC. While the same trends were seen in 0-15 cm samples at Mack Creek, the differences were less obvious. It may be that type and intensity of recent disturbances at Quartz Creek are more clearly associated with geomorphic surfaces, resulting in more obvious contrasts among surface soils.

At Mack Creek, CEC at 0-15 cm depth correlated significantly and positively with geomorphic surface

($p < .0001$, $r = 0.683$), and negatively with percent sand-sized organic matter ($p < .0001$, $r = -0.673$). At Quartz Creek, CEC at 0-15 cm depth correlated significantly and positively with both geomorphic surface ($p < .0001$, $r = .804$) and plant community ($p < .0003$, $r = .610$). CEC was not determined for 15-30 cm samples at either site.

Tendencies toward homogeneity or heterogeneity among samples at both sites and depths, as well as trends for carbon, nitrogen, CEC and pH, were consistent with expectations arising from geomorphological, soil development, and plant community information. The significant correlations between CEC and geomorphic surface at both sites are intriguing and may warrant further investigation. These trends and tendencies are thus indicators that the soil types proposed may be both reasonable and interpretable. The trends in carbon, nitrogen, CEC and pH should be considered when interpreting the following comparisons.

2. Carbon to nitrogen ratio

Carbon to nitrogen (C/N) ratios did not vary with soil type at either site or depth. The lack of significant correlations of interest for either site or depth was surprising, given the wide range of soils present at the sites. I expected soil carbon quantity and quality to differ between alluvial and colluvial soils, and among plant community types. Confounding factors may be the ubiquitous, but random, presence of charcoal and possibly wood fragments at both sites.

3. Kjeldahl-phosphorus and sodium fluoride pH

Significant differences in total Kjeldahl-phosphorus were seen only in the 0-15 cm samples at Quartz Creek. Alluvial samples (type 1) at this site were noticeably lower in phosphorus than samples from both alluvial and colluvial fans (types 2 and 3), which had similar levels. Since the entire site was disturbed, it may be that fluvial processes have reduced the phosphorus content of alluvium by 33% relative to fans, perhaps by removal of fine particles. Uniform phosphorus distribution at Mack Creek may be the result of relatively undisturbed soil development.

The two sites differed markedly with respect to changes in Kjeldahl-P content with depth (Tables 5-2 and 5-3). While the 15-30 cm samples at Quartz Creek were similar in phosphorus content to the 0-15 cm samples, the 15-30 cm samples at Mack Creek were obviously enriched relative to the 0-15 cm samples. Assuming that Kjeldahl-P is at the least a relative measure, higher values of phosphorus with depth at Mack Creek suggest that the low values at Quartz Creek may be a consequence of soil export, perhaps of a size-class rich in phosphorus, following logging. Alternatively, Mack Creek soils may contain considerable fulvic-P, which tends to leach through the profile and accumulate with depth.

From the measured NaF reactions, 93% of the 0-15 cm samples at Mack Creek and 63% of the 15-30 cm samples were rich in amorphous aluminum. Only 23% of the 0-15 cm samples at Quartz Creek, and 50% of the 15-30 cm samples, met the criterion of a NaF pH $\geq$ 10.2.

The lowest values for NaF pH were generally found in alluvial samples while the highest were found in fans, especially colluvial fans. A high NaF pH value indicates the presence of amorphous aluminum, either humus-bound aluminum or allophane-like constituents. Thus, at these sites, alluvial soils were poor, and colluvial soils were rich, in one or more of these constituents.

Sodium fluoride pH correlated significantly with total carbon only at the 15-30 cm depth at Quartz Creek ($p < .0001$, $r = 0.663$). In no case did NaF pH correlate significantly with CEC. Sodium fluoride pH of the Mack Creek 0-15 cm samples correlated significantly and positively with plant community ($p < .0020$, $r = 0.559$). The 15-30 cm samples at this site correlated significantly and positively with geomorphic surface ($p < .0008$, $r = 0.596$) and plant community ($p < .0010$, $r = 0.589$). Differences in geomorphic processes, and subsequent variation in parent material and/or soil development, could thus be causes of differences in NaF pH. Plant community differences could be either a cause (effects on soil weathering and amorphous mineral formation) or an effect (response to soil conditions associated with amorphous aluminum).

4. Extractable nitrate and exchangeable ammonium

Extractable nitrate differed significantly by soil type only among the Quartz Creek 0-15 cm samples and exchangeable ammonium differed only among the Mack Creek 0-15 cm samples. While ammonium was dominant at both sample depths at Mack Creek, roughly equal amounts of nitrate-N and ammonium-N were present in the Quartz Creek 15-30 cm samples, with somewhat greater amounts of ammonium present in the 0-15 cm samples. This was not surprising, given that the Quartz Creek site is dominated by mature red alder which is presumably fixing considerable atmospheric nitrogen. Because of the very low nitrate values, I expected to find higher C/N ratios at Mack Creek than at Quartz Creek. However, C/N ratios between the two sites were not different, perhaps because of charcoal and/or wood fragments.

Levels of extractable nitrate in both the 0-15 cm and 15-30 cm samples at Quartz Creek appeared to increase with age and/or aggradation of the geomorphic surface. A corresponding decrease in C/N ratio would thus be expected but was not seen. At this site, extractable nitrate at 0-15 cm depth correlated significantly and positively with CEC ($p < .0031$, $r = 0.522$). Exchangeable ammonium of 15-30 cm samples correlated significantly and negatively with NaF pH ($p < .0001$, $r = -0.656$). A possible hypothesis is that increasing phosphorus sorption associated with an increase in amorphous mineral content of the soil (as indicated by increasing NaF pH) led to a decrease in nitrogen mineralization due to phosphorus limitation. This may be an example of a missing "common" factor between two correlates.

Despite the abundant *A. rubra* everywhere, nitrate was more abundant in the carbon-rich soils of the older/ aggrading geomorphic surfaces, upper colluvial and alluvial fans (types 2 and 3). Since there was more nitrate at the upper slope positions, the distribution of nitrate at this site was not explained by seepage. Differences in anion exchange capacity of these soils could contribute to this pattern.

The results at Mack Creek were contrary to those at Quartz Creek. For both soil depths, the greatest quantity of extractable nitrate and exchangeable ammonium was found in the alluvial samples (type 1). This may be, in part, a result of higher nitrogen mineralization rates in the possibly warmer, moist alluvial zone. The canopy at Mack Creek was dense, except at the stream edge, and may have permitted greater insolation in the alluvial zone. Exchangeable ammonium at Mack Creek correlated significantly and negatively with plant community ($p < .0027$, $r = -0.545$), implying that as the frequency of disturbance of a plant community decreased, exchangeable ammonium decreased.

5. <u>Mineralized ammonium</u>

Mineralized ammonium trends corresponded only in part with those of carbon and nitrogen. Mineralized ammonium levels were low for soil type 2 at both sites and depths, relative to the carbon and nitrogen contents of these soil types, and to the mineralized ammonium levels in soil types 1 and 3 at each site. At Mack Creek, values were higher in the 0-15 cm samples than in the 15-30 cm samples. At Quartz Creek, however, values were roughly similar, regardless of depth, perhaps due to high nitrogen inputs from symbiotic nitrogen fixation.

Possible explanations for nitrogen mineralization within each soil type at both sites could be as follows.

When compared to the other soils at the site, the relatively high values for the 0-15 cm alluvial samples (type 1) at Mack Creek were reasonable, given that these soils were possibly warm at least during the day (due to greater insolation at the stream edge), well aerated (due to a coarse, sandy texture), and moist, all conditions that favor microbial activity. However, the low values for the mid and bottom colluvial-fan samples (type 2) at Mack Creek, and the mixed fan samples (type 2) at Quartz Creek, were difficult to explain. These samples were not unusually low in carbon, relative to the other samples at each site and depth. High values found in slope-bottom samples (type 4) at Mack Creek, and upper colluvial-fan samples (type 3) at Quartz Creek, regardless of depth, were not surprising. These samples contained the most carbon and probably were both energetically and aerobically favorable for microbial activity. Notably, 0-15 cm upper colluvial-fan samples (type 3) at Quartz Creek mineralized significantly more nitrogen than the other samples at this site, and nearly as much as samples from the most stable geomorphic surfaces at Mack Creek (fan and slope-bottom samples, type 4). The differences were great enough to suggest that these upper-profile colluvial-fan samples at Quartz Creek were especially fertile, despite the recent disturbance by logging.

Both trends and significant differences in net mineralized nitrogen plus extractable nitrate (N_m) were nearly identical to those for mineralized nitrogen, while the proportion of nitrogen mineralized (N_m/N_t) was significantly different only among Mack Creek 0-15 cm samples. The high values for proportion of nitrogen mineralized in the alluvial samples (type 1) versus the low values for the mid and bottom colluvial fans (type 2) were especially striking. At both sites, and for both depths, the proportion of nitrogen mineralized in the low carbon content alluvial samples was as great as in samples with high carbon content. Although carbon and nitrogen contents of the alluvial samples were less than those of all other samples, large amounts of nitrogen was being mineralized in the alluvial soils. Soil texture and litter quality may be the driving variables. Since alluvial soils are adjacent to the stream, the potential for nitrification and nitrate leaching to the stream is great.

B. Within-Site Contrasts -- Soil Physical Characteristics

Mean bulk-soil particle size-classes for soil types at the 0-15 cm and 15-30 cm depths were significantly different (Tables 5-5 and 5-6), as were means for particle-size characteristics of the Mack Creek 0-15 cm

Table 5-5 -- Soil physical characteristics at 0-15 cm depth. Differences among soil types within a site as indicated by analysis of variance.

		Within-Site Comparison					
		Mack Creek			Quartz Creek		
Variable (units)	Soil Type	Mean	s.e.		Mean	s.e.	
Slope* (%)	1	22	11	a	51	12	
	2	54	8	ab	63	7	
	3	71	10	b	41	9	
	4	45	15	ab			
Moisture content (%)@	1	33	3		25	1	a
	2	38	1		32	1	b
	3	40	4		31	5	ab
	4	46	4				
Fine-earth (< 2 mm soil) (%)@	1	56	6	a	51	5	a
	2	61	5	ab	55	3	a
	3	66	8	ab	28	3	b
	4	90	6	b			
2-4 mm soil (%)@	1	13	1	a	17	1	
	2	15	2	ab	15	1	
	3	10	2	abc	15	2	
	4	5	2	c			
Coarse fragments (> 4mm soil) (%)@	1	31	6	a	32	5	a
	2	24	4	ab	30	3	a
	3	23	6	ab	57	3	b
	4	5	4	b			

* immediately above the soil pit.
@ percent of the bulk soil.

Values within a column followed by the same letter (or with no letter) are not statistically different at the 95 percent confidence level by Scheffé's test.

Table 5-6 -- Soil physical characteristics at 15-30 cm depth. Differences among soil types within a site as indicated by analysis of variance.

Variable (units)	Soil Type	Within-Site Comparison: Mack Creek Mean	s.e.		Quartz Creek Mean	s.e.	
Moisture content (%)@	1	23	3	a	27	2	
	2	35	1	ab	30	1	
	3	41	4	b	27	1	
	4	45	3	b			
Fine-earth (< 2 mm soil) (%)@	1	37	4	a	38	3	a
	2	61	4	b	55	2	b
	3	62	5	b	37	5	a
	4	82	5	b			
2-4 mm soil (%)@	1	19	1	a	14	2	a
	2	12	2	b	14	1	a
	3	10	1	b	21	2	b
	4	7	1	b			
Coarse fragments (> 4mm soil) (%)@	1	44	4	a	41	4	ab
	2	28	5	ab	31	2	a
	3	28	5	ab	49	6	b
	4	11	4	b			

@ percent of the bulk soil.

Values within a column followed by the same letter (or with no letter) are not statistically different at the 95 percent confidence level by Scheffé's test.

samples (Table 5-7). Particle-size analyses were conducted only for the 0-15 cm samples at Mack Creek.

1. Slope and soil moisture content

Although slope data were presented primarily to orient the reader with regard to topography, it was clear that Mack Creek is topographically more variable than Quartz Creek. Slope was measured uphill of the soil pit, because this measurement indicates probable rate of slope-related transport.

As expected, soil moisture content generally corresponded with increasing soil carbon for both sites and depths, but especially at Mack Creek. Further, only the alluvial samples (type 1) at Mack Creek were clearly drier with depth. Otherwise, soil moisture was fairly uniform over the site. At Quartz Creek, 0-15 cm alluvial samples (type 1) were significantly drier than samples from fans (types 2 and 3), despite similar proportions of fine earth and coarse fragments.

2. Bulk soil size-classes

At Mack Creek, the proportion of the bulk soil present as fine earth ($\leq$ 2 mm) at both the 0-15 cm and 15-30 cm depth increased, and the proportion as coarse fragments

Table 5-7 -- Particle-size characteristics of Mack Creek 0-15 cm depth soils. Differences among soil types as indicated by analysis of variance. Values given are the percent of the fine earth (< 2 mm soil).

	Soil type											
	1			2			3			4		
Size-class	Mean	s.e.		Mean	s.e.		Mean	s.e.		Mean	s.e.	
Sand	53.8	3.4	ac	40.9	0.9	ab	39.7	4.4	b	59.6	3.6	c
Silt	32.8	2.9	ab	29.1	1.0	ab	38.8	3.0	a	24.3	2.3	b
Clay	10.5	1.4	ac	22.3	0.5	b	15.3	1.5	a	7.8	1.8	c
Sand-sized organic matter	2.9	0.4	a	7.7	0.3	b	6.1	1.2	ab	8.3	1.6	b
Silt + clay	43.3	3.6	ab	51.4	1.1	a	54.2	3.5	a	32.1	3.7	b
Dominant parent materials	channel and floodplain alluvium			fan colluvium			slope-related colluvium			slope-bottom colluvium and floodplain alluvium		
Overall soil texture	sandy loam			loam			loam			sandy loam		

Values within a row followed by the same letter (or with no letter) are not statistically different at the 95 percent confidence level by Scheffé's test.

($\geq$ 4 mm) decreased, from soil type 1 to type 4 (i.e. with increasing soil carbon content). Samples from the base of slopes (type 4) contained large amounts of fine earth material. Conversely, alluvial samples (type 1) contained considerable coarse fragments, especially at the 15-30 cm depth. Generally, the 2-4 mm size fraction followed the same trend as the coarse fragments.

At Quartz Creek, however, there were neither clear trends nor an apparent correspondence between size-classes and soil carbon content. The lack of trends may be an effect of soil mixing caused by logging. Also, the Quartz Creek and Mack Creek colluvial fans may have originated from very different parent materials. The 0-15 cm samples from upper colluvial fans (type 3) at Quartz Creek were quite coarse; the coarse fragment content was twice that of samples from similar surfaces at Mack Creek (type 2). This was not surprising, given the parent material from which these surfaces were formed.

Fine earth content at 15-30 cm depth at Mack Creek correlated significantly and positively with geomorphic surface and plant community (Table 5-4). Conversely, coarse fragments at this site correlated significantly and negatively with geomorphic surface ($p < .0005$, $r = -0.612$) and plant community ($p < .0012$, $r = -0.581$), and the 2-4 mm size class correlated significantly and negatively with geomorphic surface ($p < .0001$, $r = -0.660$). The fine earth fraction at 15-30 cm depth at Quartz Creek correlated significantly and positively with plant community (Table 5-4), and the 2-4 mm size class correlated significantly and positively with both geomorphic surface ($p < .0001$, $r = 0.683$) and plant community ($p < .0030$, $r = 0.523$).

Additionally, the fine earth fraction of the 0-15 cm samples at Mack Creek correlated significantly and negatively with percent silt + clay ($p < .0001$, $r = -0.689$) and percent silt ($p < .0022$, $r = -0.554$), and positively with percent sand (Table 5-4). Conversely, and expectedly, coarse fragments at the same site and depth correlated significantly and positively with percent silt + clay ($p < .0001$, $r = 0.670$) and percent silt ($p < .0015$, $r = 0.573$).

These trends and correlations indirectly suggest that the groups identified by principal components at the two sites were based on reasonable and interpretable structure in the data. At Quartz Creek, physical homogeneity of the soils at both depths and across a variety of geomorphic surfaces is expected because of the recent severe disturbance. At Mack Creek, where the time since catastrophic disturbance was relatively great, variation in soil development was expected to lead to trends between fine earth and coarse fragment distribution, carbon content of the soils, and geomorphic surfaces. Clear trends in the data with respect to these variables at Mack Creek, and no trends at Quartz Creek, supported the assertion that the soil types proposed here were real.

Plant communities are known to be indicators of soil development, and, at Quartz Creek, seem to be influenced by bulk particle size-class characteristics of the 15-30 cm samples. Bulk particle size-classes of the 15-30 cm samples at Mack Creek were strongly correlated with geomorphic surface, and only slightly less strongly with plant community. After centuries of aggradation, both differential weathering of geomorphic surfaces and soil accumulation were expected, as were differences in bulk particle size-classes and variation in plant community.

3. Soil texture and particle-size characteristics of Mack Creek 0-15 cm samples

A complete particle-size analysis was done on the Mack Creek 0-15 cm samples because I expected the clearest correlations between physical structure and other variables at this site and depth. The method used determined clay, silt, and sand size-classes more accurately than silt and sand subclasses; sums of the coarse to fine subclasses were frequently 20-25% less than the value of the corresponding size class. Data on these subclasses are therefore not presented.

Soil textural classes were determined from these data (Table 5-7). Colluvial samples (types 2 and 3) were loams, while both the alluvial and slope-bottom samples (types 1 and 4) were sandy loams. Slope bottoms were often directly adjacent to alluvium, which may partially account for their sandy nature. While alluvial and slope-bottom samples were similar in general particle-size characteristics, fan colluvium (type 2) was clearly higher in clay content than any of the other samples. Interestingly, slope-bottom samples contained the lowest proportion of both clay and silt, and yet were highest in carbon content.

Silt content correlated with extractable nitrate ($p < .0055$, $r = 0.519$) and clay content correlated with NaF pH ($p < .0082$, $r = 0.490$). The positive correlation between clay and NaF pH is confusing; an increase in NaF pH often accompanies a decrease in clay because amorphous minerals are difficult to disperse. The highest proportion of clay was found on colluvial fans (type 2). This soil type was the one for which the mineralized ammonium levels were lower than was expected. Extractable nitrate and exchangeable ammonium values followed the same trend as mineralizable ammonium, but the differences were not as significant. The geomorphic surfaces of this soil type were the only ones at the site that were dominantly occupied by the *V. alaskaense*/*V. parvifolium* plant community. The possible linkages here might be identified if sampling intensity were increased.

The usefulness of sand-sized organic matter in interpretation and prediction may be worthy of consideration. Although variable, the amount of sand-sized organic matter generally corresponded with the proportion of sand. While the correlations between percent sand-sized organic matter and CEC ($p < .0001$, $r = 0.673$), total carbon ($p < .0008$, $r = 0.599$) and geomorphic surface ($p < .0027$, $r = 0.545$) were highly significant, sand-sized organic matter also correlated with total nitrogen ($p < .0040$, $r = 0.525$). This organic fraction shows sensitivity to geomorphic stability, may be a reasonably good predictor of total carbon, nitrogen, and CEC, and may be useful when evaluating site fertility.

C. Within-Site Contrasts -- Resin Experiments

Nutrients retained by resins represent dissolved nutrients that can leach downward with the flow of water and that may be important to stream productivity, especially those nutrients found in soils adjacent to streams. At both sites, values for all resin-bound nutrients were so variable that no significant differences among soil types were found (Table 5-8). There were no correlations of interest for either site or season.

At Mack Creek, low levels of nutrients were captured on resins, regardless of season, with only nitrate in alluvial soils (type 1) captured in any quantity. Nutrients were perhaps immobilized since considerable microbial activity (as indicated by anaerobic mineralization rates) has been shown to occur at this site (Tables 5-2 and 5-3). Microbial activity in the fall may explain the somewhat higher values for resin-bound ammonium during this season. Results were different at Quartz Creek. Considerable nitrate was captured on resins during both seasons and for all soils, with alluvial (type 1) values significantly greater in the spring than in the fall. Considerable ammonium was also sorbed by spring-placed resins in alluvial soils (type 1) at Quartz Creek.

D. Between-Site Comparisons

Valid comparisons could be made only between the alluvial soils (type 1 at both sites) because type 1 soils at both sites were composed almost entirely of samples from similar geomorphic surfaces. Results of these comparisons are presented in Tables 5-9 and 5-10. The remaining soil types differed considerably in proportion of

Table 5-8 -- Results of resin experiments at 0-15 cm depth. Differences among soil types within a site as indicated by analysis of variance.

Variable (units)	Soil Type	Mack Creek Mean	Mack Creek s.e.	Quartz Creek Mean	Quartz Creek s.e.
Spring resin nitrate (mg/kg)	1	10.4	4.4	131.5	35.7
	2	0.0	0.0	162.1	30.0
	3	1.2	1.2	147.9	15.3
	4	0.0	0.0		
Spring resin ammonium (mg/kg)	1	0.1	0.1	21.7	12.3
	2	0.0	0.0	0.6	0.6
	3	0.4	0.4	2.5	2.5
	4	0.0	0.0		
Spring resin phosphorus (mg/kg)	1	3.7	1.6	1.3	0.2
	2	6.6	5.1	1.1	0.2
	3	1.6	0.9	1.3	0.1
	4	1.9	1.6		
Fall resin nitrate (mg/kg)	1	19.6	11.8	24.7	5.8
	2	0.1	0.1	151.2	60.8
	3	0.9	0.7	265.8	112.7
	4	3.4	3.3		
Fall resin ammonium (mg/kg)	1	1.7	0.2	1.2	0.0
	2	2.2	0.2	1.2	0.0
	3	1.6	0.3	1.2	0.1
	4	2.2	0.5		
Fall resin phosphorus (mg/kg)	1	1.6	0.4	1.9	0.3
	2	2.1	0.3	1.4	0.1
	3	0.8	0.3	1.2	0.2
	4	0.8	0.3		

Values within a column followed by the same letter (or with no letter) are not statistically different at the 95 percent confidence level by Scheffé's test.

Table 5-9 -- Between-site comparison of 0-15 cm depth alluvial soils as indicated by analysis of variance using the Tukey method.

Variable (units)	Mack Creek Mean	Mack Creek s.e.	Quartz Creek Mean	Quartz Creek s.e.	Level of Significance
Slope* (%)	22	11	51	12	-
Soil moisture content (%)@	33	3	25	1	0.10
Fine-earth (< 2 mm soil) (%)@	56	6	51	5	-
2-4 mm soil (%)@	13	1	17	1	-
Coarse fragments (> 4mm soil) (%)@	31	6	32	5	-
Total carbon (%)	6.0	0.6	5.4	0.5	-
Total nitrogen (N_t) (%)	0.24	0.03	0.22	0.02	-
Kjeldahl-phosphorus (%)@	0.12	0.01	0.08	0.00	0.05
C/N	23.5	1.1	26.1	1.5	-
CEC (cmol(+)/kg)	30.8	1.9	19.5	1.1	0.01
pH	5.96	0.13	6.24	0.09	-
NaF pH	10.38	0.06	9.40	0.05	0.01
Extractable nitrate (mg/kg)	0.40	0.16	2.16	0.26	0.05
Exchangeable ammonium (mg/kg)	2.07	0.28	4.03	0.38	0.05
Mineralized ammonium (mg/kg)	102.1	7.5	68.1	8.1	-
Net mineralized ammonium + extractable nitrate (N_m) (mg/kg)	97.6	7.2	69.4	8.0	-
Proportion of nitrogen mineralized (N_m/N_t)	3.9	0.2	3.6	0.6	-
Spring resin nitrate (mg/kg)	10.4	4.4	131.5	35.7	0.05
Spring resin ammonium (mg/kg)	0.1	0.1	21.7	12.3	-
Spring resin phosphorus (mg/kg)	3.7	1.6	1.3	0.2	-
Fall resin nitrate (mg/kg)	19.6	11.8	24.7	5.8	-
Fall resin ammonium (mg/kg)	1.7	0.2	1.2	0.0	-
Fall resin phosphorus (mg/kg)	1.6	0.4	1.9	0.3	-

* immediately above the soil pit. @ percent of the bulk soil.

Table 5-10 -- Between-site comparison of 15-30 cm depth alluvial soils. Differences among soils as indicated by analysis of variance using the Tukey method.

Variable (units)	Mack Creek Mean	Mack Creek s.e.	Quartz Creek Mean	Quartz Creek s.e.	Level of Significance
Soil moisture content (%)@	23	3	27	2	-
Fine-earth (<2 mm soil) (%)@	37	4	38	3	-
2-4 mm soil (%)@	19	1	1	0	0.01
Coarse fragments (> 4mm soil) (%)@	44	4	41	4	-
Total carbon (%)	2.9	0.5	1.2	0.0	0.01
Total nitrogen (N_t) (%)	0.14	0.02	0.6	0.1	0.01
Kjeldahl-phosphorus (%)	0.35	0.01	0.13	0.00	0.01
C/N	20.4	1.2	25.7	2.0	-
pH	6.38	0.09	6.41	0.11	-
NaF pH	10.00	0.08	9.94	0.09	-
Extractable nitrate (mg/kg)	0.45	0.23	1.90	0.37	0.10
Exchangeable ammonium (mg/kg)	3.14	1.09	1.76	0.13	-
Mineralized ammonium (mg/kg)	40.5	6.3	58.9	8.0	-
Net mineralized ammonium + extractable nitrate (N_m) (mg/kg)	37.8	5.7	60.4	8.1	-
Proportion of nitrogen mineralized (N_m/N_t)	2.8	0.2	3.1	0.5	-

@ percent of the bulk soil.

samples from various geomorphic surfaces (Table 5-1) and were therefore not comparable.

Mack Creek 0-15 cm alluvial samples were significantly wetter, higher in Kjeldahl-P and amorphous aluminum (as indicated by NaF pH), and had a significantly greater cation exchange capacity than samples of the same depth from Quartz Creek. Quartz Creek 0-15 cm samples, however, contained significantly more extractable nitrate, exchangeable ammonium, and resin-absorbed nitrate (during the spring). It appears that organic matter accumulation and soil profile development strongly influenced 0-15 cm alluvial soils at Mack Creek while biological N-fixation by red alder affected similar soils at Quartz Creek.

Similar characterizations can be made for the 15-30 cm depth samples at the two sites. The Mack Creek alluvial samples contained significantly more 2-4 mm soil, total carbon, and Kjeldahl-P (all of which may result from organic matter accumulation) than the Quartz Creek alluvial samples, which had significantly higher amounts of total nitrogen and extractable nitrate. Interestingly, differences were most significant in the 15-30 cm samples, suggesting that this depth, and perhaps even lower depths, are important when distinguishing between sites and should not be overlooked in future surveys.

Explanations for the observed between-site differences in resin-captured nutrients may include excess ammonium production by the abundant red alder at Quartz Creek, and less biological uptake at Quartz Creek than at Mack Creek. The dominant alluvial plant species at Quartz Creek (P. munitum) may produce less biomass annually than the dominant species at Mack Creek (R. spectabilis and O. horridum), and overstory (red alder vs. mixed-conifer) uptake may be greater at Mack than at Quartz

From these data, it appears that little nitrate and no ammonium leach to the stream at Mack Creek, during either the spring or fall season. Conversely, considerable nitrate may leach to the stream during both of these seasons at Quartz Creek, as well as some ammonium in the spring. Interestingly, during the spring, considerable ammonium was also leaching through the upper profile of alluvial soils at Quartz Creek, possibly implying low uptake at this time of the year.

Although levels of total carbon and nitrogen at 0-15 cm depth were similar in alluvial samples at both sites, levels of extractable nitrate, exchangeable ammonium, and spring resin nitrate were significantly greater at Quartz Creek. In the 15-30 cm alluvial samples, levels of carbon, nitrogen, Kjeldahl-P and extractable nitrate were significantly different at the two sites. While carbon and phosphorus were greater at Mack Creek, nitrogen and extractable nitrate were greater at Quartz Creek. A possible explanation of the results at Quartz Creek is that red alder is fixing a great deal of ammonium at 0-15 cm depth, and that some of this ammonium was nitrified and leached to the 15-30 cm depth.

Since extractable nitrate in the 15-30 cm depth alluvial samples of the two sites was only significantly different at the 0.10 level, potential nitrate leaching to the stream from alluvial soils should be relatively similar at the two sites. Nitrate and ammonium analyses of the stream water were conducted concurrent with spring resin placement. Samples were collected every 3-4 days (C. Dahm, unpublished data). Ammonium levels were < .005 μg/l for all samples at both sites on all dates. Over the 4/22 - 6/29/83 period, the mean nitrate content of 17 samples collected at Mack Creek was .086 ± .005 μg/l. At Quartz Creek, mean nitrate content of the 16 samples collected between 4/15 -6/9/83 was .015 ± .002 μg/l. An F-test of the means determined these nitrate levels to be significantly different at the 0.001 level.

In summary, little ammonium leached to the stream at either site, and, despite more than an order of magnitude greater dissolved nitrate in alluvial soils at Quartz Creek, nitrate levels were 5.7 times greater in Mack Creek than in Quartz Creek. Thus, nitrate leaching to the stream at Quartz Creek was especially retarded.

Further, since resin bags measure dissolved, hence leachable, nitrate, the ratio of nitrate concentration in the stream to that in the soil can be calculated. This ratio was .0001 at Quartz Creek and .008 at Mack Creek, suggesting that the Mack Creek site may be "leakier" than the Quartz Creek site.

Possible explanations of the above include that:

(1) biological processes may be immobilizing both ammonium and nitrate in alluvial soils at Quartz Creek more than at Mack Creek;

(2) subsurface hydrological transport of nitrate from non-alluvial soils to the stream may be considerably greater at Mack Creek than at Quartz Creek;

(3) greater denitrification may have occurred in the alluvial soils at Quartz Creek than in those at Mack Creek; and

(4) quantity and quality of allocthonous litter in Quartz Creek may be greater and/or higher than in Mack Creek, resulting in more rapid biological immobilization of ammonium and nitrate leached to the stream.

III. Conclusions

The trends and correlations presented suggest that the groups identified by PCA were based on reasonable and interpretable structure in the data. The structure relates to carbon content, particle size characteristics, and amorphous mineral content of the soil. Soils with higher carbon contents developed generally on older and/or aggrading geomorphic surfaces. Geomorphic surface and plant community often correlated well with soil characteristics and may be useful variables when mapping the distribution of third-order riparian soils of the region.

Several general characteristics of the soils at Mack and Quartz Creeks can be drawn from the data:

1. Riparian soils of these sites are loams or sandy loams, and are less acidic than upland soils of the region;

2. Factors such as charcoal and wood fragments may confound estimates of soil carbon content;

3. Fans, especially colluvial fans, are the geomorphic surface most enriched in amorphous aluminum. Frequency of amorphous aluminum enrichment of the 0-15 cm depth samples was 70% greater at Mack Creek than at Quartz Creek;

4. Fine earth content of the 15-30 cm depth is positively correlated with plant community type, as has been observed by other workers;

5. The potential for nutrient leaching appears to be highest in the spring;

6. Differences between sites were most significant at 15-30 cm depth. Sampling at this depth, and perhaps at lower depths, should not be overlooked in future surveys.

Variation in soil development at Mack Creek was expected as the time since catastrophic disturbance was relatively great. This site is topographically more variable than the Quartz Creek site. Soils of increasing age/aggradation at Mack Creek had both higher carbon and fine earth contents. Slope-bottom soils were sandy and carbon-rich, providing excellent conditions for microbial mineralization. Colluvial fans had the highest clay contents. Correlations between geomorphic surface and sediment coarseness or silt/clay contents have been noted by other workers. Correlations between NaF pH and plant community or geomorphic surface raise questions as to which variable is independent, and which dependent.

Mack Creek appears to be a nitrogen immobilizing system. Mineralizable nitrogen levels were high only in the alluvial and slope-bottom soils. Although the Mack Creek soil types differed significantly in exchangeable ammonium content, they were similar in extractable nitrate content. The highest levels of extractable nitrate and exchangeable ammonium were found in alluvial soils, and were negatively correlated with plant community. Nitrate was retained in quantity only on resins placed in alluvial soils. Despite a considerably lower total nitrogen content, the proportion of nitrogen mineralized in alluvial soils equaled that of the slope-bottom soils. There would thus appear to be a potential for nitrogen to leach to the stream from alluvial soils. Measurable nitrate in spring-collected stream water samples was indeed found by Cliff Dahm at these sites.

Soils at Quartz Creek, at both depths and across a variety of surfaces, were physically homogeneous, possibly because of the recent severe disturbance. There was no apparent correspondence between soil size-classes and carbon contents, possibly due to soil mixing caused by logging. Nitrogen and CEC levels of these soils were particularly well correlated with geomorphic surface, perhaps reflecting differences in influence of the recent disturbance on geomorphic surfaces.

Quartz Creek is a nitrogen-fixing (generating) system. Mineralizable ammonium levels were greatest in the carbon-rich upper colluvial fans. Soils differed in extractable nitrate contents which were highest in the upper colluvial and alluvial fan soils, and was correlated with CEC. Considerable nitrate was retained by resins in all soils during both seasons sampled, with greater amounts measured in alluvial soils during the spring than in the fall. Resin-bound ammonium in alluvial soils was also greatest in the spring.

Alluvial soils of the two sites differed as follows:

1. Mack Creek alluvium is characterized by organic matter accumulation and greater soil profile development. The 0-15 cm depth soils are wetter than those of Quartz Creek, rich in Kjeldahl-P and amorphous aluminum, and have a high CEC. The 15-30 cm depth soils of Mack Creek have higher carbon and Kjeldahl-P contents than do similar soils at Quartz Creek.

2. Quartz Creek alluvium is strongly influenced by biological nitrogen fixation. Both soil depths had much greater extractable nitrate contents than did soils of Mack Creek. High levels of exchangeable ammonium characterized the 0-15 cm depth soil and total nitrogen content of the 15-30 cm depth was greater at Quartz Creek than at Mack Creek.

3. Although extractable nitrate contents of the 15-30 cm depth soils were not greatly different at the two sites, nitrate levels in Mack Creek were approximately 6 times greater than in Quartz Creek, suggesting either that

nitrate leaching in Quartz Creek alluvial soils is retarded, or that nitrate is more rapidly removed by biological activity in Quartz Creek.

Chapter 6

CONCLUSIONS

I. Summary of the Results

From the data presented, it appears that both soil development and plant species distribution are influenced by the variable effect of the stream on the different geomorphic surfaces. It seems reasonable also to hypothesize that soil fertility in riparian ecosystems is linked to stability of the geomorphic surface at Mack and Quartz Creeks, and possibly at other third-order forested stream sites in the western Cascades.

Principal component analysis and discriminant analysis identified plausible soil types in heterogeneous riparian areas, despite small sample sizes. These soil types probably represent colluvial or illuvial complexes. PCA showed variables associated with carbon accumulation and mineral weathering to constitute the most important factors separating observations. The tight clustering of observations when arrayed by geomorphic surface suggests a correspondence between geomorphic surface and soil development, and that geomorphic surface may be an effective means of blocking these systems.

General conclusions regarding site characteristics include the following:

1. there are clear trends in carbon and nitrogen at both sites that are, to some extent, associated with geomorphology;

2. NaF pH values suggest that amorphous aluminum content may be linked to geomorphic processes;

3. available nitrogen is more abundant at Quartz Creek;

4. mineralized nitrogen (microbial biomass) is more abundant at Mack Creek, and is not nitrified to any extent; and

5. driving variables for the Mack Creek alluvial soils appear to be associated with weathering (C CEC, P, NaF pH), and for the Quartz Creek soils may be related to nitrogen fixed by red alder.

Future work might include further investigation of:

1. the positive correlation at both sites between CEC at 0-15 cm depth and geomorphic surface;

2. common factors which may better explain the observed correlations between:

(a) NaF pH and nitrogen-mineralization (factor may be greater P-sorption, hence unavailability, with increasing amorphous aluminum content);

(b) extractable nitrate level and carbon content at Quartz Creek (factor may be anion exchange capacity);

(c) Kjeldahl-P distribution (factors may be soil particle size-class or form of phosphorus, i.e. fulvic);

3. the possible mechanisms accounting for higher nitrate levels in the stream at the Mack Creek site in the spring, despite the far greater apparent potential for nitrate leaching from Quartz Creek soils to the stream; and

4. the linkages between the *Vaccinium alaskaense*/*Vaccinium parvifolium* plant community on colluvial fans at Mack Creek, high clay and amorphous aluminum contents of the 0-15 cm depth soils, and low nitrogen mineralization in these soils.

II. A Proposed Experimental Design for Riparian Soils

Since there is a strong association between soil type and geomorphic feature, I propose that riparian soils of third-order montane stream systems, or those of other very heterogeneous systems, may be objectively sampled by an experimental design based on blocks that correspond with geomorphic surfaces. I further suggest that the important measurement variables in similar soils of the vicinity are relatively few in number, and that these correspond, at least in part, with the differentiating variables identified by discriminant analysis (Table 4-4). Additional variables of importance are likely to be associated with the factors and processes that describe the first two principal components. In greatly different systems, the process of soil formation may be dominated by factors other than those measured here. Consequently, the variables of most importance which differentiate among soils will not necessarily be the same as those identified here.

Blocks may need to be discontinuous if the areas sampled are to be large enough to represent the various geomorphic surfaces. More intensive sampling of discontinuous blocks, defined by geomorphic surfaces, may yield insight regarding the character of riparian soils and the distribution of plant communities associated with these soils.

A more highly refined approach to riparian soil characterization, such as the one proposed above, could be of considerable value in the effort to define buffer strips around streams. The present "guesstimate" approach, in which an arbitrary distance from the stream is used to define rigid corridors, is inadequate. It is well established that variation in vegetation types adjacent to streams is necessary for highly productive fisheries. If we can identify relatively stable geomorphic features, with soils of known chemical and physical characteristics, it may be that we can develop marking guides for stream biologists which would permit the identification of ragged-edge buffer strips. The outcome could be the identification of variables which may be considered during economic assessment, and the eventual optimal utilization of both our riparian-timber and fisheries resources.

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APPENDIX

Variables measured.

I. **Sample point description**

Slope (%)
Distance to bank-full-width (ft)
Geomorphic surface
Plant community

II. **Soil profile characterization**

Horizon thickness (cm)
Horizon stone content (%)
Horizon structure, consistence, and mottling
Fine root depth (cm)
Root abundance within horizons
Depth to ground water (saturated zone)(cm)

III. **Visual soil evaluation**

Wet soil hue, value and chroma
Dry soil hue, value and chroma
Evidence of stream-worked stones
Presence of charcoal (< 2 mm, 2-4 mm, and > 4 mm size categories)

IV. **Soil physical characteristics**

A. **Bulk soil**

Fine earth fraction (< 2 mm size category) (%)
2-4 mm size category (%)
Coarse fragment fraction (> 4 mm size category) (%)

B. **Particle-size analysis of the fine-earth**
(Mack Creek 0-15 cm samples only)

0-2 μm clay (%)
2-5 μm, 5-20 μm, and 20-45 μm silt (%)
.045-.105 mm, .105-.25 mm, .25-.5 mm, .5-1 mm, and 1-2 mm sand (%)
.045-2 mm organic matter (%)

V. **Soil chemical characteristics**

pH
NaF pH
CEC (cmol(+)/kg)
Extractable NO_3^- and exchangeable NH_4^+ (mg/kg)
Mineralized NH_4^+ (mg/kg)
Total Kjeldahl NH_4^+ and ortho-phosphate (mg/kg)
Total Leco Carbon (%)

VI. **Mixed-bed resin measurements**

10 week Spring resin NO_3^-, NH_4^+, and PO_4^{2-} (mg/kg)
10 week Fall resin NO_3^-, NH_4^+, and PO_4^{2-} (mg/kg)

(Filter paper decomposition experiments for Kermit Cromack were run concurrent with resin placement.)

(Stream water was analyzed concurrently for NO_3^- and NH_4^+ in the spring by Cliff Dahm.)