Sediment Delivery to Headwater Stream Channels Following Road Construction and Timber Harvest in the Blue Mountains, Oregon

by

Robert Earl Gill

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Many studies have focused on improving our understanding of the effects of timber harvesting activities on soil, water, and fisheries resources. Much of this work has led to the development and widespread use of soil erosion prediction models by land managers. This widespread use has often resulted in model applications that are outside the bounds in which the models were developed. There is currently no adequate method for predicting the quantity of sediment delivered to first and second order channels following road construction and harvesting in areas of ash-influenced soils in the Blue Mountains of eastern Oregon. The objectives of this study were: (1) to determine the amount and rate of sediment delivery to ephemeral (first and second order) stream channels following road construction and logging, and (2) to evaluate the WWSED sediment yield predictions.

A variety of methods were employed to accomplish these objectives, including: in-channel and on-slope sediment trapping for quantity and rate determination, physical characterization of the area contributing flow and sediment, physical characterization of the soil samples themselves, and statistical analysis for extrapolation of results.

No statistically significant relationships between the quantity of sediment yielded versus either inherent or management disturbance factors could be concluded from this data set. While there appears to be no significant relationship between inherent or management induced disturbance factors and sediment yield, there has been a two-fold increase in sediment yield when comparing 1993 to 1991 sediment yields, and a ten-fold increase in sediment yield when comparing 1993 to 1992 sediment yields. The R-Squared values for 1993 sediment yield versus inherent values were considerably higher than 1991 or 1992 values.

It can be concluded that while there was an increase in annual sediment yield in the Syrup Creek Study Area, there is no statistically significant relationship between this increase and inherent or management factors. This may be due, in part, to the limited data set with only three years of observations. It is likely that there are other inherent and management factors which would help explain the variation in sediment yields.

Results indicate that the WWSED Model has drastically over estimated the sediment yield from this area. From this, we can conclude that the variability of natural systems is far more complex than can be simplified into a prediction model.

Several additional years of measurement are necessary. The WWSED model predicts sediment yield for a seven year period. At a minimum, measurements should continue for an additional four years and preferably longer. In addition, it is recommended that a pumping sampler be installed at the mouth of the study area to quantify total suspended load yielding the watershed. This may assist additional years of sampling and provide a more robust data set in which to evaluate the WWSED model.

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INTRODUCTION

Many studies have focused on improving our understanding of the effects of timber harvesting activities on soil, water, and fisheries resources. Much of this work has led to the development and widespread use of soil erosion prediction models by land managers. This use has resulted in model applications that are outside the bounds in which the models were developed, for example, different soil and geologic types, and different hydrologic and climatic regimes.

There is currently no validated method for predicting the quantity of sediment delivered to first and second order channels following road construction and harvesting in areas of ash-influenced soils. Ash-influenced soils are common throughout central and eastern Oregon. It is commonly held that sedimentation increases with increasing slopes and with increasing amounts of surface soil disturbance. There is, however, little (if any) available data of actual quantities of ash-influenced soil moved from disturbed sites to stream channels.

It is commonly accepted that sediment eroded from road fill-slopes contributes a very large proportion of the total sediment reaching streams. It has been shown that the surface condition of a road fill and the distance to a stream channel controls the amount of sediment actually reaching the stream. The application of this concept in a soil erosion model requires that the amounts and conditions be measured in the field and delivery coefficients derived for typical conditions.

A soil erosion (sediment yield) prediction model (R1-R4 Sed Model) has been developed by a working group of soil scientists, hydrologists, and watershed specialists of the USDA Forest Service, Intermountain Region, Northern Region, and the Intermountain Forest and Range Experiment Station (Cline et al. 1981). The procedure was developed principally for watersheds in or generally associated with the Idaho Batholith. The model was adapted for use on the Wallowa-Whitman National Forest. This adaptation is known as WWSED.

The WWSED model produces quantified estimates of sediment yields prior to management (natural sediment yield) and sediment yields for seven years in response to various management scenarios. The types of management activities included in the model are roading, logging, and fire. The model estimates on-site erosion for a given management activity, modifies the amount of erosion according to general land unit characteristics, delivers the eroded material to the stream system, and routes it through the watershed to a critical stream reach. Here interpretations are intended to be made by qualified professionals on the potential effect of the delivered sediment.

The WWSED model simplifies an extremely complex physical system and is developed from a limited data base. Although it produces specific quantitative values for sediment yield (i.e., tons/sq. mi./year), the results are intended to be treated as relative indicators of how real systems may respond. Values currently produced by this procedure are probably only useful as comparisons where large differences among alternatives are produced and not for predicting specific quantities of sediment yielded. Validation of the sediment delivery coefficients of this model will allow for improved prediction of sediment yield and reduced error associated with current predictions.

Study Objectives

The objectives of this study were: (1) to determine the amount and rate of sediment delivery to ephemeral (first and second order) stream channels following road construction and logging, and (2) to evaluate the WWSED sediment yield predictions.

LITERATURE REVIEW

Little research has been done in eastern Oregon and Washington involving erosion and sedimentation in streams, and even to a lesser extent, research concerning the embryonic survival of salmonids. This review will focus on the results of studies conducted in the Pacific coast conifer type of western Oregon and Washington, as well as studies conducted in the western inland conifer type of the Rocky Mountains in an attempt to address sediment increases due to logging and roading, and the effects it has on fish production. Though the norms may vary greatly because of differences in the inherent erodibility of soils and in geology, climate, landform, and vegetation, the framework for conceptual ideas is available and can be applied to many forest management activities in the Blue Mountains.

Climate

The climate in the inland conifer type forest varies widely. Generally, precipitation ranges from more than 30 inches annually at higher elevations to less than 20 inches annually in lower elevation forests (Swank et al. 1989). More than 75 percent of the annual precipitation is snow.

In contrast, climate throughout the Pacific coast conifer region is generally characterized by heavy fall and winter precipitation and relatively dry summer periods. In western Oregon and Washington, average annual precipitation ranges from about 40 inches in the inland valleys to more than 150 inches along the Pacific coast (Swank et al. 1989). At upper elevations, snowpack depth may reach 100 inches in some years but generally is 35 to 60 inches.

The climate in the Blue Mountains is characteristic of the snow dominated inland conifer type. Precipitation varies but is drastically less than the Pacific coast type climate.

More than half of the annual precipitation occurs as snow during the winter months. However, summer rainfall does occur. Storms may be of short duration, high intensity convectional type. Thunder storms with intensities of 3.9 inches per hour occur periodically (Buckhouse and Gaither 1982). Note that it is during these storms that the threat of erosion is most prevalent.

Natural Erosion Rates

Water is the primary mechanism for transporting substances within and from forested lands. The processes of precipitation, interception by plant surfaces, transpiration, infiltration of water into the soil, and stream runoff are common to all forests. However, the magnitude and relative importance of processes varies considerably between forest types. Furthermore, management practices can alter these processes, which then produce changes in soil and water characteristics.

Sedimentation involves the detachment, transport, and deposition of particles by this flowing water. The "natural" or "background" sediment rate varies dramatically depending on the geology, soil erodibility, landform, vegetation, and local hydrology and climate. For example, Megahan (1972) reported sedimentation rates from undisturbed watersheds in the Idaho Batholith to range from 4.0 to 24.2 tons/sq. mi./year. Leaf (1974) reported average sediment yields of 8.2 and 5.6 tons/sq. mi./year in the Rocky Mountains of Colorado. Beschta (1978) reported an average 98 tons/sq. mi./year in Flynn Creek in the Coast Range of Oregon. The Umatilla National Forest reported 27 tons/sq. mi./year has been measured as occurring in a basaltic watershed in the Mill Creek drainage (about 30 sq. mi.) (pers. comm. Hauter 1992). The Payette National Forest reported 25.6 tons/sq. mi./year has been measured for gneiss granitic areas (about 1 to 2 1/2 square mile) (pers. comm. Hauter 1992). The inherent variability in natural systems makes it difficult to isolate a background sedimentation rate due to the difference in geology, soils, vegetation, and climate of different geographic areas.

Forest management activities associated with timber harvesting can affect the physical, chemical, and biological properties of the soil. If these activities increase soil erosion, then water quality may be decreased through stream sedimentation with an accompanying loss of long-term site and stream productivity (Swank et al. 1989). The type and magnitude of erosion depends on the amount of soil exposed by management practices, the kind of soil, steepness of the slope, weather conditions, and treatments following disturbance, such as broadcast burning. We can infer however, that under undisturbed forest conditions, surface erosion is relatively low because enough vegetation and litter protects the soil surface. Soil permeability is normally high because there is relatively little soil compaction occurring, thus little or no overland flow.

Management Related Erosion Rates

Any management activity that exposes and/or compacts the soil and reduces infiltration can concentrate surface runoff and thereby accelerate erosion. Felling trees alone seldom causes erosion although some soil compaction and surface gouging may occur during the operation (Swank et al. 1989). In contrast, road building, skidding and stacking logs, and some site prep activities can produce major soil surface disturbance that greatly increases the erosion on a site.

The amount of erosion and sedimentation vary widely within the inland conifer type. Following timber harvest, however, surface erosion usually accelerates in response to disruption of the soil structure during logging (roads, skidtrails, and landings), removal of protective cover, increased raindrop impact and wind movement, and reduced infiltration rates (resulting from compaction) that create overland flow (Swank et al. 1989). Logging on course-textured, permeable soils with careful road building produced little sediment yield in the Rocky Mountains of Colorado (Swank et al. 1989). In southwestern ponderosa pine forests, sedimentation varied from 1.3 tons/acre (832 ton/sq. mi.) when 31% of the basal area was removed to 27 tons/acre (17,280 tons/sq. mi.) under 100% removal (Swank et al. 1989).

Disturbance by road construction can contribute substantially to erosion in sensitive areas. Roads accelerate surface erosion by increasing slope gradients on cut and fill slopes, intercepting subsurface flow, and concentrating overland flow on road prisms and in channels.

A 7.7 fold increase in suspended sediment yield in the first year following road construction was reported in Johnson Gulch Creek of western Montana (Anderson and Potts 1987). A study by Megahan and Kidd (1972) illustrates the relative effects of timber harvesting in relation to road construction on steep granitic slopes in Idaho. Surface erosion rates on an area influenced by ground cable logging were increased 1.6 times over undisturbed erosion rates for a 6 year study period. In contrast, erosion rates on logging roads were 220 times greater than on undisturbed sites. The combined effect of cutting plus skidding and roads increased sediment production over 45 times for the entire watershed (Megahan 1972).

Although large erosion rates from roads occur immediately after logging, these decrease rapidly after disturbance (Beschta 1978, Megahan 1972). Within 5 years, erosion rates were greatly reduced but still greater than under undisturbed conditions (Megahan 1972). It is doubtful that erosion on roads in the Idaho Batholith will permanently decrease, within a reasonable time, to the level that existed before disturbance (Megahan 1972). The road tread and steep cut slopes are composed of weathered granitic bedrock that continues to disintegrate after exposure faster than natural stabilization can take place. The material resulting from bedrock disintegration is readily transported during subsequent runoff events.

As discussed earlier, the amount of stream sedimentation resulting from timber harvesting depends largely on the amount of disturbance occurring during logging and subsequent erosion. Soil disturbance is more related to the type of logging operation than to silvicultural system in the Pacific coast region. Brown and Krygier (1971) showed that clear-cut logging may produce little or no change in sediment concentrations in small streams in comparison with road construction. Beschta (1978) reported a five fold increase the first year after logging and slash burning in the Oregon Coast Range.

A major disturbance during timber harvesting is road construction. Substantial increases in sediment yields have been noted on watersheds during and following the construction of forest roads. Beschta (1978) and Brown and Krygier (1971) found that midslope roads in steep terrain were the leading factor of increased sediment production in the Coast Range of Oregon. Erosion rates on roads and landings in southwestern Oregon were 100 times those on undisturbed areas, while erosion on harvested areas was 7 times that of undisturbed sites (Swank et al. 1989). However, a study of the Middle Santiam River basin in the Cascade Range of Oregon reported that the absence of significant long-term increases in sediment export during basin development and the infrequent occurrence of landslides suggests that the forest management techniques used were largely successful in protecting water quality and minimizing watershed disturbance (Sullivan 1985). It is worth noting that this study area may be of a stable nature, therefore these techniques may not be suitable for protecting water quality in other geographic regions.

The amount of stream sedimentation resulting from roads depends largely on the quality of construction and maintenance. Roads requiring a four to six inch lift of 1.5 to 3 inch minus aggregate reduced sediment production by approximately 80 percent over un-graveled road surfaces (Burroughs and King 1989). Burroughs and King (1989) reported drastic reductions in sediment production by treating cut and fill slopes with erosion control measures such as, erosion mats, chips, gravel, straw or hydromulch.

The two primary processes by which roads contribute sediment to stream systems are by increasing the incidence of mass soil failures in a watershed, and by surface erosion of road prisms and the transport of this material into streams (Bilby et al. 1989). Thus, we can expect that road construction would be likely to increase mass erosion hazards because of failures in both cut and fill slopes. Mass erosion is most likely to occur during large rainfall and/or snow events when subsurface flows are generated in side slopes or in road cut and fill slopes (Beschta 1978, Megahan 1972). Thus a watershed must have not only the potential for failure but also a hydrological event of sufficient magnitude before an increase in sediment production occurs (Beschta 1978). However, properly constructed roads on gentle to moderate slopes on stable topography present little hazard. Both construction difficulty and erosion hazard increase rapidly when roads are pushed into steep terrain, cut into erosive soils or unstable slopes, or encroached on stream channels (Megahan 1972, Megahan and Kidd 1972).

Landslides are an important source of sediment in both undisturbed and managed steep drainages in the Pacific Northwest. Human activities probably have little influence on large, deep-seated, massive earthflows. However, smaller and shallower avalanche and debris torrents are most prone to be influenced by forest management activities (Swank et al. 1989), and of those, roads have been the major activity associated with shallow landslides. Proper forestry practices addressing drainage, road construction and maintenance, compaction of road fill, and the incorporating of organic debris can reduce landslide related erosion (Swank et al. 1989).

Road use is also a major factor attributing to sedimentation. A heavily used road segment was found to contribute 130 times as much sediment as an abandoned road (Reid and Dunne 1984). A paved road, along which cut slopes and ditches are the only sources of sediment, yielded less than 1% as much sediment as a heavily used road with gravel surface (Reid and Dunne 1984). Reid and Dunne (1984) found that during a period of heavy traffic (more than four loaded trucks per day) roads contributed sediment at 7.5 times the rate of the same roads on days when they were not being used. Sediment concentrations produced during periods of active road use represent a combination of flushing of accumulated material from the road and movement of sediment being produced at the time (Bilby et al. 1989).

Implications to Fisheries Resources

Although soil erosion and sedimentation are natural and healthy functions of stream systems, accelerated sediment delivery can be detrimental to salmonid habitats. The amount of acceleration and its impact at a particular site are important concerns when evaluating potential impacts.

Once soil and organic materials arrive at a channel, their downstream movement depends on many factors, including material characteristic (particle size and quantity), hydraulic forces (magnitude of high flows, size of stream, etc.), and the availability of large roughness elements (large woody debris, etc.) that provide channel stability (Heede and Rinne 1990).

When fine sediments are in transport, the intrusion of some of the particles into relatively clean or porous streambed gravels will occur. If the sediment source continues, increased amounts of fines may settle deeper into the streambed as the gravels are exposed to more and larger freshets (Beschta 1991). The infiltration of fines into streambed gravels can alter the quality of the bed for spawning fish.

The effects of forest management activities on salmonid habitat have ranged from severe to undetectable. Severe effects occurred in the South Fork Salmon River, Idaho. Fifteen years of heavy logging and road construction in the South Fork basin in the Idaho Batholith followed by large floods in 1962, 1964 and 1965 caused massive sedimentation in the river (Platts et al. 1989). Roads were the largest contributors of sediment.

Spawning habitat of summer chinook salmon and summer steelhead were overwhelmed with fine granitic sediments. In 1966, fine sediment in spawning areas ranged from 45 to 80% particles less than 4.7 mm in diameter. A moratorium was declared on timber harvest and road construction in the basin in 1966. By 1974, fine sediments in the spawning areas had decreased to near optimum levels (12 to 26%) for the basin (Platts et al. 1989).

Other studies have shown smaller increases in fine sediments in stream substrates after logging and road construction (pers. comm. Beschta 1991, Chapman 1988, Everest et al. 1987). In some instances, clear-cut logging may produce little or no change in the sediment concentration in small streams (Brown and Krygier 1971). The greatest changes are often associated with road building operation that proceeds logging and slash burning (Beschta 1978, Brown and Krygier 1971). The effects on salmonids have been variable but usually less severe and of shorter duration when the size of the sediment source areas is quickly reduced (Everest et al. 1987).

Sediment has been the focus of attention by biologists investigating the potential impacts of land use activities for decades (Chapman 1988, Everest et al. 1987). Most studies on salmonids have been concerned with the effects of sedimentation on egg and fry survival; however, Everest et al. (1987) emphasizes that little effort has been made to relate sediment as a limiting factor to salmonid populations.

Everest et al. (1987) and Chapman (1988) discuss several laboratory studies documenting that fine sediments can reduce the reproductive success of salmonids. Fine sediments do this by reducing the permeability of gravels, which impede intragravel flow and deplete the availability of dissolved oxygen to developing embryos (Johnson 1980). Low dissolved oxygen can cause direct mortality or delay the development of alevins.

Laboratory studies have investigated the effects of fine sediments out of context with natural aquatic ecosystems (Chapman 1988, Everest et al. 1987). None of these studies can assist managers in determining if sediment is limiting natural populations of salmonids (Everest et al. 1987). What can be inferred about the laboratory studies is that at some specific life stages salmonids are vulnerable to deposited and suspended inorganic sediment in closely controlled studies (Chapman 1988). The exact effects of chronic sedimentation on salmonids have been difficult to determine due to the complexity in studying natural ecosystems.

Part of the problem of documenting effects of sediment generated by forest management results from the concurrent multiple environmental changes caused by natural events (such as large storms) and management activities (Everest et al. 1987). Roads and logging activities near streams cause simultaneous changes in sediment loads, solar radiation, channel morphology, water temperature, streamflow and other features of the stream environment (Brown and Krygier 1971, Scrivener and Brownlee 1989). Isolating the effects of sediment is difficult.

Platts et al. (1989) speculated that the massive sedimentation in the South Fork Salmon River, Idaho, reduced the run of summer chinook salmon in that system. Sediment was undoubtedly a contribution to the decline of the run, but its effects could not be separated from the simultaneous high mortality of the upstream and downstream migrants at dams on the Columbia and Snake Rivers (Everest et al. 1987). Also, various salmonid species utilizing forested watersheds exhibit numerous variations in life history patterns, behavior, and habitat preferences, and therefore exhibit different responses to sedimentation (Everest et al. 1987, Chapman 1988, Young et al. 1990).

The structure of salmonid redds mitigates the effects of fine sediment on survival of incubating embryos. Chapman (1988) found that the permeability of the egg pocket greatly exceeds that of the surrounding substrate and that of redd areas outside the egg pocket. Simulated egg pockets (those used in lab studies) do not model actual egg pocket conditions so effects on survival due to various percentages of fines have produced results that are quantitatively inconsistent among and within fish species. Natural variability also exists within the natural egg pocket, embryonic survival varies among species as egg viability comes under the influences of natural selection (Young et al. 1990). Under certain circumstances fine sediments within the redd environment of salmonids can directly reduce the egg-to-fry survival and fry quality by reducing intragravel flow and dissolved oxygen content.

Field studies (described by Everest et al. 1987 and Chapman 1988) have been mainly conclusive in assessing the extent and duration of the effects of chronic sedimentation on salmonid populations at the subbasin level. Research conducted on Carnation Creek, British Columbia (Scrivener and Brownlee 1989), however, attempted to linked increases in streambed sediments with decreases in chum salmon fry and to a lesser extent to decreases in coho salmon escapement at the basin level.

The Carnation Creek study documented increases of 4.8 and 4.7% in pea gravel and sand in spawning areas after logging was begun. The study also compiled data on the number of seaward moving chum and coho salmon fry and coho smolts. Annual survival from potential egg deposition to emigrant chum fry was correlated with annual quality of spawning gravels. Survival declined an average of 9.9% since 1978. Size of emigrants has also declined as gravel quality declined. Because chum salmon fry move to sea soon after emergence, one can assume that decreases in the number and size of fry should result in decreases in returning adults (Everest et al. 1987). However, no clear trend in numbers of returning adults, either up or down, has been evident. Coho salmon egg to fry survival also decreased (13.9%) in relation to declining quality of spawning gravel, but at the same time the average number of coho smolts leaving the basin increased 42%. Where prelogging distribution was made up of almost an equal combination of 1+ and 2+ aged fish, post logging distribution was made up almost entirely of 1+ aged fish. Other factors have compensated for decreased fry production caused by sedimentation. These positive impacts are attributed to a combination of increases in stream temperature that results in earlier emergence (Holtby 1988) and increases in dissolved nutrients that result in higher productivity (Everest et al. 1987). Ironically with the increased number of 1+ juveniles reaching the marine environment, total escapement has declined. The effects of changes in smolt characteristics associated with logging on smolt-to-adult survival are confounded by recruitment variability associated with fluctuations in any of the potentially large number of ocean conditions that affect smolt survival (Holtby 1988).

The results of the Carnation Creek study (and others described by Everest et al. 1987 and Chapman 1988) indicate that the effects of fine sediment on salmonids are difficult to isolate from other environmental changes resulting from forest management.

Sediment Yield Prediction

Much of the information presented above has led to the development and widespread use of soil erosion prediction models by land managers. This use has primarily been associated with project planning to assess a range of alternatives for the purpose of assessing local and cumulative effects of the activity on watershed and fisheries resources.

Larson (1981) provides a brief review of several techniques for predicting sediment yields from watersheds and an evaluation of "An Approach to Water Resources Evaluation of Non-Point Silvicultural Sources" (WRENS) procedure. Many of the assumptions and data used in the WRENS procedures were used in the development of other techniques.

In techniques discussed here, sediment yield estimates are produced using a computerized, adapted version of the "Guide for Predicting Sediment Yields from Forested Watersheds" (Cline et al. 1981), commonly known as the Region 1 - Region 4 (R1-R4) sediment model. The Wallowa-Whitman Sediment Model (WWSED) generally uses the R1-R4 procedures, factors and equations for modeling sediment, however, it has also been modified to include research data unavailable at the time of R1-R4 publication (Burroughs and King 1989, Packer and Christensen 1964, Heede 1990).

A major difference between the WWSED model and the R1-R4 model is the use of a filter strip concept. The WWSED model uses a filter strip concept which essentially assumes that sediment generated from more than 200 feet away from a stream does not reach the channel. Thus, in the WWSED model, not all roads, harvest units and fires contribute sediment to a stream. In the WWSED model, sediment yield is dependent upon how close the sediment-generating activity is to the stream, whereas, the R1-R4 model assumes that all roads, fires and harvest units in a watershed contribute sediment.

The WWSED model calculates sediment yield expected in a typical flow year. Where choices arise in the model, the conservative option is usually chosen (the one generally leading to a higher derived sediment yield). As an example, available water data for a ten-year storm event was employed to generate sediment in a typical year. Additionally, cautions in the application of the R1-R4 model are equally applicable to the WWSED model. While the model generates quantitative results, it is best to use these numbers in a qualitative fashion, tempered with professional judgment.

Basic Components of the WWSED Model

The WWSED model calculates sediment yield in a given watershed (fourth order and higher) for a 7 year period following project implementation. Management activity and fire history for six years prior to project implementation are also included in the calculations to account for differences between natural and existing sediment yield.

Four major components are used in calculating sediment yield estimates from past and proposed activities. These factors are:

1) Natural erosion,
2) Fire erosion,
3) Road-related erosion,
4) Harvest-related erosion.

Natural erosion accounts for erosion of the pristine watershed prior to any other sediment generating activity, such as fire, roads and logging. This portion of the WWSED model calculates a baseline erosion rate for a given watershed, based on the area of the drainage and a research-derived rate of 26 tons/sq. mi./year for rock types prevalent on the Wallowa-Whitman National Forest. This rate was developed from natural erosion rates found on the Umatilla and Payette National Forests, as discussed earlier. The geologic types found on the Umatilla and Payette cover the range of erodibilities for the Wallowa-Whitman National Forest (pers. comm. Hauter 1992). Therefore, the two sediment yield values are considered close enough to first average and then assign a single value to all Wallowa-Whitman geologic types.

Table 1 shows the baseline sediment contributions from fire, roads and logging according to assumptions in the WWSED Model based on Cline et al. (1981). These baseline erosion rates are modified by numerous factors in the model such as road type, sediment delivery ratio (percent of sediment generated that actually reaches the stream), mitigation measures, fire intensity, harvest prescription and harvest method.

□ Year After Origin	1	2	3	4	5	6	7
Roads[1]	67500	18000	5000	5000	5000	5000	5000
Fire[2]	550	120	25	5	0	0	0
Logging[3]	340	180	140	90	40	20	0

Table 1. Sediment yield (tons/sq. mi./year) predictions used by the WWSED model for roads, fire and logging, by year after origin (Cline et al. 1981).

1/ Road area includes horizontal distance from toe of fill to top of cut. Standard 16-foot road assumed to have sustained 5-7 percent grade, balanced construction, inslope with ditch, native surface, and cross drains at 500-foot spacing constructed in granitic materials on a 50 percent side slope and is annually maintained.

2/ Standard fire is assumed to have burned at high intensity and consumed at least 40 percent of standing vegetation. Side slope is assumed to be approximately 45 percent.

3/ Standard logging system is clearcut with tractor yarding. Temporary roads and skid trails are assumed cross ditched and seeded as part of standard logging practice.

Fire erosion accounts for both natural and prescribed fire. The intensity of the fire, slope and location relative to the filter strip influence the amount of fire-derived sediment that reaches a stream. If any portion of a high or moderate intensity fire extends into the filter strip then the entire fire area is assumed to contribute sediment to the stream. It is assumed that low intensity prescribed fires do not contribute sediment regardless of their location, while natural low intensity fires produce sediment only from areas within the filter strip. Sediment yield from fire is assumed to decrease rapidly following the event, and is assumed to decrease to zero in five years (Table 1).

Sediment yield from roads is influenced by surface type, road stability, slope, and distance from the filter strip. In general, unimproved dirt roads contribute more sediment than other road types because of the natural surface and assumed poor stability. Additionally, roads contribute more sediment than any other activity considered by the WWSED model (Table 1). After an initially high erosion rate following road construction, sediment yield from roads levels out, yet continues indefinitely. Sediment from roads contribute significantly to elevated sediment yield above natural levels in some subwatersheds.

Sediment yield due to timber harvest is dependent upon slope, harvest type, yarding method and location relative to the filter strip. Harvest types are split into two categories, clearcut and partial cut. Clearcut units include clearcuts and clearcuts with reserve trees. All other harvest prescriptions are considered partial cuts and are treated equally. Each yarding method has a different potential to increase sediment yield. Helicopter yarding has the lowest sediment yield, while skyline, cable and tractor yarding each contribute increasing amounts of sediment yield according to the WWSED model. As shown in Table 1, initial sediment yield from timber harvest is lower than fire, but sediment is generated for a longer period of time.

Existing sediment yield accounts for past management activities (roads and timber harvest) and fire by augmenting the natural sediment yield based on the values given in Table 1.

Conclusions

Forest management activities often cause concurrent changes in suspended and deposited sediments in streams, stream bank stability, dissolved nutrients, water temperature, stream channel morphology and large woody debris, to mention a few. These changes in combination can produce negative, positive and neutral effects on salmonid populations (Chapman 1988, Everest et al. 1987, Platts et al. 1989, Scrivener and Brownlee 1989). The general consensus concerning forest management is; if sediment delivery to streams occurs with timber harvesting and roading, then increases in fine sediment in the streambed gravels may occur.

Research generally supports the hypothesis that salmonid embryonic survival declines in substrates as quantities of fine sediment increase. Fines tend to reduce gravel permeability and pore space, as well as dissolved oxygen in water available to embryos, thus influencing incubation success. Research generally supports the argument that roads in forested watersheds are the leading producer of sediment. There is evidence, however, that properly located, constructed and maintained forest roads are largely successful in protecting water quality.

Multiple effects of forest management on salmonids have rarely been examined at a basin-wide level, so the present knowledge for isolating the effects of a single variable is not well developed. Measured increases in sediment due to logging and roading are as variable as the inherent "natural" system itself.

DESCRIPTION OF STUDY AREA

The Syrup Creek study watershed is located in the Starkey Experimental Forest and Range near La Grande, Oregon (Figure 1.). The watershed is approximately 3.5 square miles in size and is drained by a fourth order channel (2.4 miles) which is fed by numerous first (14.2 miles), second (6.2 miles), and third order (3.2 miles) streams (Figure 2). All the drainages within the study area are ephemeral with the majority of the water coming off the area in early spring (April and May). The rather open nature of this country, especially the southerly ponderosa pine types and open grassland communities result in rapid snow melt events and an early water loss from the area. The 2230 acre study area has a mean elevation of 4190 feet, a mean slope of about 16 percent and a 100 degree aspect (southeast).

Climate

The climate in the Blue Mountains is characteristic of the snow dominated inland conifer type described by Swank et. al. (1989). Precipitation in this area averages approximately 20 inches per year. More than half of the annual precipitation occurs as snow during the winter months. However, summer rainfall does occur. Storms may be of short duration, high intensity convectional type.

Geology and Soils

The Syrup Creek area is underlain by Columbia River Basalt which is a hard, relatively competent rock type. The landscape is rolling, relatively non-dissected, and stable. Ridge tops are broad and trend in an East-West direction. Current erosion

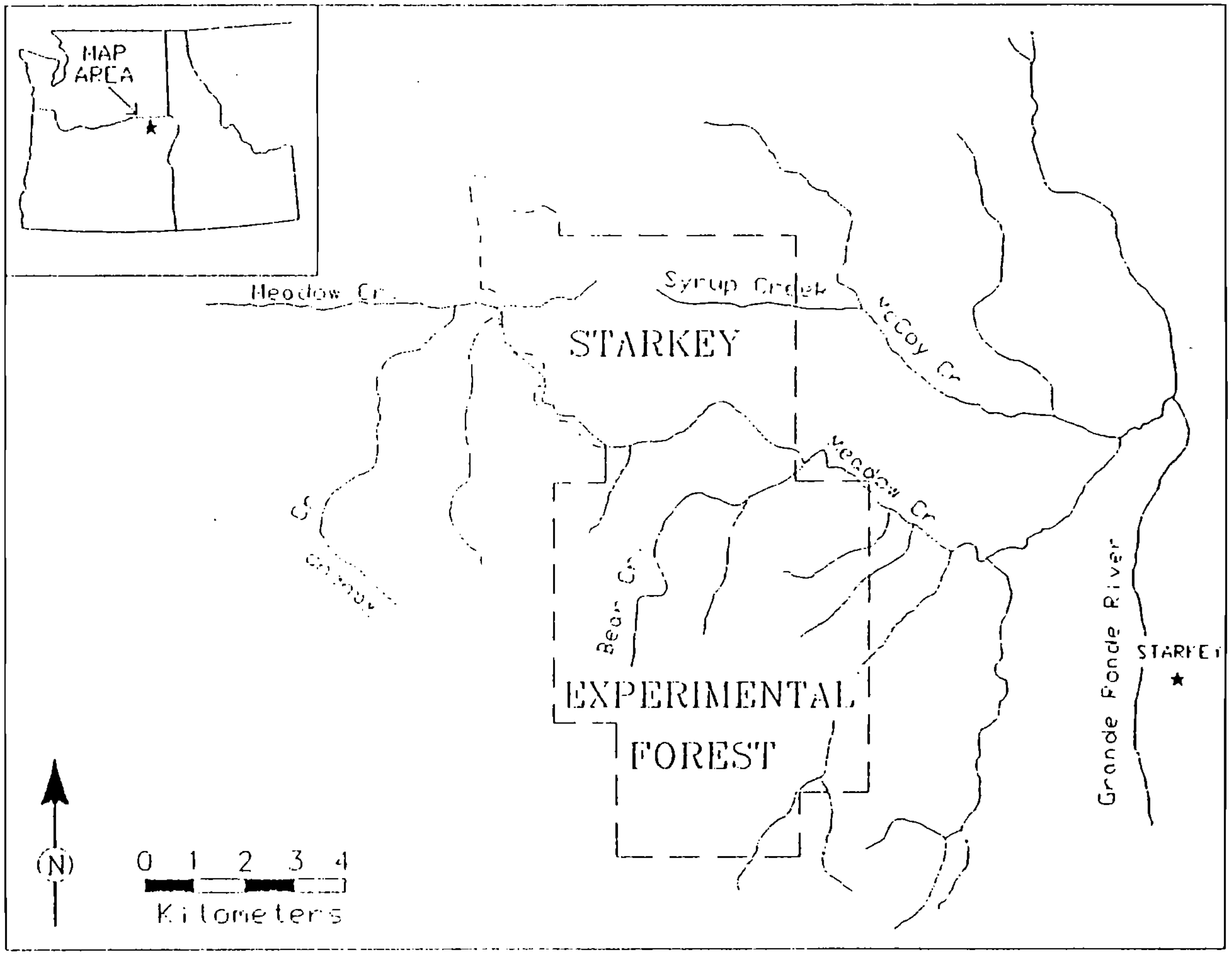

Figure 1. Project study area. Upper Grande Ronde River Watershed in the Blue Mountains of northeast Oregon.

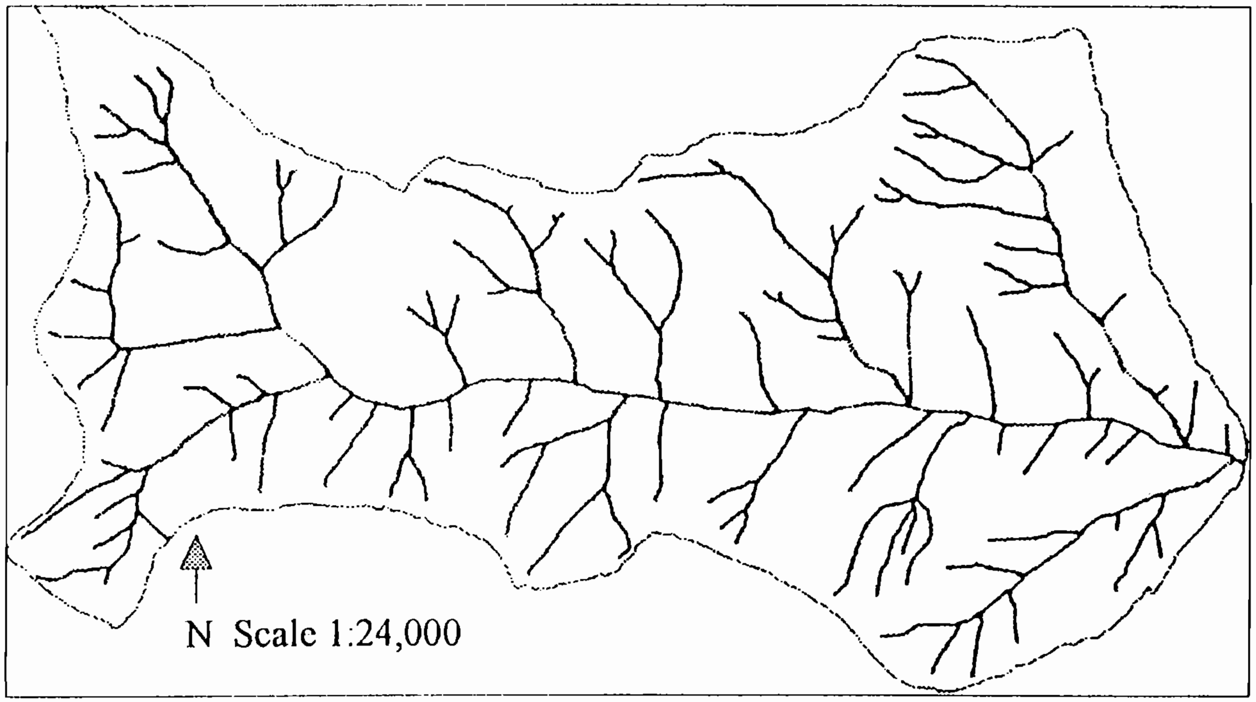

Figure 2. Stream network for the Syrup Creek study area.

problems are associated with roads, overland flow on open grassland communities and stream bank erosion during spring runoff events.

The soils and their related productivity potentials have been defined here based on the presence or absence of volcanic ash. Figure 3 illustrates the ash dominate soils for the study area.

Volcanic Ash Dominated Soils

Volcanic ash dominated sites can be characterized as having higher water holding capacities, greater effective rooting depths and higher productive potentials. The deeper deposits of volcanic ash can be identified by the presence of grand fir and larch with the grand fir usually creating a closed canopy. These deep ash deposits occur on northerly, toe slope positions. The moderately deep ash deposits usually contain lodgepole pine, larch, and occasionally Douglas-fir and ponderosa pine in transition zones. The moderately deep ash deposits occur on broad ridge tops and on slopes with a northerly aspect.

Non-Ash Derived Soils

These soils developed in loess and residuum and colluvium derived from basalt. These soils can be characterized as having low to moderate effective water holding capacities, shallow rooting depths and moderate to low productive potentials. These sites are dominated by ponderosa pine and Douglas-fir. The sites with the least soil development are grassland communities followed by those with marginally productive ponderosa pine communities (10-20 inches of effective rooting depths).

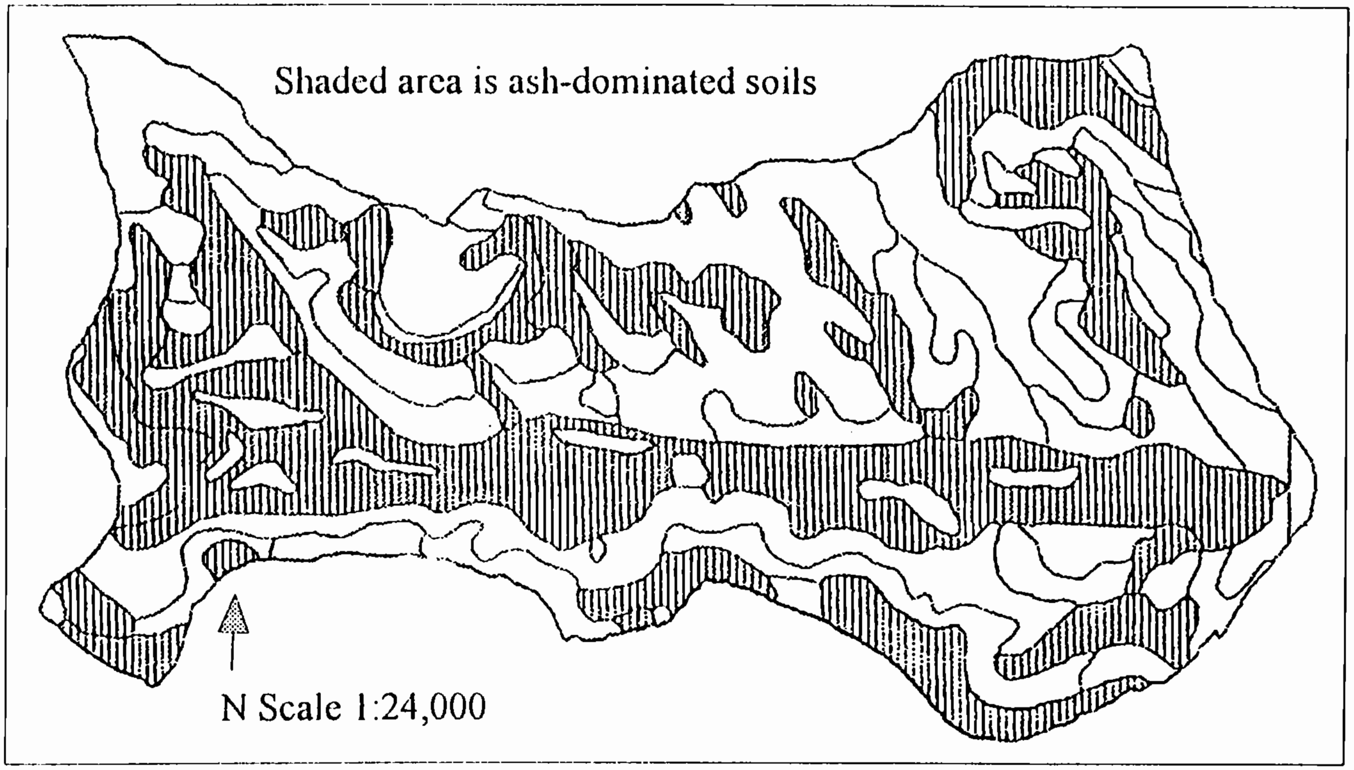

Figure 3. Soils map for the Syrup Creek study area. Ash dominate and non-ash dominated soils.

Grazing History

Domestic ungulate grazing has occurred within the study area for well over a century. More recently, approximately 70 deer and 70 elk have free range of the study area for the period of about mid-March to mid-December of each year. In addition, approximately 50 cow/calf pairs occupy the area for about five weeks each year during the grazing season of mid-June to October 1.

Logging History

Early (around 1927) timber harvest activity of the Mt. Emily Lumber Company resulted in a logging railroad to their timber holdings up the Grande Ronde River. This railroad included a line up Syrup Creek. The Syrup Creek area was in private holding until a land exchange in 1938 when the U.S. Forest Service assumed ownership. Nearly all the merchantable timber was cut on this property between 1933 and 1935 and was moved by railroad (Skovlin 1991).

There have been small salvage sales in the area and most recently the small sale associated with the construction of a game fence. The previous road system was in poor condition in terms of stability, logging and stream sedimentation. None of the roads had more than spot-rock surfacing. The majority of the roads were located on scabs and ridge tops with the exception of two fords across Syrup Creek and the old railroad bed, now a road, up the floodplain.

A major modification of the forest vegetation occurred in the Syrup Creek watershed beginning in 1991. Silviculture objectives for this area, in addition to harvesting mature and overmature trees, was to develop healthy, fully stocked and productive timber stands, composed primarily of budworm and Douglas-fir bark beetle resistant species, ponderosa pine and Western larch. Silvicultural treatments emphasized regeneration harvest methods due to the extensive insect damage.

Harvest prescriptions included 925 acres of clearcut with reserve trees, 81 acres of shelterwood, 291 acres of intermediate harvest and 10 acres of individual tree selection. Logging systems included 1095 acres of tractor, 175 acres of skyline and 37 acres of tractor swing to skyline. Post harvest cultural work included 800 acres of broadcast burning, 150 acres of grapple piling, 100 acres of pre-commercial thinning and stand cleaning, 150 acres of gopher baiting, and 900 acres of planting.

Implementation resulted in harvesting 11.3 MMBF of timber from 1307 acres treated. To facilitate harvest, 2.9 miles of the existing road system were reconstructed and 25.6 miles of new road were constructed.

METHODS

Local Characteristics

The rate of soil erosion for a given geographic area is a function of climate, vegetation, and soil physical characteristics. In order to establish a reference point in which to compare results of this study with current and/or future information, characteristics of the local environment were measured.

The area contributing runoff and sediment to the in-channel trapping locations was characterized in terms of elevation, area, vegetative cover, down woody debris, length of stream channel, slope, and aspect. These characteristics are important in understanding the conditions in which sediment transport occurred. Basin area was measured by standard traversing methods and recorded in acres. Vegetative cover was characterized by visual observation. The number of pieces of course woody debris within the contributing areas was measured by visual observation.

Precipitation measurements were obtained from the weather station located approximately five miles east at the Starkey Experimental Forest and Range Headquarters. Mean elevations, slope and aspect were measured by Digital Elevation Modeling in Geographic Information Systems (GIS).

Disturbance factors, such as roads, logging and fire, were measured. The length of road potentially contributing sediment to stream channels above sediment traps were measured using a hip-chain and recorded to the nearest foot. The amount of area being disturbed by logging and fire was estimated from mapping exercises and recorded to the nearest acre.

In-Channel Sediment Sampling

An in-channel sediment trap was installed in each of twelve ephemeral drainages representative of the watershed in the fall of 1990 (Figure 4). Six were installed within the north aspect of the watershed and six within the south aspect of the watershed. Site specific placement of sediment traps was based on specific characteristics that facilitated construction and reduced the risk of trap failure. It was necessary for the sediment trap location to be sufficiently incised as to provide a large enough catch basin volume (approximately 2 - 5 cubic yards) and to have sufficient quantities of woody materials (logs) available for construction and maintenance of sediment traps.

These were constructed utilizing woody materials, straw bales and filter cloth perpendicular to the channel to act as a filter dam (Figure 5). Construction consisted of placing logs perpendicular to the stream channel secured by wiring them to steel fence posts driven into the ground downstream of the log. Straw bales were then placed upstream of the secured log structure, approximately to the height of the top log (3+ feet). Filter cloth was then placed to line the entire catch basin area. Style 3401 Typar Brand filter fabric was selected because of its strength and filtering abilities. This fabric has a thickness of 15 mils., an Equivalent Opening Size (EOS) of 70 - 100 U.S. Std. Sieve (0.17 mm), a flux of 230 gal./ft.^{2}/min. at 10 inches of water head and a coefficient of water permeability (K) of 2 x 10^{-2} cm./sec.. To reduce the risk of damage by deer and elk, deer and elk repellent was distributed on and around the straw bales during installation.

These catch basins were designed to function as filters as well as settling ponds, and were designed to trap all sizes of material from all sources above the traps, both bedload and suspended load. The goal was to have no streamflow over the catch basin, but to allow all water to filter through the fabric.

Materials (organic and inorganic) were collected from the traps annually following each spring runoff period (between July 01 and September 15) in 1991, 1992 and 1993.

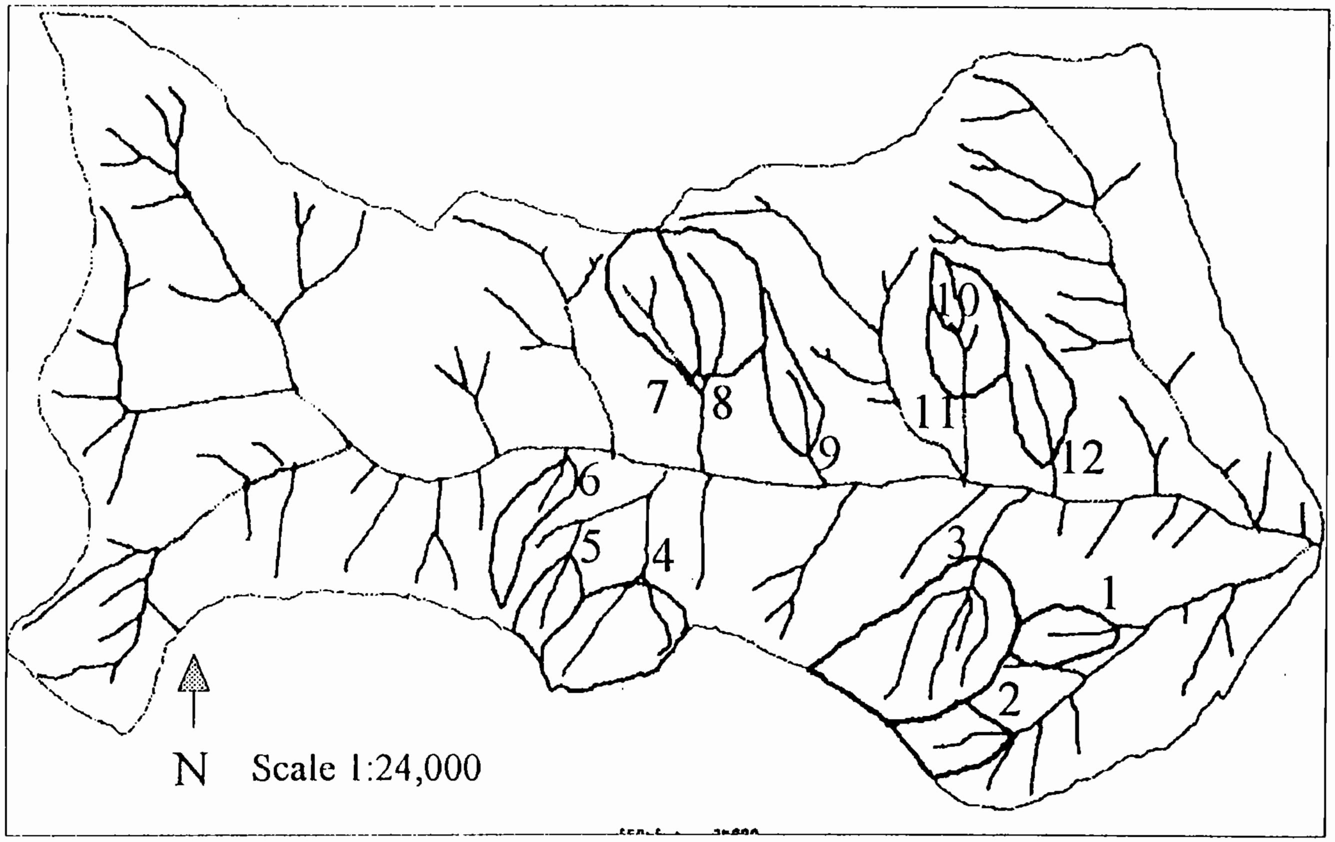

Figure 4. In-channel sediment trap locations within the Syrup Creek study area.

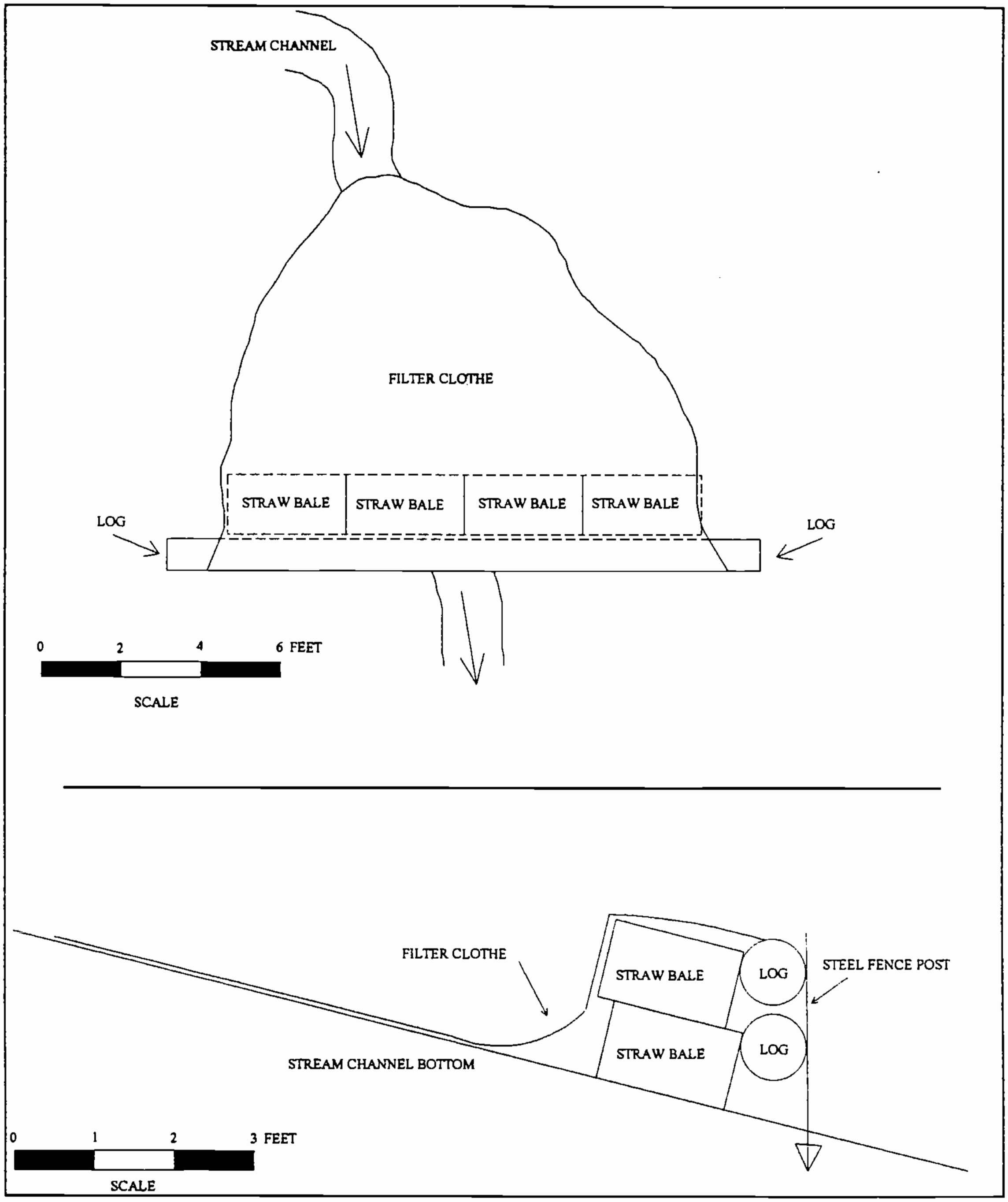

Figure 5. Plan view (top) and cross-section (bottom) depicting in-channel sediment trap design.

Sampling took place following spring runoff but before significant fall rains occurred. The majority of materials were collected by sweeping and shoveling into storage containers. Some quantities of materials were too fine in structure to be collected by sweeping and shoveling due to the ash content in many of the soils. For this reason, a generator-driven vacuum cleaner was used to collect the remaining fine material, as well as retrieve the fine materials entrained in the fibers of the filter cloth. Where feasible, all of the material from each sediment trap was then transported to the laboratory for sample analysis.

On-slope Sediment Sampling

On-slope surface sediment transport was sampled utilizing small (30-cm aperture) sheet metal sediment traps as described by Wells and Wohlgemuth (1987). Sixty-three (63) traps were installed at approximate distances of 5, 10, 15, 20, 25, 35 and 50 feet downslope from road fills and on undisturbed slopes in the fall of 1991 (Figure 6). These boxes were installed as to minimize any local disturbance that may result in sedimentation.

Materials (organic and inorganic) were collected from the sediment boxes following the spring runoff period (between July 01 and September 15) of 1992. Sample collection occurred after spring runoff but prior to the occurrence of fall rains. Sampling was accomplished by brushing the contents into storage containers and transporting to the laboratory for sample analysis. Only those sediment boxes visibly containing sediment (inorganic material) were sampled and considered for laboratory analysis. Those boxes containing only organic materials were cleaned and maintained for the following years analysis.

Sample Analysis

A laboratory analysis was necessary to determine the relative quantities of sediment (inorganic material) found in the samples.

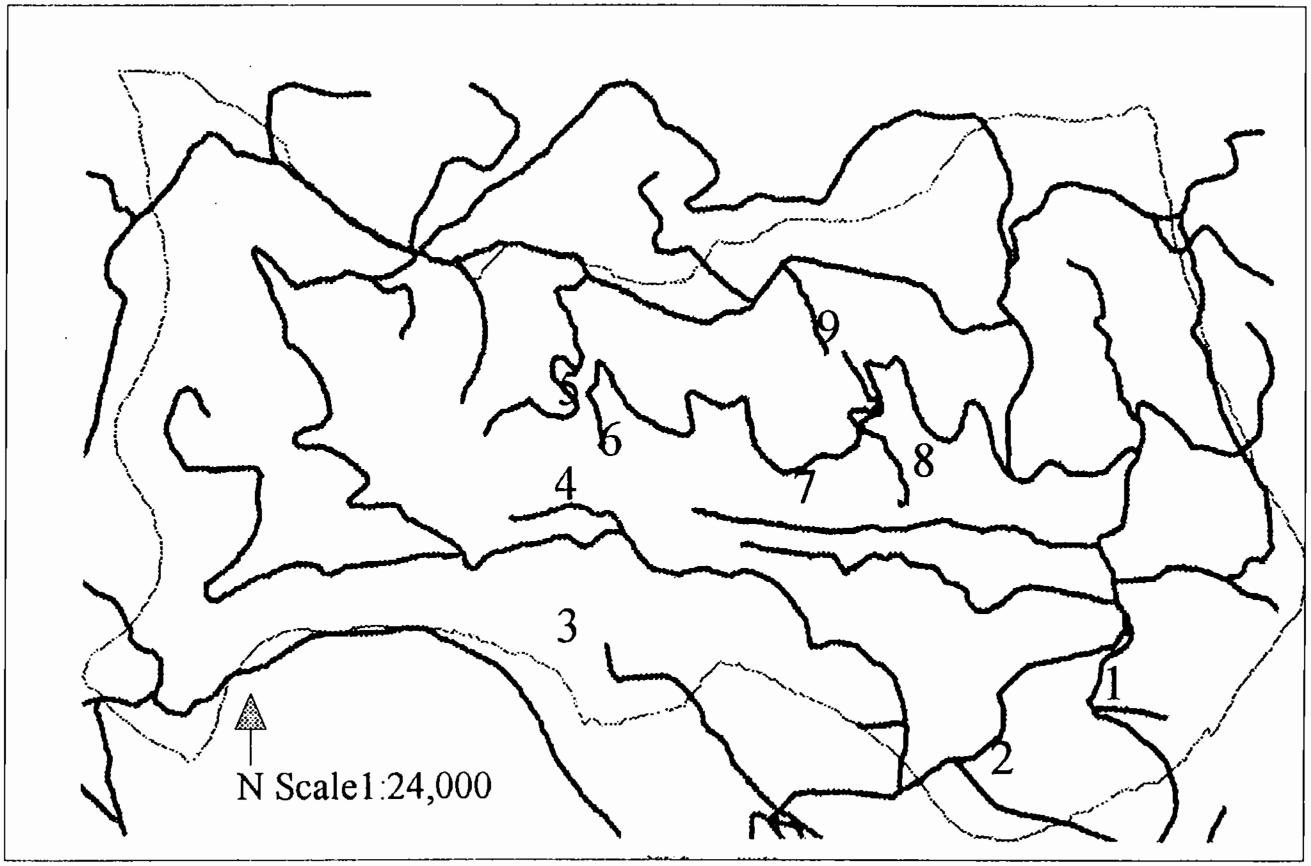

Figure 6. On-slope sediment boxes located below road fills within the Syrup Creek study area.

Collections from each sampling location were spread out on a table and allowed to air dry. Samples were then sieved through a 0.5 inch screen to separate the large organic materials such as tree needles, sticks and twigs and any large inorganic particles such as large pebbles. The separations were then weighed to the nearest 0.01 grams and recorded. Stones larger than 0.50 inches were very rare.

The sample portion passing the 0.5 inch screen was processed through a series of "splitting" to attain a well mixed representative subsample. Depending on the size of the sample, up to eight splits were performed. Small samples were not processed through the splitting procedures.

The subsample from each sampling location was placed in eight (8) tared crucibles. The eight crucibles were then re-weighed and placed in the drying oven for approximately 24 hours at 105^{o}C. Crucibles were allowed to cool for one hour before re-weighing to determine the relative amount of water in each crucible sample. The difference between the initial weight and the post-drying weight is the amount of water in the sample. To express as a percentage, the following equation was used for each crucible (C1-C8) measured:

Equation 1. Amount of water expressed as a percent.

$$\frac{\text{Initial Weight (g) - Post-Drying Weight (g)}}{\text{Initial Weight (g)}} = \text{\% Water Content}$$

Following drying, crucibles were placed in the muffle furnace for 6 hours at 425-450^{o}C and again re-weighed to determine the relative amount of organic material in each crucible sample. The difference between the post-drying weight and the post-muffle furnace weight is the amount of organic material in the sample. To express as a percentage, the following equation was used for each crucible (C1-C8) measured:

Equation 2. Amount of organic material expressed as a percent.

$$\frac{\text{Post-Drying Weight (g) - Post-Muffle Weight (g)}}{\text{Initial Weight (g)}} = \text{\% Organic Content}$$

All recorded measurements were entered into a spreadsheet, where calculations were performed to determine the relative amounts of moisture, organics and inorganics (sediment) in each of the eight crucibles for each of the sampling collections. The eight measurements were averaged to determine an average percent content of moisture and organic material for each sampling location.

Equation 3. Average percent of water.

$$(\text{C1 Water Content (\%)} + \ldots + \text{C8 Water Content (\%)}) \div 8 = \text{Average \% Water}$$

Equation 4. Average percent of organic material.

$$(\text{C1 Organic Content (\%)} + \ldots + \text{C8 Organic Content (\%)}) \div 8 = \text{Average \% Organic}$$

The Hydrometer Method of grain size analysis was performed on selected sampling locations to obtain an estimate of the distribution of soil particle sizes (Bowles 1978). This data was plotted on a semilog plot of percent finer vs. grain diameters.

The average moisture and organic content was then extrapolated back to the weights of the initial samples. This determined the total amount of organic and inorganic material caught at each sampling location.

Sediment Yield Predictions

Changes in sediment yield due to road construction, logging and fire in the Syrup Creek study area were predicted using the WWSED model. Modeling was performed with the same assumptions and intensity to be consistent with past modeling efforts on the Wallowa-Whitman National Forest, La Grande Ranger District.

Analysis of data from sampling methods and site characterizations determined the quantity and rate of sediment delivered to Syrup Creek. These measurements were compared to those predicted by the WWSED model.

RESULTS AND DISCUSSION

The average annual and monthly precipitation for the period of record (1984-1993) was 20.76 inches and 1.48 inches, respectively. Precipitation was found to be variable throughout the study period of 1991 through 1993 (Figure 7). Precipitation in 1991 was characterized by an above average year with an annual total of 23.85 inches. Maximum monthly precipitation was 5.28 inches occurring in November. Of particular interest to this study was the occurrence of an estimated 15 to 20 year runoff event in Meadow Creek. This was the result of days of rain following a warm period in which soils were saturated from recent snow melt. The second and third weeks of May, 1991 had 1.08 and 2.76 inches of rain respectively. The majority of which fell in a one to two day period.

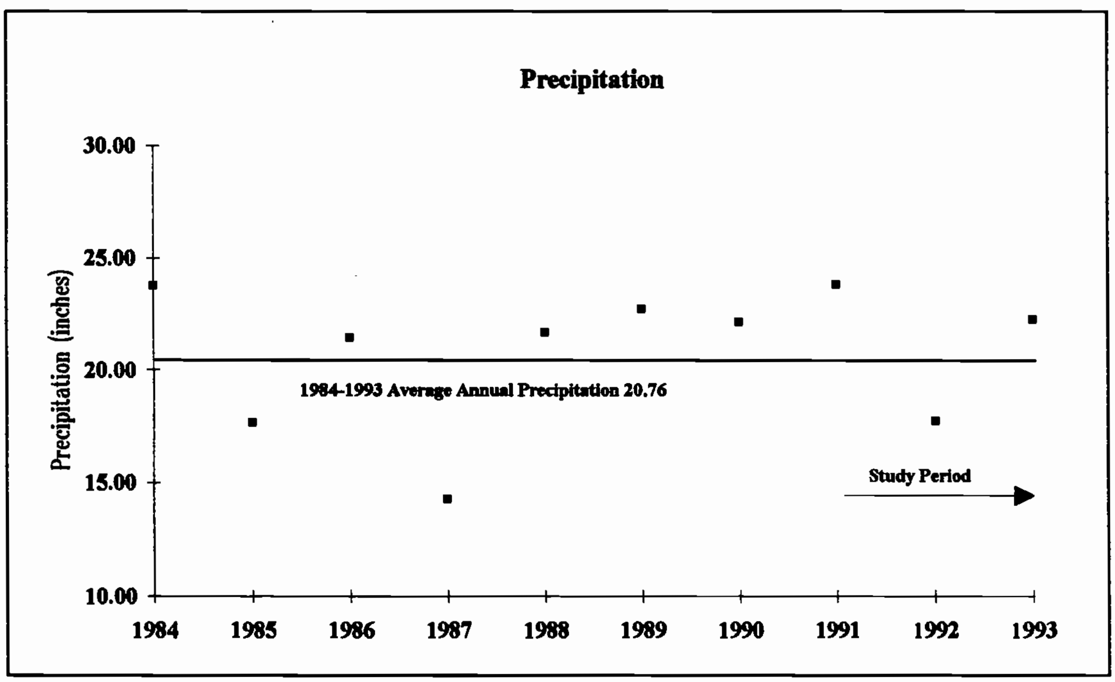

Figure 7. Annual precipitation for the period of record, 1984 to present, at the Starkey Experimental Forest and Range headquarters, Blue Mountains, Oregon.

Precipitation in 1992 was below average with an annual total of 17.15 inches. Maximum monthly precipitation was 3.05 inches occurring in November. Precipitation in 1993 was again above average yielding an annual total of 22.28 inches. Maximum monthly precipitation was 3.46 inches in April and 3.48 inches in June. Appendix B summarizes precipitation for the period of record at the Starkey Experimental Forest and Range Headquarters.

The following tables list the inherent properties of the 12 in-channel sediment trap contributing areas (Table 2), and also the management disturbance factors associated with the 12 sediment trapping locations (Table 3). Sample location number 5 was a control basin in which no ground disturbing activity was to take place. The site logging plan changed to include this area into an adjacent harvest unit. As a result, the in-channel sediment trap was destroyed. A different control (number 5A) was located outside of the analysis area.

Location	Area (ac)	Elevation, m	Slope (deg)	% Area >30% Slope	Aspect (deg)
1	10.02	1210	6.9	0	88
2	10.15	1272	7.3	3.7	87
3	33.84	1252	8.6	0	35
4	36.82	1320	10.5	5.8	32
5	9.38	1337	10.3	1.5	30
5A	63.31	1381	2.9	6.2	87
6	13.15	1292	9.8	0	17
7	29.78	1300	7.2	0	164
8	24.88	1293	7.6	0	175
9	8.68	1264	8.6	1.3	148
10	3.72	1272	8.6	0	167
11	18.67	1247	9.5	0	169
12	17.86	1225	7.2	0	156

Table 2. Inherent properties associated with the in-channel sediment sampling locations.

Location	Roads (ft) Existing	New	Distance to trap (ft)	Stream Channel (ft)	Harvest (ac) Tractor	Skyline	Rx Fire (ac)
1	0	267	164	199	2	0	0
2	0	0	319	90	3	0	0
3	0	0	275	664	42	0	18
4	0	471	477	361	10	13	0
5	0	0	0	n/a	9	0	9
5A	0	0	0	235	0	0	0
6	0	266	74	195	13	0	13
7	0	85	660	902	8	7	0
8	0	70	545	1082	16	0	0
9	0	0	445	230	12	0	0
10	0	0	0	100	0	0	0
11	0	346	246	492	5	0	0
12	0	526	737	737	0	0	0
Total	0	2031	3942	5287	120	20	40

Table 3. Management disturbance factors associated with the in-channel sediment sampling locations.

The relative quantities of sediment found in the samples, based upon laboratory analysis, are presented in Appendix C.

Grain size analysis was conducted on samples from locations 3, 8 and 10. Results show a range of diameters from 0.001 mm to 0.048 mm. Grain size distribution curves show clay content ranging from 0 to about 30 percent.

Sediment yields from the twelve in-channel sampling locations are summarized in Table 4, and total sediment yield in tons per square mile are illustrated in Figure 8.

Location	Yield (tons/sq. mi.) 1991	1992	1993
1	0.53	0.27	0.11
2	0.01	0.04	0.02
3	0.13	0.04	1.07
4	1.06	0.14	3.85
5	-	0.03	-
5A	-	-	0.00
6	0.03	0.10	0.18
7	0.01*	0.00	0.03
8	0.06	0.01	0.12
9	0.01	0.02	0.09
10	3.57	0.87	2.27
11	0.82	0.02	0.14
12	0.02	0.03	0.13
Means	0.37	0.07	0.74

*Estimated, see text

Table 4. Sediment yield in tons/sq. mi./year by in-channel sediment sampling location for the study period 1990 - 1993.

The in-channel sediment samples for locations 5 and 7 were mistakenly combined during the 1991 laboratory sample analysis. Samples from locations 5 and 7 are combined in Table 4 and shown as 7.

As indicated, sample location 5 was a control basin in which no ground disturbing activity took place. Field notes indicate that the sample collected from site 5 was primarily organic material. Therefore, it is speculated that the yield of sites 5 and 7 combined is actually representative of the yield from site 7.

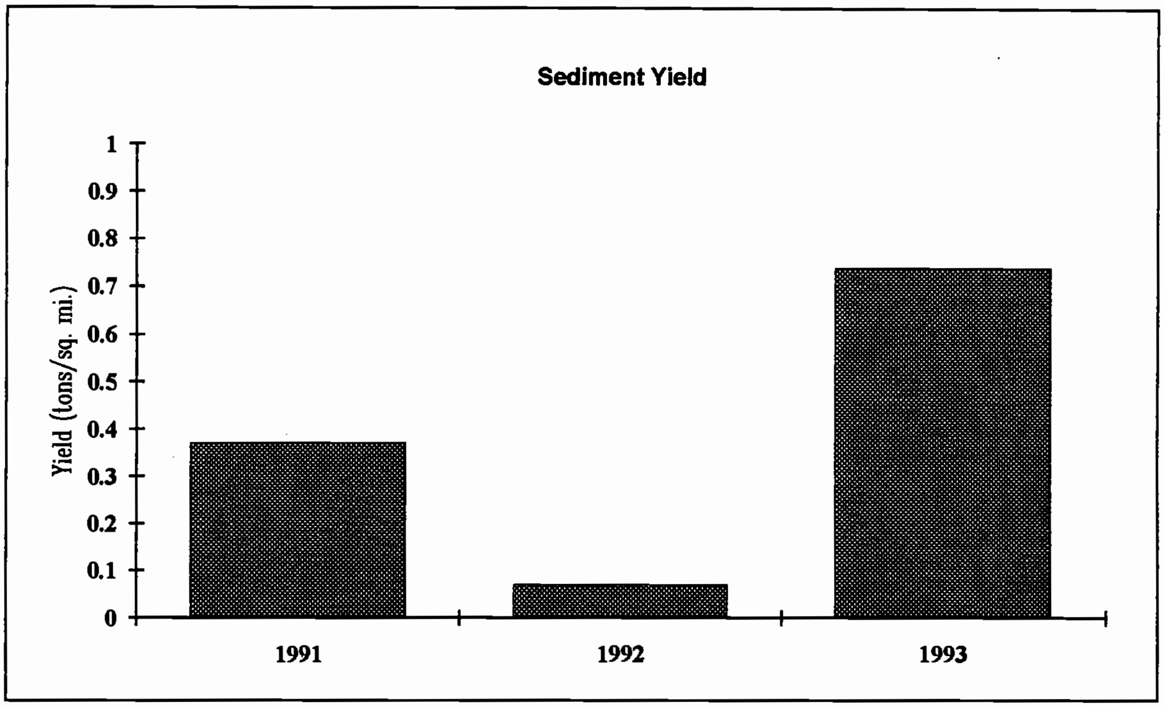

Figure 8. Sediment yield in tons/sq. mi. for the Syrup Creek study area.

No statistically significant relationships between the quantity of sediment yielded versus either inherent or management disturbance factors could be concluded from this data set. Precipitation and sediment yield (Figure 9) did not show a significant relationship, based on t-test results with 43 degrees of freedom and the 5% level of significance (Figure 10).

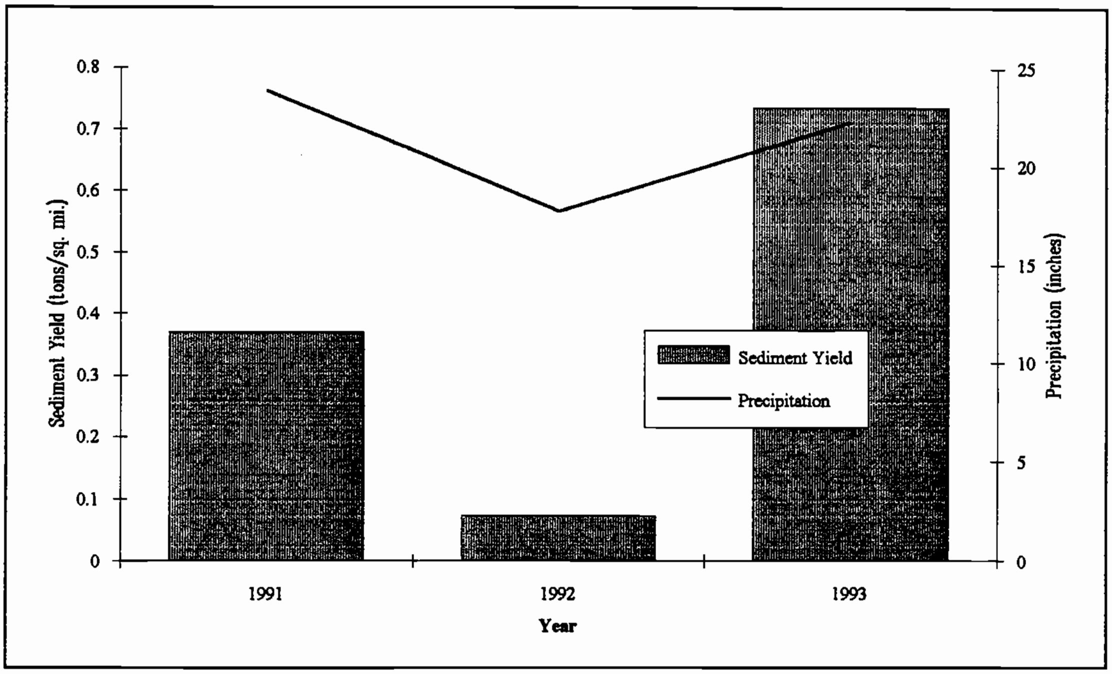

Figure 9. Sediment yield and precipitation for the study period of 1990-1993.

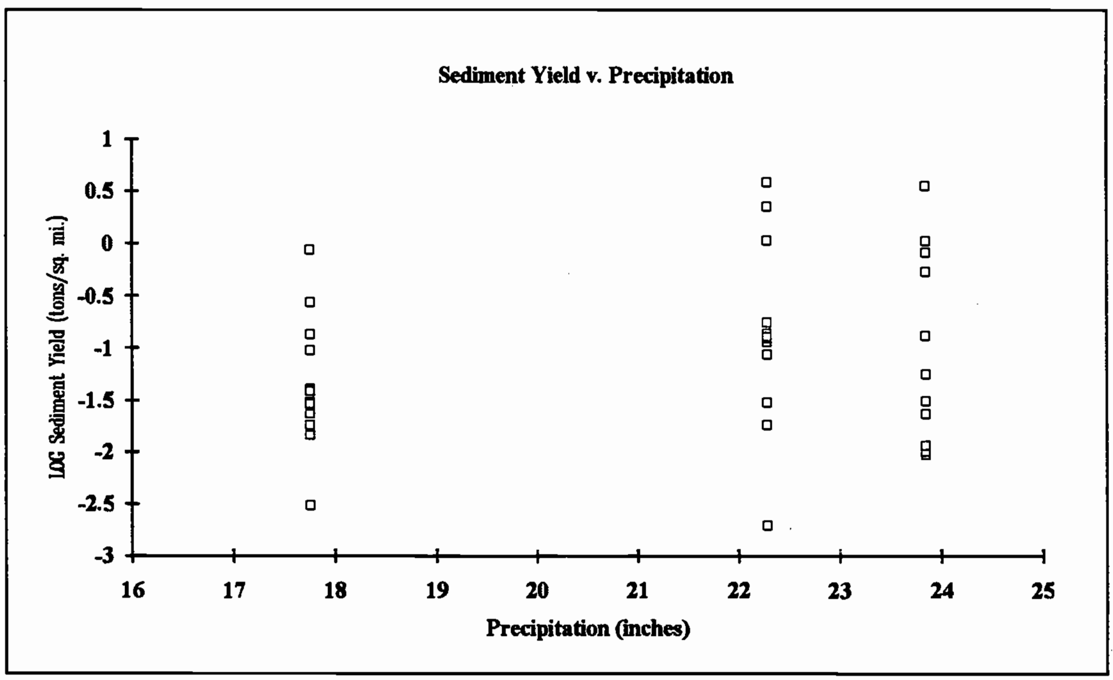

Figure 10. Linear regression of LOG sediment yield versus precipitation for the study period of 1990 to 1993.

The inherent factors described in Table 2 did not show a relationship to the amount of sediment yielded, correlation coefffficients ranges from 0.05 to 0.45 (Table 5).

	r-Squared
Area	0.09
Elevation	0.05
Slope	0.12
% Area >30% Slope	0.18
Aspect	0.08
All	0.39
Precipitation	0.45

Table 5. R-Squared values from linear regression analysis for inherent factors and their relationship to sediment yield.

Management disturbance factors illustrated in Table 3 did not show a significant relationship to sediment yield, r-Squared ranges from 0.0004 to 0.45 (Table 6).

	r-Squared
Roads	0.07
Distance to Trap	0.01
Stream Channel	0.00
Tractor Harvest	0.01
Skyline Harvest	0.44
Rx Fire	0.00
All	0.45

Table 6. R-Squared values from linear regression analysis for management induced disturbance factors and their relationship to sediment yield.

While there appears to be no significant relationship between inherent or management induced disturbance factors and sediment yield, there has been a two-fold increase in sediment yield when comparing 1993 to 1991 sediment yields, and a ten-fold increase in sediment yield when comparing 1993 to 1992 sediment yields. The r-Squared values for 1993 sediment yield versus inherent values were considerably higher than 1991 or 1992 values. Figure 10 shows sediment yield by year and the management factors that occurred.

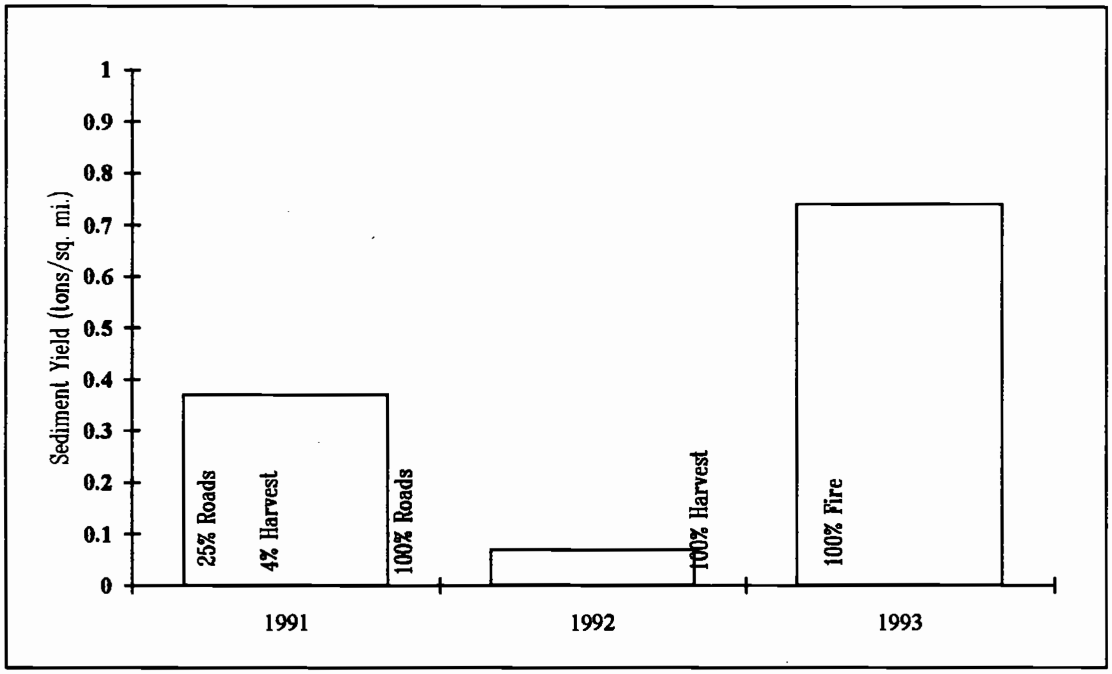

Figure 11. Sediment yield by year of study and the management activities completed to that date.

The WWSED Model predicted 32.95 tons/sq. mi. of sediment would be produced in 1991. This prediction included natural erosion and management induced increases. Measured yields were 0.37 tons/sq. mi. with a maximum measured yield of 3.57 tons/sq. mi.. The model predicted that 25.06 tons/sq. mi. and 24.92 tons/sq. mi. would be produced in 1992 and 1993, respectively. However, measured values were 0.07 tons/sq. mi. and 0.74 tons/sq. mi., with maximum yields of 0.87 tons/sq. mi. and 3.85 tons/sq. mi., respectively. Figures 12 and 13 compares predicted and measured values.

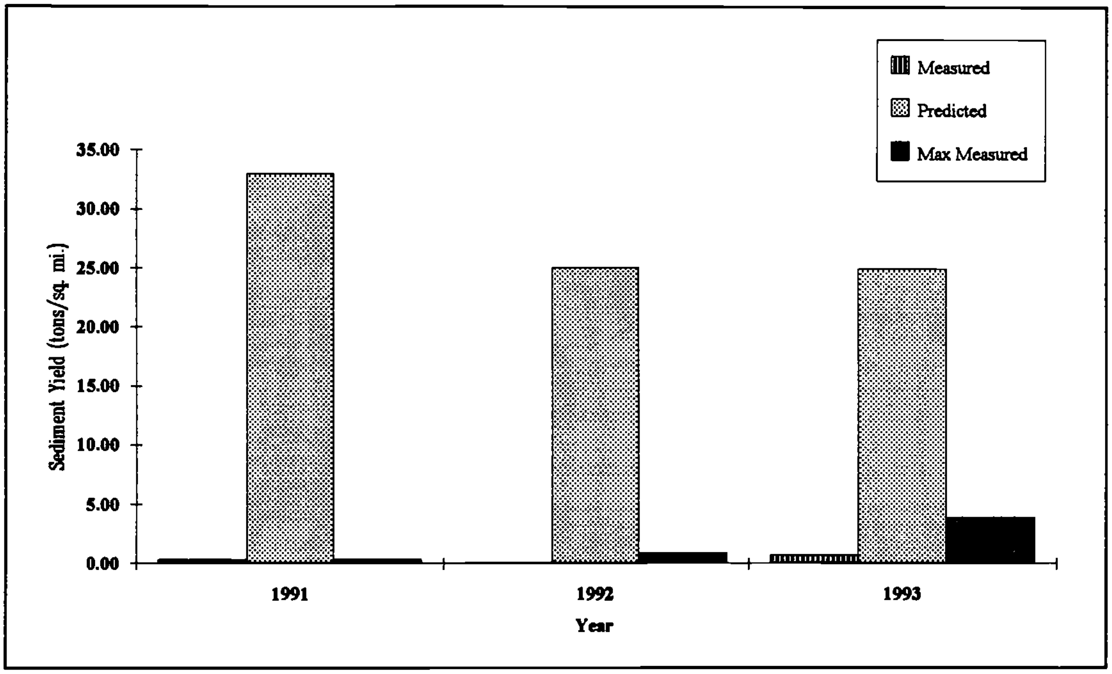

Figure 12. Sediment yield predicted from the WWSED model and the average and maximum measured from the study area.

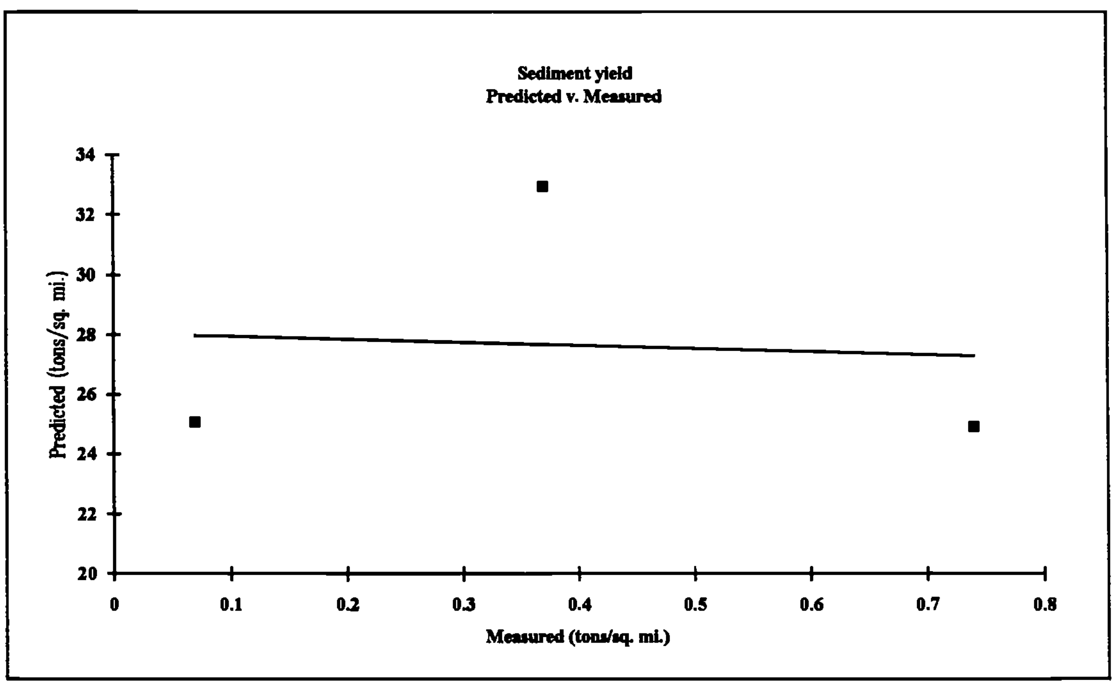

Figure 13. An X-Y plot of sediment yield predicted by the WWSED versus average sediment yield measured from the study area.

On-slope sediment boxes were sampled in 1992. Insufficient field time existed to accomplish field sampling in 1993. Of the 63 on-slope sediment boxes sampled in 1992, only two boxes from one sampling location (on-slope site 7) yielded measurable quantities of sediment. The box located 10 feet from the road fill yielded 7.75×10^{-6} tons (7.03 grams) and the box located 30 feet from the road fill yielded 1.72×10^{-5} tons (15.64 grams). All other sediment boxes either were disrupted by cattle, elk or humans, or did not contain measurable quantities of sediment.

While insufficient data exists to examine factors responsible for these data, one can conclude that sediment delivery did occur 30 feet downslope of the road fill. The WWSED model assumes that disturbances within 200 feet of the channel potentially contribute sediment. From this data we know that delivery to the stream may have occurred if the road was within 30 feet of the channel.

Disturbance by animals was visible at many sites within the small basins and on-slope sediment traps. Cattle, elk and deer populations create some soil disturbance. Succulent forage persist late into the summer near the channels and cattle and elk both use these areas heavily. An animal damage index was not developed with this study. Gophers may also be a significant factor as their populations increase rapidly when the forest canopy is reduced and large increases in grass, forbs and brush species occur.

Swanson and Grant (1982) reviewed numerous studies of surface erosion and found that all of the studies measured surface erosion rates with collection boxes placed along the hillslope, and periodically cleaned of the accumulated soil material. The method in which on-slope surface erosion was measured in this study is consistent with common research methods found in the literature.

The use of in-channel catch basins as described in this study was not present in the literature. Methods commonly being employed focused primarily on suspended sediment sampling. These methods included but are not limited to, splitters of various kinds, Coshocton Wheels and pumping water samplers.

Qualitatively, the in-channel sediment catch basins proved to be highly effective in meeting the objective of trapping sediments. The small grain sizes recovered suggest that a substantial enough velocity break in stream flow existed as to settle out and filter these fine sediments. Only three catch basins showed evidence of over flowing. This was not a significant concern in the sampling effectiveness since the potential fraction lost was likely extremely fine in nature and probably would not have added significantly to the total sample.

Measurements were conducted relatively high (upstream) in ephemeral and intermittent stream channels. It is speculated that if sampling were conducted lower (downstream) in the stream channel, a larger increase in sediment yield would have been measured. This is in part due to the increased volumes of discharge able to detach and transport additional sources of sediment, such as streambank and channel scour, and additional management related sources missed by the sampling frequency used. For example, culvert failure occurred at a stream crossing not associated with one of the 12 sampling locations.

The in-channel catch basin methodology employed here may not have been as effective in trapping and filtering sediments at locations further downstream due to the risk of trap structural failure or significant over flow. The design of traps would need to be much larger and constructed of additional materials, both of which result in added strength and cost.

Conclusions

It can be concluded that while there was an increase in sediment yield in the Syrup Creek Study Area, there is no statistically significant relationship between this increase and inherent or management factors. This may be due, in part, to the limited data set with only three years of observations. It is likely that there are other inherent and management factors which would help explain the variation in sediment yields.

It has also been shown that the WWSED Model drastically over-estimates the sediment yield from this area. From this, we can conclude that the variability of natural systems is far more complex than can be simplified into a prediction model.

Several additional years of measurement are necessary. The WWSED model predicts sediment yield for a seven year period. At a minimum, measurements should continue for an additional four years and preferably longer. In addition, it is recommended that a pumping sampler be installed at the mouth of the study area to quantify total suspended load yielding the watershed. This may assist additional years of sampling and provide a more robust data set in which to evaluate the WWSED model.

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APPENDIX A: Unit Conversion Factors

Table 7. Unit Conversion Factors.

km	= 1.609 * mi
m	= .3048 * ft
cm	= 2.54 * in
cu m	= 0.02832 * cu ft
acre	= 640 * sq. mi.
g	= 453.6 * lb
^{o}F	= (1.8 * ^{o}C) + 32
l	= 3.785 * gal

APPENDIX B: Year Precipitation Summary

Monthly Totals

Month	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
JAN		0.23	2.33	2.33	2.97	4.04	2.36	1.85	0.49	2.13
FEB		1.89	5.25	1.62	1.41	1.66	1.91	0.92	1.77	0.72
MAR	3.21	2.02	1.85	1.76	3.41	2.86	1.94	2.83	1.06	2.61
APR	1.90	1.38	1.50	1.09	2.21	2.09	2.70	2.81	2.50	3.46
MAY	1.94	2.38	1.51	1.73	2.05	3.92	2.45	4.18	0.68	1.35
JUN	2.77	1.19	0.92	1.22	1.79	1.25	2.16	2.83	2.04	3.48
JUL	0.70	0.69	0.72	0.91	0.00	1.15	0.47	0.65	1.49	2.55
AUG	3.05	0.37	0.22	0.11	0.41	1.45	1.01	0.69	0.29	2.22
SEP	1.29	1.98	2.09	0.05	0.89	1.04	0.61	0.02	0.74	0.00
OCT	2.49	1.35	0.93	0.05	0.10	0.97	2.18	0.56	1.56	0.67
NOV	3.03	3.32	3.67	1.44	4.01	1.56	2.46	5.28	3.05	1.39
DEC	3.38	0.87	0.45	1.93	2.44	0.73	1.92	1.23	2.08	1.70
Avg/Mo	2.38	1.47	1.79	1.19	1.81	1.89	1.85	1.99	1.48	1.86
Total/Yr	23.76	17.67	21.44	14.24	21.69	22.72	22.17	23.85	17.75	22.28

Table 8. Year Precipitation Summary.

Location	Crucible #	Tare (g)	Sample Wt. + Tare (g)	Sample Wt. (g)	Dry Wt. + Tare (g)	Dry Wt. (g)	Muffle Wt. + Tare (g)	Muffle Wt. (g)	% Moisture	% Organic		
1*91	5*1	23.42	41.00	17.58	39.62	16.20	34.83	11.41	7.85	27.25	Starting Organic Material >0.5 in. (g):	966.80
1*91	5*2	23.64	40.48	16.84	39.08	15.44	34.37	10.73	8.31	27.97	Starting Material <0.5 in. (g):	11481.10
1*91	5*3	27.28	44.34	17.06	42.92	15.64	38.59	11.31	8.32	25.38		
1*91	5*4	24.83	44.58	19.75	42.93	18.10	38.02	13.19	8.35	24.86	Average % Moisture:	8.11
1*91	5*5	28.55	44.68	16.13	43.33	14.78	39.20	10.65	8.37	25.60	Average % Organic:	25.97
1*91	5*6	28.02	39.95	11.93	38.96	10.94	35.90	7.88	8.30	25.65		
1*91	5*7	28.13	41.30	13.17	40.19	12.06	36.26	8.13	8.43	29.84	Total Organic (g):	3870.36
1*91	5*8	22.90	38.96	16.06	37.84	14.94	34.43	11.53	6.97	21.23	Total Inorganic (g):	7567.53
2*91	0*1	23.83	27.63	3.80	27.19	3.36	24.36	0.53	11.58	74.47	Starting Organic Material >0.5 in. (g):	382.70
2*91	0*2	23.73	28.98	5.25	28.34	4.61	24.58	0.85	12.19	71.62	Starting Material <0.5 in. (g):	862.70
2*91	0*3	22.96	28.14	5.18	27.49	4.53	23.72	0.76	12.55	72.78		
2*91	0*4	23.33	30.46	7.13	29.55	6.22	24.75	1.42	12.76	67.32	Average % Moisture:	12.35
2*91	0*5	23.13	28.15	5.02	27.52	4.39	24.03	0.90	12.55	69.52	Average % Organic:	71.85
2*91	0*6	23.11	28.11	5.00	27.47	4.36	23.88	0.77	12.80	71.80		
2*91	0*7	23.20	28.23	5.03	27.60	4.40	23.92	0.72	12.52	73.16	Total Organic (g):	955.32
2*91	0*8	23.63	29.28	5.65	28.61	4.98	24.42	0.79	11.86	74.16	Total Inorganic (g):	136.25
3*91	1*1	24.02	38.32	14.30	36.91	12.89	33.04	9.02	9.86	27.06	Starting Organic Material >0.5 in. (g):	732.30
3*91	1*2	23.61	35.86	12.25	34.62	11.01	31.24	7.63	10.12	27.59	Starting Material <0.5 in. (g):	10263.10
3*91	1*3	23.64	36.90	13.26	35.58	11.94	32.08	8.44	9.95	26.40		
3*91	1*4	23.52	36.22	12.70	34.96	11.44	31.65	8.13	9.92	26.06	Average % Moisture:	9.89
3*91	1*5	23.13	37.56	14.43	36.16	13.03	32.59	9.46	9.70	24.74	Average % Organic:	28.70
3*91	1*6	26.59	38.51	11.92	37.37	10.78	34.34	7.75	9.56	25.42		
3*91	1*7	23.31	34.23	10.92	33.15	9.84	30.11	6.80	9.89	27.84	Total Organic (g):	3605.87
3*91	1*8	24.30	35.08	10.78	33.99	9.69	29.19	4.89	10.11	44.53	Total Inorganic (g):	6302.00
4*91	6*1	28.33	53.82	25.49	51.96	23.63	47.67	19.34	7.30	16.83	Starting Organic Material >0.5 in. (g):	5501.30
4*91	6*2	25.55	52.39	26.84	50.29	24.74	45.53	19.98	7.82	17.73	Starting Material <0.5 in. (g):	75349.30
4*91	6*3	23.32	49.19	25.87	47.16	23.84	42.63	19.31	7.85	17.51		
4*91	6*4	28.24	51.44	23.20	49.56	21.32	45.33	17.09	8.10	18.23	Average % Moisture:	8.07
4*91	6*5	24.62	54.06	29.44	51.73	27.11	46.58	21.96	7.91	17.49	Average % Organic:	18.50
4*91	6*6	27.32	51.42	24.10	49.35	22.03	44.62	17.30	8.59	19.63		
4*91	6*7	28.00	50.79	22.79	48.86	20.86	44.46	16.46	8.47	19.31	Total Organic (g):	18998.08
4*91	6*8	23.73	45.07	21.34	43.26	19.53	38.72	14.99	8.48	21.27	Total Inorganic (g):	55331.37
5 & 7*91	24	28.13	35.03	6.90	34.46	6.33	30.19	2.06	8.26	61.88	Starting Organic Material >0.5 in. (g):	1373.60
5 & 7*91	59	28.02	39.53	11.51	38.65	10.63	33.26	5.24	7.65	46.83	Starting Material <0.5 in. (g):	2714.60
5 & 7*91	6	28.01	36.08	8.07	35.40	7.39	30.65	2.64	8.43	58.86		
5 & 7*91	1	23.33	33.51	10.18	32.68	9.35	27.18	3.85	8.15	54.03	Average % Moisture:	8.34
5 & 7*91	17	25.03	33.03	8.00	32.35	7.32	27.48	2.45	8.50	60.88	Average % Organic:	61.07
5 & 7*91	2	23.41	32.60	9.19	31.81	8.40	25.85	2.44	8.60	64.85		
5 & 7*91	35	25.56	32.94	7.38	32.31	6.75	27.27	1.71	8.54	68.29	Total Organic (g):	2916.83
5 & 7*91	11	27.94	35.40	7.46	34.76	6.82	29.32	1.38	8.58	72.92	Total Inorganic (g):	830.53

Table 9. Laboratory Analysis Results.

Location	Crucible #	Tare (g)	Sample Wt. + Tare (g)	Sample Wt. (g)	Dry Wt. + Tare (g)	Dry Wt. (g)	Muffle Wt. + Tare (g)	Muffle Wt. (g)	% Moisture	% Organic		
6*91	23	28.25	37.14	8.89	36.41	8.16	31.48	3.23	8.21	55.46	Starting Organic Material >0.5 in. (g):	914.20
6*91	3	23.73	34.15	10.42	33.29	9.56	28.03	4.30	8.25	50.48	Starting Material <0.5 in. (g):	1506.50
6*91	21	27.32	38.02	10.70	37.14	9.82	31.70	4.38	8.22	50.84		
6*91	33	28.44	40.78	12.34	39.72	11.28	33.56	5.12	8.59	49.92	Average % Moisture:	8.35
6*91	30	26.11	36.78	10.67	35.84	9.73	30.02	3.91	8.81	54.55	Average % Organic:	53.29
6*91	44	28.33	38.01	9.68	37.17	8.84	31.70	3.37	8.68	56.51		
6*91	87	22.89	32.24	9.35	31.47	8.58	26.25	3.36	8.24	55.83	Total Organic (g):	1640.70
6*91	39	27.27	37.28	10.01	36.50	9.23	31.22	3.95	7.79	52.75	Total Inorganic (g):	577.89
8*91	12	28.32	40.81	12.49	40.02	11.70	35.82	7.50	6.33	33.63	Starting Organic Material >0.5 in. (g):	988.50
8*91	10	23.63	38.30	14.67	37.39	13.76	32.60	8.97	6.20	32.65	Starting Material <0.5 in. (g):	3366.90
8*91	8	27.99	44.73	16.74	43.73	15.74	38.91	10.92	5.97	28.79		
8*91	92	24.63	39.44	14.81	38.50	13.87	33.54	8.91	6.35	33.49	Average % Moisture:	6.38
8*91	37	28.01	43.26	15.25	42.30	14.29	37.10	9.09	6.30	34.10	Average % Organic:	34.31
8*91	34	26.78	40.55	13.77	39.66	12.88	34.90	8.12	6.46	34.57		
8*91	0	24.83	37.13	12.30	36.31	11.48	31.67	6.84	6.67	37.72	Total Organic (g):	2080.58
8*91	41	28.55	39.58	11.03	38.83	10.28	34.47	5.92	6.80	39.53	Total Inorganic (g):	1996.76
9*91	2*1	23.54	30.43	6.89	29.88	6.34	24.81	1.27	7.98	73.58	Starting Organic Material >0.5 in. (g):	485.10
9*91	2*2	26.54	35.08	8.54	34.40	7.86	28.33	1.79	7.96	71.08	Starting Material <0.5 in. (g):	753.40
9*91	2*3	23.10	34.04	10.94	33.20	10.10	25.80	2.70	7.68	67.64		
9*91	2*4	23.37	30.20	6.83	29.64	6.27	24.51	1.14	8.20	75.11	Average % Moisture:	7.99
9*91	2*5	26.03	34.99	8.96	34.28	8.25	27.93	1.90	7.92	70.87	Average % Organic:	73.44
9*91	2*6	25.37	32.65	7.28	32.06	6.69	26.74	1.37	8.10	73.08		
9*91	2*7	23.96	31.00	7.04	30.43	6.47	25.04	1.08	8.10	76.56	Total Organic (g):	999.63
9*91	2*8	24.09	30.36	6.27	29.86	5.77	24.87	0.78	7.97	79.59	Total Inorganic (g):	139.91
10*91	3*1	25.85	46.20	20.35	45.56	19.71	41.47	15.62	3.14	20.10	Starting Organic Material >0.5 in. (g):	4851.30
10*91	3*2	25.74	52.08	26.34	51.27	25.53	46.62	20.88	3.08	17.65	Starting Material <0.5 in. (g):	23996.50
10*91	3*3	24.71	55.01	30.30	53.98	29.27	48.38	23.67	3.40	18.48		
10*91	3*4	24.31	55.85	31.54	54.72	30.41	48.97	24.66	3.58	18.23	Average % Moisture:	3.41
10*91	3*5	25.23	50.76	25.53	49.84	24.61	45.23	20.00	3.60	18.06	Average % Organic:	18.19
10*91	3*6	25.44	51.28	25.84	50.37	24.93	46.00	20.56	3.52	16.91		
10*91	3*7	24.72	51.72	27.00	50.76	26.04	45.93	21.21	3.56	17.89	Total Organic (g):	9049.94
10*91	3*8	24.79	52.26	27.47	51.33	26.54	46.34	21.55	3.39	18.17	Total Inorganic (g):	18814.56
11*91	7*1	25.02	48.67	23.65	47.32	22.30	42.53	17.51	5.71	20.25	Starting Organic Material >0.5 in. (g):	2336.60
11*91	7*2	28.44	50.68	22.24	49.47	21.03	45.45	17.01	5.44	18.08	Starting Material <0.5 in. (g):	27811.80
11*91	7*3	28.01	51.31	23.30	50.05	22.04	45.93	17.92	5.41	17.68		
11*91	7*4	28.31	56.94	28.63	55.41	27.10	50.52	22.21	5.34	17.08	Average % Moisture:	5.33
11*91	7*5	27.99	58.41	30.42	56.85	28.86	52.14	24.15	5.13	15.48	Average % Organic:	16.71
11*91	7*6	26.78	60.36	33.58	58.64	31.86	53.66	26.88	5.12	14.83		
11*91	7*7	26.11	58.35	32.24	56.66	30.55	51.69	25.58	5.24	15.42	Total Organic (g):	6860.70
11*91	7*8	27.94	61.31	33.37	59.57	31.63	54.60	26.66	5.21	14.89	Total Inorganic (g):	21682.03

Table 9. Laboratory Analysis Results Continued.

Location	Crucible #	Tare (g)	Sample Wt. + Tare (g)	Sample Wt. (g)	Dry Wt. + Tare (g)	Dry Wt. (g)	Muffle Wt. + Tare (g)	Muffle Wt. (g)	% Moisture	% Organic		
12*91	4*1	26.35	38.09	11.74	37.33	10.98			6.47	93.53	Starting Organic Material >0.5 in. (g):	1056.50
	4*1	26.35			37.06	10.71	29.87	3.52			Starting Material <0.5 in. (g):	2101.60
12*91	4*2	25.17	38.10	12.93	37.26	12.09	29.52	4.35	6.50	59.86		
12*91	4*3	24.62	38.89	14.27	37.98	13.36	29.88	5.26	6.38	56.76		
12*91	4*4	25.28	38.81	13.53	37.93	12.65	29.96	4.68	6.50	58.91	Average % Moisture:	6.58
12*91	4*5	24.47	39.85	15.38	38.85	14.38	29.77	5.30	6.50	59.04	Average % Organic:	65.37
12*91	4*6	25.94	38.09	12.15	37.29	11.35	29.79	3.85	6.58	61.73		
12*91	4*7	25.83	37.38	11.55	36.61	10.78	29.16	3.33	6.67	64.50	Total Organic (g):	1963.27
12*91	4*8	25.54	35.89	10.35	35.16	9.62	28.06	2.52	7.05	68.60	Total Inorganic (g):	589.55
1*92	2*1	24.02	32.63	8.61	32.04	8.02	26.69	2.67	6.85	62.14	Starting Organic Material >0.5 in. (g):	5359.60
1*92	2*2	25.44	33.71	8.27	33.16	7.72	28.36	2.92	6.65	58.04	Starting Material <0.5 in. (g):	10308.60
1*92	2*3	25.83	35.73	9.90	35.08	9.25	29.82	3.99	6.57	53.13		
1*92	2*4	23.41	31.52	8.11	30.96	7.55	26.23	2.82	6.91	58.32	Average % Moisture:	6.63
1*92	2*5	27.78	40.17	12.39	39.39	11.61	33.45	5.67	6.30	47.94	Average % Organic:	55.57
1*92	2*6	24.83	32.09	7.26	31.59	6.76	27.19	2.36	6.89	60.61		
1*92	2*7	28.02	37.10	9.08	36.52	8.50	31.92	3.90	6.39	50.66	Total Organic (g):	10732.65
1*92	2*8	23.74	32.38	8.64	31.82	8.08	27.18	3.44	6.48	53.70	Total Inorganic (g):	3897.03
2*92	1*1	25.85	29.92	4.07	29.53	3.68	26.57	0.72	9.58	72.73	Starting Organic Material >0.5 in. (g):	956.30
2*92	1*2	26.35	30.68	4.33	30.26	3.91	27.23	0.88	9.70	69.98	Starting Material <0.5 in. (g):	2585.20
2*92	1*3	23.63	32.92	9.29	32.02	8.39	26.33	2.70	9.69	61.25		
2*92	1*4	23.31	28.03	4.72	27.59	4.28	24.29	0.98	9.32	69.92	Average % Moisture:	9.62
2*92	1*5	25.38	30.97	5.59	30.43	5.05	26.54	1.16	9.66	69.59	Average % Organic:	67.74
2*92	1*6	23.37	29.86	6.49	29.23	5.86	24.92	1.55	9.71	66.41		
2*92	1*7	26.32	30.99	4.67	30.54	4.22	27.23	0.91	9.64	70.88	Total Organic (g):	2615.49
2*92	1*8	26.30	34.67	8.37	33.86	7.56	28.74	2.44	9.68	61.17	Total Inorganic (g):	585.26
3*92	1*1	25.85	30.48	4.63	30.08	4.23	26.66	0.81	8.64	73.87	Starting Organic Material >0.5 in. (g):	1766.30
3*92	1*2	26.35	32.55	6.20	31.99	5.64	27.61	1.26	9.03	70.65	Starting Material <0.5 in. (g):	6023.90
3*92	1*3	23.63	29.04	5.41	28.59	4.96	24.84	1.21	8.32	69.32		
3*92	1*4	23.31	30.40	7.09	29.80	6.49	25.04	1.73	8.46	67.14	Average % Moisture:	8.25
3*92	1*5	25.38	36.17	10.79	35.32	9.94	29.90	4.52	7.88	50.23	Average % Organic:	61.24
3*92	1*6	23.37	33.95	10.58	33.13	9.76	27.75	4.38	7.75	50.85		
3*92	1*7	26.32	34.47	8.15	33.81	7.49	29.04	2.72	8.10	58.53	Total Organic (g):	5309.83
3*92	1*8	26.30	38.31	12.01	37.37	11.07	31.44	5.14	7.83	49.38	Total Inorganic (g):	1837.63
4*92	7*1	28.56	40.86	12.30	39.72	11.16	35.46	6.90	9.27	34.63	Starting Organic Material >0.5 in. (g):	1950.60
4*92	7*2	25.55	39.82	14.27	38.59	13.04	34.55	9.00	8.62	28.31	Starting Material <0.5 in. (g):	13363.20
4*92	7*3	26.11	37.42	11.31	36.27	10.16	31.98	5.87	10.17	37.93		
4*92	7*4	22.90	37.76	14.86	36.57	13.67	32.67	9.77	8.01	26.24	Average % Moisture:	9.81
4*92	7*5	23.14	30.90	7.76	30.04	6.90	26.66	3.52	11.08	43.56	Average % Organic:	36.88
4*92	7*6	23.62	31.86	8.24	30.99	7.37	27.43	3.81	10.56	43.20		
4*92	7*7	25.02	37.50	12.48	36.35	11.33	32.05	7.03	9.21	34.46	Total Organic (g):	6687.04
4*92	7*8	23.65	31.45	7.80	30.55	6.90	26.91	3.26	11.54	46.67	Total Inorganic (g):	7124.90

Table 9. Laboratory Analysis Results Continued.

Location	Crucible #	Tare (g)	Sample Wt. + Tare (g)	Sample Wt. (g)	Dry Wt. + Tare (g)	Dry Wt. (g)	Muffle Wt. + Tare (g)	Muffle Wt. (g)	% Moisture	% Organic		
5*92	3*1	22.96	28.02	5.06	27.63	4.67	23.45	0.49	7.71	82.61	Starting Organic Material >0.5 in. (g):	1465.30
5*92	3*2	27.32	32.49	5.17	32.09	4.77	27.93	0.61	7.74	80.46	Starting Material <0.5 in. (g):	3441.90
5*92	3*3	26.78	33.08	6.30	32.58	5.80	27.59	0.81	7.94	79.21		
5*92	3*4	28.45	34.67	6.22	34.17	5.72	29.25	0.80	8.04	79.10	Average % Moisture:	7.82
5*92	3*5	28.01	32.85	4.84	32.47	4.46	28.48	0.47	7.85	82.44	Average % Organic:	81.13
5*92	3*6	26.53	31.28	4.75	30.91	4.38	27.06	0.53	7.79	81.05		
5*92	3*7	25.94	31.11	5.17	30.71	4.77	26.46	0.52	7.74	82.21	Total Organic (g):	4143.33
5*92	3*8	28.33	32.72	4.39	32.38	4.05	28.78	0.45	7.74	82.00	Total Inorganic (g):	380.24
6*92	4*1	25.17	29.89	4.72	29.56	4.39	26.64	1.47	6.99	61.86	Starting Organic Material >0.5 in. (g):	1043.60
6*92	4*2	25.63	34.96	9.33	34.44	8.81	30.84	5.21	5.57	38.59	Starting Material <0.5 in. (g):	3605.80
6*92	4*3	25.23	36.79	11.56	36.22	10.99	32.40	7.17	4.93	33.04		
6*92	4*4	23.52	28.98	5.46	28.61	5.09	25.41	1.89	6.78	58.61	Average % Moisture:	5.94
6*92	4*5	26.59	34.16	7.57	33.71	7.12	30.55	3.96	5.94	41.74	Average % Organic:	44.76
6*92	4*6	23.63	31.44	7.81	30.99	7.36	27.88	4.25	5.76	39.82		
6*92	4*7	24.70	36.63	11.93	35.99	11.29	31.74	7.04	5.36	35.62	Total Organic (g):	2595.41
6*92	4*8	26.03	32.84	6.81	32.42	6.39	29.10	3.07	6.17	48.75	Total Inorganic (g):	1777.87
7*92	8*1	23.96	29.39	5.43	28.96	5.00	24.41	0.45	7.92	83.79	Starting Organic Material >0.5 in. (g):	644.70
7*92	8*2	24.63	31.61	6.98	31.07	6.44	25.86	1.23	7.74	74.64	Starting Material <0.5 in. (g):	704.60
7*92	8*3	23.33	32.49	9.16	31.78	8.45	25.30	1.97	7.75	70.74		
7*92	8*4	23.13	29.46	6.33	28.96	5.83	24.22	1.09	7.90	74.88	Average % Moisture:	7.72
7*92	8*5	23.11	31.94	8.83	31.25	8.14	25.09	1.98	7.81	69.76	Average % Organic:	74.14
7*92	8*6	23.54	31.81	8.27	31.20	7.66	25.63	2.09	7.38	67.35		
7*92	8*7	28.00	35.81	7.81	35.21	7.21	29.57	1.57	7.68	72.22	Total Organic (g):	1117.30
7*92	8*8	27.28	32.16	4.88	31.79	4.51	27.90	0.62	7.58	79.71	Total Inorganic (g):	127.83
8*92	5*1	24.08	31.73	7.65	31.20	7.12	26.30	2.22	6.93	64.05	Starting Organic Material >0.5 in. (g):	878.00
8*92	5*2	23.20	32.23	9.03	31.65	8.45	26.40	3.20	6.42	58.14	Starting Material <0.5 in. (g):	1347.30
8*92	5*3	28.31	35.72	7.41	35.24	6.93	30.84	2.53	6.48	59.38		
8*92	5*4	24.73	38.08	13.35	37.27	12.54	30.64	5.91	6.07	49.66	Average % Moisture:	6.25
8*92	5*5	25.54	34.74	9.20	34.21	8.67	29.63	4.09	5.76	49.78	Average % Organic:	56.04
8*92	5*6	23.33	31.44	8.11	30.99	7.66	27.10	3.77	5.55	47.97		
8*92	5*7	24.47	32.60	8.13	32.09	7.62	27.47	3.00	6.27	56.83	Total Organic (g):	1578.09
8*92	5*8	28.01	35.66	7.65	35.16	7.15	30.38	2.37	6.54	62.48	Total Inorganic (g):	508.09
9*92	6*1	27.94	31.02	3.08	30.76	2.82	28.26	0.32	8.44	81.17	Starting Organic Material >0.5 in. (g):	2186.30
9*92	6*2	25.29	29.88	4.59	29.46	4.17	25.83	0.54	9.15	79.08	Starting Material <0.5 in. (g):	2251.40
9*92	6*3	24.94	29.92	4.98	29.47	4.53	25.54	0.60	9.04	78.92		
9*92	6*4	28.13	32.67	4.54	32.25	4.12	28.62	0.49	9.25	79.96	Average % Moisture:	8.99
9*92	6*5	24.30	29.27	4.97	28.84	4.54	25.20	0.90	8.65	73.24	Average % Organic:	78.24
9*92	6*6	24.31	30.94	6.63	30.32	6.01	25.22	0.91	9.35	76.92		
9*92	6*7	23.83	29.03	5.20	28.56	4.73	24.49	0.66	9.04	78.27	Total Organic (g):	3751.31
9*92	6*8	23.73	28.63	4.90	28.19	4.46	24.35	0.62	8.98	78.37	Total Inorganic (g):	287.55

Table 9. Laboratory Analysis Results Continued.

Location	Crucible #	Tare (g)	Sample Wt. + Tare (g)	Sample Wt. (g)	Dry Wt. + Tare (g)	Dry Wt. (g)	Muffle Wt. + Tare (g)	Muffle Wt. (g)	% Moisture	% Organic		
10*92	2*1	24.02	32.52	8.50	32.03	8.01	26.91	2.89	5.76	60.24	Starting Organic Material >0.5 in. (g):	4039.00
10*92	2*2	25.44	36.90	11.46	36.26	10.82	30.07	4.63	5.58	54.01	Starting Material <0.5 in. (g):	11022.20
10*92	2*3	25.83	34.82	8.99	34.26	8.43	28.48	2.65	6.23	64.29		
10*92	2*4	23.41	31.23	7.82	30.75	7.34	25.47	2.06	6.14	67.52	Average % Moisture:	5.46
10*92	2*5	27.78	39.04	11.26	38.47	10.69	33.24	5.46	5.06	46.45	Average % Organic:	53.05
10*92	2*6	24.83	40.28	15.45	39.52	14.69	33.05	8.22	4.92	41.88		
10*92	2*7	28.02	40.32	12.30	39.68	11.66	33.82	5.80	5.20	47.64	Total Organic (g):	9665.94
10*92	2*8	23.74	40.59	16.85	39.79	16.05	32.65	8.91	4.75	42.37	Total Inorganic (g):	4573.50
11*92	7*1	28.56	38.12	9.56	37.43	8.87	30.23	1.67	7.22	75.31	Starting Organic Material >0.5 in. (g):	2922.10
11*92	7*2	25.55	34.90	9.35	34.22	8.67	27.03	1.48	7.27	76.90	Starting Material <0.5 in. (g):	2907.10
11*92	7*3	26.11	35.11	9.00	34.46	8.35	27.52	1.41	7.22	77.11		
11*92	7*4	22.90	31.90	9.00	31.25	8.35	24.31	1.41	7.22	77.11	Average % Moisture:	7.19
11*92	7*5	23.14	34.20	11.06	33.40	10.26	25.27	2.13	7.23	73.51	Average % Organic:	76.40
11*92	7*6	23.62	29.88	6.26	29.43	5.81	24.52	0.90	7.19	78.43		
11*92	7*7	25.02	32.42	7.40	31.89	6.87	26.01	0.99	7.16	79.46	Total Organic (g):	4932.88
11*92	7*8	23.65	33.36	9.71	32.68	9.03	25.56	1.91	7.00	73.33	Total Inorganic (g):	477.18
12*92	3*1	22.96	33.08	10.12	32.33	9.37	25.07	2.11	7.41	71.74	Starting Organic Material >0.5 in. (g):	3428.60
12*92	3*2	27.32	34.95	7.63	34.38	7.06	28.74	1.42	7.47	73.92	Starting Material <0.5 in. (g):	3668.40
12*92	3*3	26.78	34.43	7.65	33.86	7.08	28.21	1.43	7.45	73.86		
12*92	3*4	28.45	37.14	8.69	36.48	8.03	30.18	1.73	7.59	72.50	Average % Moisture:	7.51
12*92	3*5	28.01	35.70	7.69	35.12	7.11	29.73	1.72	7.54	70.09	Average % Organic:	72.22
12*92	3*6	26.53	39.49	12.96	38.52	11.99	29.47	2.94	7.48	69.83		
12*92	3*7	25.94	36.14	10.20	35.37	9.43	27.99	2.05	7.55	72.35	Total Organic (g):	5820.65
12*92	3*8	28.33	35.76	7.43	35.20	6.87	29.74	1.41	7.54	73.49	Total Inorganic (g):	743.71
1*93	1*1	28.33	42.30	13.97	41.28	12.95	33.48	5.15	7.30	55.83	Starting Organic Material >0.5 in. (g):	4646.90
1*93	1*2	28.02	40.73	12.71	39.73	11.71	31.77	3.75	7.87	62.63	Starting Material <0.5 in. (g):	4964.40
1*93	1*3	28.01	38.35	10.34	37.55	9.54	31.20	3.19	7.74	61.41		
1*93	1*4	28.45	43.14	14.69	42.07	13.62	33.87	5.42	7.28	55.82	Average % Moisture:	7.58
1*93	1*5	27.94	40.44	12.50	39.47	11.53	31.68	3.74	7.76	62.32	Average % Organic:	59.64
1*93	1*6	28.01	42.75	14.74	41.64	13.63	32.90	4.89	7.53	59.29		
1*93	1*7	28.13	41.95	13.82	40.92	12.79	32.96	4.83	7.45	57.60	Total Organic (g):	7255.62
1*93	1*8	28.00	39.57	11.57	38.68	10.68	31.48	3.48	7.69	62.23	Total Inorganic (g):	1627.32
2*93	1	23.64	29.32	5.68	28.52	4.88	25.20	1.56	14.08	58.45	Starting Organic Material >0.5 in. (g):	549.60
2*93	2	26.35	33.34	6.99	32.63	6.28	27.44	1.09	10.16	74.25	Starting Material <0.5 in. (g):	1582.70
2*93	3	25.38	33.42	8.04	32.64	7.26	26.74	1.36	9.70	73.38		
2*93	4	23.62	30.84	7.22	30.14	6.52	24.95	1.33	9.70	71.88	Average % Moisture:	10.39
2*93	5	23.63	27.56	3.93	27.18	3.55	24.10	0.47	9.67	78.37	Average % Organic:	73.07
2*93	6	26.32	32.28	5.96	31.68	5.36	27.09	0.77	10.07	77.01		
2*93	7	26.53	31.75	5.22	31.23	4.70	27.34	0.81	9.96	74.52	Total Organic (g):	1648.94
2*93	8	25.36	29.86	4.50	29.42	4.06	25.97	0.61	9.78	76.67	Total Inorganic (g):	261.83

Table 9. Laboratory Analysis Results Continued.

Location	Crucible #	Tare (g)	Sample Wt. + Tare (g)	Sample Wt. (g)	Dry Wt. + Tare (g)	Dry Wt. (g)	Muffle Wt. + Tare (g)	Muffle Wt. (g)	% Moisture	% Organic		
3*93	3*1	23.61	49.14	25.53	46.76	23.15	41.70	18.09	9.32	19.82	Starting Organic Material >0.5 in. (g):	6166.40
3*93	3*2	23.52	50.84	27.32	48.29	24.77	42.72	19.20	9.33	20.39	Starting Material <0.5 in. (g):	72366.30
3*93	3*3	24.63	43.77	19.14	41.83	17.20	37.16	12.53	10.14	24.40		
3*93	3*4	23.33	45.59	22.26	43.55	20.22	39.19	15.86	9.16	19.59	Average % Moisture:	9.22
3*93	3*5	26.35	53.96	27.61	51.52	25.17	46.38	20.03	8.84	18.62	Average % Organic:	20.11
3*93	3*6	24.93	48.80	23.87	46.71	21.78	42.30	17.37	8.76	18.48		
3*93	3*7	26.32	49.99	23.67	47.85	21.53	43.25	16.93	9.04	19.43	Total Organic (g):	20152.01
3*93	3*8	25.63	51.50	25.87	49.12	23.49	43.90	18.27	9.20	20.18	Total Inorganic (g):	51136.99
4*93	4*1	23.32	47.31	23.99	45.29	21.97	41.50	18.18	8.42	15.80	Starting Organic Material >0.5 in. (g):	12808.78
4*93	4*2	23.63	45.40	21.77	43.57	19.94	40.16	16.53	8.41	15.66	Starting Material <0.5 in. (g):	263524.34
4*93	4*3	28.01	49.07	21.06	47.25	19.24	43.74	15.73	8.64	16.67		
4*93	4*4	27.27	50.77	23.50	48.87	21.60	45.39	18.12	8.09	14.81	Average % Moisture:	8.39
4*93	4*5	28.13	51.07	22.94	49.25	21.12	46.09	17.96	7.93	13.78	Average % Organic:	15.40
4*93	4*6	27.94	49.05	21.11	47.20	19.26	43.62	15.68	8.76	16.96		
4*93	4*7	28.31	52.11	23.80	50.20	21.89	46.83	18.52	8.03	14.16	Total Organic (g):	52308.72
4*93	4*8	27.99	50.02	22.03	48.08	20.09	44.70	16.71	8.81	15.34	Total Inorganic (g):	200853.15
5*93	1	24.63	31.30	6.67	30.66	6.03	25.32	0.69	9.60	80.06	Starting Organic Material >0.5 in. (g):	667.60
5*93	2	23.33	30.47	7.14	29.77	6.44	24.05	0.72	9.80	80.11	Starting Material <0.5 in. (g):	1596.20
5*93	3	23.73	30.16	6.43	29.53	5.80	24.36	0.63	9.80	80.40		
5*93	4	23.20	30.58	7.38	29.86	6.66	24.01	0.81	9.76	79.27	Average % Moisture:	9.69
5*93	5	24.72	32.91	8.19	32.12	7.40	25.91	1.19	9.65	75.82	Average % Organic:	79.37
5*93	6	25.63	31.50	5.87	30.94	5.31	26.25	0.62	9.54	79.90		
5*93	7	23.53	31.33	7.80	30.58	7.05	24.35	0.82	9.62	79.87	Total Organic (g):	1869.87
5*93	8	23.83	31.31	7.48	30.58	6.75	24.63	0.80	9.76	79.55	Total Inorganic (g):	174.59
6*93	6*1	24.63	38.48	13.85	37.17	12.54	32.67	8.04	9.46	32.49	Starting Organic Material >0.5 in. (g):	2548.90
6*93	6*2	23.33	32.58	9.25	31.57	8.24	27.82	4.49	10.92	40.54	Starting Material <0.5 in. (g):	5807.40
6*93	6*3	23.72	39.01	15.29	37.77	14.05	33.74	10.02	8.11	26.36		
6*93	6*4	23.20	33.25	10.05	32.12	8.92	27.78	4.58	11.24	43.18	Average % Moisture:	9.73
6*93	6*5	24.72	37.90	13.18	36.55	11.83	31.93	7.21	10.24	35.05	Average % Organic:	33.94
6*93	6*6	25.63	41.30	15.67	39.83	14.20	34.99	9.36	9.38	30.89		
6*93	6*7	23.54	39.74	16.20	38.30	14.76	33.51	9.97	8.89	29.57	Total Organic (g):	4271.83
6*93	6*8	23.83	37.89	14.06	36.54	12.71	31.84	8.01	9.60	33.43	Total Inorganic (g):	3271.35
7*93	7*1	24.08	31.73	7.65	30.70	6.62	26.46	2.38	13.46	55.42	Starting Organic Material >0.5 in. (g):	1685.00
7*93	7*2	24.92	31.45	6.53	30.58	5.66	27.04	2.12	13.32	54.21	Starting Material <0.5 in. (g):	3259.40
7*93	7*3	24.70	34.35	9.65	33.10	8.40	28.13	3.43	12.95	51.50		
7*93	7*4	23.52	33.58	10.06	32.31	8.79	27.38	3.86	12.62	49.01	Average % Moisture:	12.79
7*93	7*5	25.28	36.46	11.18	35.11	9.83	30.06	4.78	12.08	45.17	Average % Organic:	50.36
7*93	7*6	24.47	34.36	9.89	33.04	8.57	27.77	3.30	13.35	53.29		
7*93	7*7	25.23	34.34	9.11	33.20	7.97	28.66	3.43	12.51	49.84	Total Organic (g):	3111.05
7*93	7*8	26.59	39.16	12.57	37.65	11.06	32.06	5.47	12.01	44.47	Total Inorganic (g):	1201.01

Table 9. Laboratory Analysis Results Continued.

Location	Crucible #	Tare (g)	Sample Wt. + Tare (g)	Sample Wt. (g)	Dry Wt. + Tare (g)	Dry Wt. (g)	Muffle Wt. + Tare (g)	Muffle Wt. (g)	% Moisture	% Organic		
8*93	1	25.94	40.48	14.54	39.09	13.15	33.68	7.74	9.56	37.21	Starting Organic Material >0.5 in. (g):	2077.80
8*93	2	24.94	40.49	15.55	39.06	14.12	33.69	8.75	9.20	34.53	Starting Material <0.5 in. (g):	7982.10
8*93	3	24.70	40.57	15.87	39.08	14.38	33.28	8.58	9.39	36.55		
8*93	4	23.52	38.66	15.14	37.18	13.66	31.30	7.78	9.78	38.84	Average % Moisture:	9.44
8*93	5	25.28	40.42	15.14	38.99	13.71	33.69	8.41	9.45	35.01	Average % Organic:	36.17
8*93	6	24.47	42.01	17.54	40.43	15.96	34.64	10.17	9.01	33.01		
8*93	7	25.23	39.31	14.08	37.94	12.71	32.55	7.32	9.73	38.28	Total Organic (g):	4768.50
8*93	8	26.60	40.25	13.65	38.97	12.37	34.07	7.47	9.38	35.90	Total Inorganic (g):	4342.24
9*93	9*1	28.55	33.55	5.00	32.99	4.44	29.82	1.27	11.20	63.40	Starting Organic Material >0.5 in. (g):	4880.40
9*93	9*2	23.63	29.93	6.30	29.24	5.61	25.35	1.72	10.95	61.75	Starting Material <0.5 in. (g):	3821.40
9*93	9*3	25.55	30.97	5.42	30.36	4.81	27.07	1.52	11.25	60.70		
9*93	9*4	27.27	33.31	6.04	32.66	5.39	29.15	1.88	10.76	58.11	Average % Moisture:	11.09
9*93	9*5	22.89	27.31	4.42	26.80	3.91	23.96	1.07	11.54	64.25	Average % Organic:	61.06
9*93	9*6	23.41	28.91	5.50	28.30	4.89	24.83	1.42	11.09	63.09		
9*93	9*7	26.59	33.64	7.05	32.87	6.28	28.81	2.22	10.92	57.59	Total Organic (g):	6672.73
9*93	9*8	23.53	28.63	5.10	28.07	4.54	25.03	1.50	10.98	59.61	Total Inorganic (g):	1064.26
10*93	10*1	25.74	47.64	21.90	46.49	20.75	40.00	14.26	5.25	29.63	Starting Organic Material >0.5 in. (g):	5025.40
10*93	10*2	24.62	46.88	22.26	45.72	21.10	39.73	15.11	5.21	26.91	Starting Material <0.5 in. (g):	17141.00
10*93	10*3	23.13	48.72	25.59	47.45	24.32	41.03	17.90	4.96	25.09		
10*93	10*4	25.44	46.24	20.80	45.19	19.75	39.40	13.96	5.05	27.84	Average % Moisture:	4.91
10*93	10*5	25.82	51.55	25.73	50.38	24.56	44.47	18.65	4.55	22.97	Average % Organic:	25.11
10*93	10*6	22.95	49.51	26.56	48.19	25.24	41.64	18.69	4.97	24.66		
10*93	10*7	25.84	59.30	33.46	57.79	31.95	50.88	25.04	4.51	20.65	Total Organic (g):	9083.26
10*93	10*8	24.83	54.02	29.19	52.62	27.79	45.86	21.03	4.80	23.16	Total Inorganic (g):	11994.24
11*93	11*1	23.37	38.29	14.92	37.24	13.87	30.43	7.06	7.04	45.64	Starting Organic Material >0.5 in. (g):	2771.10
11*93	11*2	23.30	42.38	19.08	41.14	17.84	33.60	10.30	6.50	39.52	Starting Material <0.5 in. (g):	6710.60
11*93	11*3	24.01	45.16	21.15	43.86	19.85	36.45	12.44	6.15	35.04		
11*93	11*4	24.78	46.09	21.31	44.71	19.93	36.58	11.80	6.48	38.15	Average % Moisture:	6.52
11*93	11*5	26.29	47.33	21.04	45.93	19.64	37.55	11.26	6.65	39.83	Average % Organic:	39.19
11*93	11*6	23.09	43.42	20.33	42.16	19.07	34.94	11.85	6.20	35.51		
11*93	11*7	25.02	42.76	17.74	41.58	16.56	34.35	9.33	6.65	40.76	Total Organic (g):	5220.10
11*93	11*8	23.32	43.71	20.39	42.39	19.07	34.43	11.11	6.47	39.04	Total Inorganic (g):	3643.68
12*93	12*1	25.39	35.06	9.67	34.15	8.76	27.41	2.02	9.41	69.70	Starting Organic Material >0.5 in. (g):	2355.30
12*93	12*2	23.73	34.99	11.26	33.97	10.24	26.31	2.58	9.06	68.03	Starting Material <0.5 in. (g):	1594.90
12*93	12*3	23.83	33.03	9.20	32.13	8.30	25.65	1.82	9.78	70.43		
12*93	12*4	23.64	33.99	10.35	33.04	9.40	25.95	2.31	9.18	68.50	Average % Moisture:	9.31
12*93	12*5	25.53	36.46	10.93	35.43	9.90	27.75	2.22	9.42	70.27	Average % Organic:	69.34
12*93	12*6	26.53	37.09	10.56	36.12	9.59	28.70	2.17	9.19	70.27		
12*93	12*7	25.94	37.72	11.78	36.64	10.70	28.56	2.62	9.17	68.59	Total Organic (g):	3241.96
12*93	12*8	25.36	35.48	10.12	34.54	9.18	27.56	2.20	9.29	68.97	Total Inorganic (g):	340.40

Table 9. Laboratory Analysis Results Continued.

Location	Crucible #	Tare (g)	Sample Wt. + Tare (g)	Sample Wt. (g)	Dry Wt. + Tare (g)	Dry Wt. (g)	Muffle Wt. + Tare (g)	Muffle Wt. (g)	% Moisture	% Organic		
On-slope Sediment Boxes Sample year 1992												
07B	B1	24.62	36.04	11.42	35.32	10.70	28.39	3.77	6.30	60.68	**Starting Organic Material >0.5 in. (g):**	**0**
	B2	23.10	36.45	13.35	35.69	12.59	28.48	5.38	5.69	54.01	**Starting Material <0.5 in. (g):**	**46.32**
	B3	25.36	36.19	10.83	35.51	10.15	28.61	3.25	6.28	63.71		
	B4	24.79	35.51	10.72	34.83	10.04	28.19	3.40	6.34	61.94	**Average % Moisture:**	**6.15**
											Average % Organic:	**60.09**
											Total Organic (g):	**27.79**
											Total Inorganic (g):	**15.64**
07E	E1	25.74	38.82	13.08	38.22	12.48	32.77	7.03	4.59	41.67	**Starting Organic Material >0.5 in. (g):**	**0**
											Starting Material <0.5 in. (g):	**13.08**
											Average % Moisture:	**4.59**
											Average % Organic:	**41.67**
											Total Organic (g):	**5.43**
											Total Inorganic (g):	**7.03**

Table 9. Laboratory Analysis Results Continued.