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Title: PREDICTING LOGGING DEBRIS ACCUMULATION IN NATURAL STREAMBEDS: A METHOD FOR FOREST MANAGERS.

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This study has analyzed factors which affect the accumulation of terrestrial organic debris within natural gravel streambeds. In addition, the amounts, sizes, and physical conditions of intruded material were measured, along with the effect of the detritus on intragravel dissolved oxygen levels.

Measurements indicate that aged intragravel detritus had no significant impact on subsurface dissolved oxygen levels. The organic material extracted from the streambeds was composed primarily of highly conditioned woody material, which is characterized by a very low B.O.D. These measurements support the hypothesis that decomposing organic material produces only a temporary demand on intragravel dissolved oxygen supplies. Previous work has indicated that this demand has generally been met after only 60 days.

One hundred and forty-four frozen core samples of ten streambeds were taken as a means of analyzing subsurface organic debris concentrations. These cores provided the data needed to calculate

streambed porosity, median cobble size, and average detritus size. In addition, stream gradient and surface debris loading were measured.

Subsurface organic debris concentrations were found to be extremely variable. The range of values observed, in grams of detritus per liter of pore volume, was 1.4 to 439.9. The mean value was 29.3 grams per liter of pore volume, with a standard deviation of 52.9. These values indicate that organic material may provide a severe threat to subsurface dissolved oxygen levels, especially if high concentrations of fresh, finely divided material, such as leaves or needles, are present. Although the impacts exerted by organic material are only temporary, there may be a detrimental impact on the fisheries resource if a large B.O.D. is produced at the time alevins are dependent on intragravel dissolved oxygen.

Regression equations for predicting subsurface debris concentrations were developed. It was observed that subsurface debris accumulations can generally be expected to increase with increases in streambed porosity, surface debris loading, and median cobble size. Concentrations can be expected to decrease with increases in stream gradient.

Estimates developed with these models cannot be expected to yield accurate values under all conditions, and the possibility of high variability must be anticipated. However, the models developed in this study do provide a means of predicting subsurface debris accumulations in natural gravel streambeds under a variety of conditions. In addition, the measurement and analysis techniques described will encourage future research which will further develop an understanding of the small stream ecosystem.

Predicting Logging Debris Accumulation In Natural Streambeds: A Method For Forest Managers

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I. INTRODUCTION

The small, headwater streams of the Western Oregon mountains are part of an extremely dynamic system. This system encompasses not only the flowing surface waters, but the subsurface, intragravel flow, and the surrounding terrestrial environment as well. A thorough understanding of the interactions of these primary systems is essential for a basic understanding of the ecosystem as a whole.

Three primary linkages between the aquatic and terrestrial ecosystems were described by Likens and Bormann (1974). Meteorologic linkages include air movements, precipitation, and other climatic factors. Geologic vectors include movements which are the result of gravity, such as mass movements or erosion. Finally, the biologic linkage involves transport as a direct result of animal activity.

Linkages between the terrestrial and aquatic systems have several common characteristics. First of all, each may be considered as movement. Organic material, sediment, or other terrestrial materials are carried into the stream channel, where they may have a severe impact on the aquatic system. Secondly, each of the three linkages may be dramatically influenced by man's activities.

Road-related mass movements and erosional loss of nutrient-bearing sediments, as well as movement of logging debris into stream channels are but a few examples of how man may influence the relationships of terrestrial and aquatic ecosystems. It becomes apparent, therefore, that the effects of any land treatment on the lotic system must be considered carefully before initiating any land management plan.

II. LITERATURE REVIEW

Terrestrial organic material is a common component in the small, headwater stream systems of Western Oregon. Naturally occuring material may move into the stream system as the result of blowdown, fire, insect damage, disease, or other natural mortality. Debris may also enter the stream channel as a direct result of logging. The amount of this material that moves into the stream channel is dependent on cutting methods and stream protection techniques employed.

The impacts of both naturally occuring and logging debris are often very similar. It is important, however, to consider the relative amounts of material present before and after any land treatment, the stability of the material present, and the amounts of finely divided material, which generally produces the greatest impact on water quality.

The amounts of organic material present in five Western Oregon streams before logging, after falling, and, finally, after yarding, were examined by Lammel (1972). This work concluded that, although there is generally a substantial increase in the amount of organic material present after falling, there is generally less material in the stream after yarding than in the original, undisturbed condition. However, the amount of fresh, finely divided material, such as needles or small twigs, is often increased after yarding. This is significant because finely divided material generally produces the greatest impact on the water quality of the system.

Since organic material is commonly found in small headwater streams, it is important to consider the impacts of this material on the water quality of the stream. Organic material may influence the dissolved oxygen content of the stream water, as well as its taste, color, and odor. In addition, large material may influence the amount and timing of sediment release, and may have a substantial impact on streambed stability.

As organic material deteriorates, it produces a biochemical oxygen demand. That is, organisms involved in detritus decomposition produce an oxygen requirement. The oxygen used by these organisms is removed from the supply available for use by fish. Ponce (1974) quantified the biochemical oxygen demand of three tree species common to the Pacific Northwest. It was determined that large amounts of finely divided detritus may reduce dissolved oxygen contents to below critical levels for anadromous fish. The threat to the oxygen supply is especially critical for finely divided material, such as leaves or small twigs, which has a greater surface area to volume ratio than larger pieces. Coarse woody material is much slower to decompose, and requires less oxygen over a given time period.

Decomposing organic material may also be responsible for adding leachate, primarily sugars and phenols, to the stream water. Leachates not only exert a high B.O.D., but may also cause a change in the taste, color, and odor of the water if very high concentrations are present. Generally, however, problems from excessive leachates are very rare, occuring only in ponded or very slow moving waters of low gradient streams.

The history and role of large debris in selected stream channels was studied by Swanson, et al. (1976). Large debris in streams may be either desirable or undesirable for the stream system, depending on the extent of debris loading and the individual stream characteristics. For example, excessive amounts of debris may form debris jams, which block fish passage, cause spawning areas to become ponded, or increase streambank cutting. Movement of these accumulations of debris may be responsible for destroying spawning areas by scouring the streambed.

On the other hand, large debris may stabilize the streambed by encouraging pool-riffle formations, and by improving energy dissipation in the system. In addition, debris jams slow the routing of fine organic material through the stream system, allowing more efficient processing of the detritus. Finally, organic material may provide hiding and rearing habitat for fish. It is obvious that organic material in a streambed has both advantages and disadvantages, both of which must be considered when developing potential debris management plans.

Flow And Dispersion In A Porous Gravel Streambed

Early research compared beds of sand or gravel to a series of tubular passages, similar to pipes. Fair and Hatch (1933) and other researchers of that period assumed only laminar flow occured in a porous medium, and attempted to extend equations which had been developed for flow through pipes to flow through a bed of sand. These attempts were relatively successful, and their results were generally verified.

Later research recognized a wider range of states of flow, from laminar to turbulent, through porous media. In addition, as a fluid flows through a porous medium, it mixes with other fluid particles, or is dispersed. Dispersion was defined by Scheidegger (1961) as "the mixing of individual fluid elements caused by the complexities of a pore system". This process should be distinguished from the process of diffusion, which is mixing caused by the random intrinsic motion of the water molecules.

Early attempts to describe the process of dispersion considered only dispersion parallel to the direction of flow. This model was found to be inadequate, but was expanded by Bear (1961), who hypothesized: "only that part of each velocity component which is either parallel or normal to the mean direction of flow is of significance". Hence, more recent models consider both lateral and longitudinal dispersion in a porous medium.

At this time, dispersion of flow through a porous medium may best be described by a model developed by Saffman (1959), which defines the medium as "an assemblage of randomly oriented straight pores, such that the path of any element through the medium would be a sequence of statistically independent steps, whose direction and duration vary in some random manner". This model may be called a "Random Walk Model". In addition, Harleman and Rumer (1963) and others have attempted to develop coefficients of lateral and longitudinal dispersion for the various states of flow. These coefficients may be used to provide an additional means of describing dispersion of flow through a porous medium.

In addition to flow within the streambed gravels, it is important to examine the processes of interchange between intragravel flow and the surface waters. Vaux (1962) explains that interchange is influenced by several streambed characteristics, including the streambed surface profile, gravel permeability, gravel bed depth, and the irregularity of the streambed surface. Upwelling will occur if the streambed permeability or the depth of the porous bed decreases, or if the streambed surface is concave upward. On the other hand, downwelling will occur if the streambed permeability or depth of the bed increases, or if the streambed surface is convex upward. These conclusions agreed with work done by Pyper (1956), who used dyes as tracers as a means of following the path of water through streambed gravels.

Intragravel flow and dispersion play an essential role in supplying dissolved oxygen throughout the redds to developing fish embryos. Redds are constructed to increase flow through the gravels by increaseng the roughness of the streambed surface. In this manner, the embryos are insured a continuous supply of dissolved oxygen. In addition, intragravel flow is available to remove excessive fines, as well as toxic metabolic waste products, from the redds. Hence, it appears that a natural means has been developed for utilizing the basic mechanisms of flow and dispersion through a porous medium to the greatest possible advantage. This system may fail, however, if loadings of either organic or inorganic fines exceed some limit.

The Fisheries Resource And The Intragravel Environment

The effects of logging debris on fish production were examined by Narver (1971). This work pointed out that debris may influence production at each stage of the fish life cycle, either through alteration of water quality or through modification of channel characteristics. Our primary concern here will be the embryo, or intragravel development stage, and how it is influenced by organic material.

The intragravel environment was described by McNeil (1966) as the most important factor influencing anadromous fisheries survival. For example, spawning-bed gravel size may influence several factors important to developing fish embryos. McNeil and Ahnell (1964) describe the ideal spawning bed as consisting of gravels ranging in diameter from one to 15 centimeters, with a minimum of fines. The size composition of the bottom materials influences such essential characteristics as water velocity, dissolved oxygen availability, mineral and waste metabolite removal, and osmotic pressure around the eggs. These characteristics are all related to streambed permeability, which is a function of the gravel size distribution. It should be noted that, generally, excesses of fines are removed by fall and winter freshets, even though fines in the spawning gravels may have been significantly increased due to natural or man-caused events in the area.

Embryos located in streambeds require a continuous supply of dissolved oxygen, which must be supplied by intragravel flow through the redds. Silver, et al. (1963) found that fry from embryos raised at high dissolved oxygen levels were generally larger and healthier than fry raised at lower dissolved oxygen concentrations. This work also concluded that higher subsurface water velocities were required at lower dissolved oxygen levels to supply the total amount of dissolved oxygen required for optimum fish development.

Organic material intruded into the streambed may reduce the supply of dissolved oxygen to the redds in several ways. First, as organic material decomposes it produces a biochemical oxygen demand, as described earlier in this report. Any loss of dissolved oxygen in the intragravel waters may be critical, especially if flow velocities or interchange rates with surface waters are low. Secondly, organic debris which becomes incorporated into a streambed may be responsible for reduced permeability within the streambed gravels. Reduced flow velocities and increased upwelling caused by the blocked pore spaces may dramatically reduce the dissolved oxygen supplied to developing embryos.

Thirdly, as terrestrial organic material is conditioned in an aquatic system, leachates, primarily sugars and phenols, are released. In addition to exerting a very high B.O.D., these substances may be directly toxic to fish. The exact toxicity of leachates has not been identified, but Ponce (1974) demonstrated that lack of dissolved oxygen in the system would cause fish mortality before toxic levels of the leachates could be reached.

Water moving through the redds is also responsible for the removal of toxic waste products. The principle metabolites produced by embryos are CO_2 and ammonia. Once again, it is important to note that subsurface flow through the gravels must not be reduced through blockage of pore spaces by intruded organic material.

Organic material may also influence developing fish embryos indirectly in several ways. For example, large organic material often forms dams which may trap large quantities of inorganic sediment. When the debris is removed, either by man or by natural means, large quantities of sediment are flushed through the stream system. Such massive amounts of material may be responsible for a temporary decrease in streambed permeability, thus blocking the essential exchange of surface and subsurface waters. It has already been pointed out, however, that fines are generally removed by fall and winter freshets when sediment accumulates in a streambed.

On the other hand, organic debris in streams may also be benificial to the fisheries resource in several ways. Cummins (1974) states that small mountain stream ecosystems are heterotrophic. That is, they are dependent on plant material from the terrestrial environment as their primary energy source. Different size classes of detritus are processed by selective groups of organisms specifically adapted to utilize the various components of the organic debris. In this manner, terrestrial plant material provides one of the initial steps in the food chain of first and second order streams.

It is apparent that the interactions of terrestrial organic material in aquatic ecosystems are extremely complex. Excessive quantities of debris may be deleterious to water quality, the fisheries resource and other stream fauna, and to the morphology of the stream channel. On the other hand, a certain amount of material is important to the energy balance of the stream. It is essential, therefore, that great care be taken during any land treatment to maintain the natural balance within the small stream ecosystem. However, our understanding of the many roles of organic material in the ecology of small streams is still far from complete.

Intrusion Of Organic Material Into A Gravel Streambed

The importance of debris that becomes incorporated into the streambed has been examined and the actual intrusion processes will now be discussed. A knowledge of those characteristics which make one stream more succeptable to debris intrusion than another stream is essential for making effective stream management decisions. Unfortunately, very little work has been done which addresses this problem.

An attempt to model debris intrusion into an artificial gravel streambed under high and low flow conditions was made by Garvin (1975). Low flow conditions involved a stable streambed, with little or no gravel movement. Under this condition, debris concentrations within the gravels were highly variable, especially within the surface-to-sixteen centimeter layer. The streambed characteristics which were found to significantly affect the intrusion of debris under low flow conditions were organic debris size and streambed pore volume. The high flow study considered debris intrusion into a moving streambed. Extremely high variability was encountered under this condition, with natural random errors which were too great to permit any significant model results.

Accumulation of different size classes of organic material may vary between streams due to differences in the mechanisms of intrusion for small, versus large pieces. Although no work has been done which examines these mechanisms, several general theories may be stated. It is probable that non-particulate debris enters the streambed only during periods of bed movement. That is, as bed materials move during periods of high flow, surface organic material becomes interspersed with the moving gravels. The organic material settles along with the gravels, and is thus incorporated into the streambed. It is also possible that bedload material may settle out, forming a gravel layer over non-moving organic material. Although no specific research can be cited, it is probable that one or both of these mechanisms is instrumental in the incorporation of large pieces of organic material into natural gravel streambeds.

Particulate organic material may become intruded into streambed gravels through the same processes as the larger material. In addition, particulate matter may enter the streambed by settling, or it may be carried into the gravels by water flowing into the streambed. It is possible that particulate organic material may be dispersed through the streambed by subsurface water flow. In many respects, such material may act much like inorganic sediments, although differences in settling and movement may result from differences in the densities of organic, versus inorganic sediments.

The debris intrusion work done by Garvin is of limited practical value because it was done under artificial conditions, in a concrete flume. The results of the flume study must now be verified by examining debris intrusion for natural gravel streambeds. This will enable land managers to develop a more comprehensive understanding of the potential impacts of any land management operation.

III. OBJECTIVES

The next step toward enabling land managers to predict the impact a terrestrial treatment will have on the aquatic and fisheries resources is to provide a practical means of evaluating the amounts of intragravel organic material present before the treatment. This project has been designed to answer the following questions important to land managers:

1. What are the amounts, sizes, and physical conditions of organic debris found in the gravel streambeds of undisturbed, head-water streams?
2. What are the primary field characteristics commonly measured by land managers which may influence the intrusion of organic material into gravel streambeds?
3. What is the relationship between amounts and types of organic debris within the streambed and intragravel dissolved oxygen?

IV. METHODS

Ten streams from throughout Western Oregon were chosen for study, as listed in Table I. These samples were selected to provide a variety of commonly observed conditions for undisturbed, headwater streams. Prominent variables which were considered during stream selection included streambed gravel composition, stream gradient, surface debris loading, natural or man-caused disturbance, and accessability.

The ten streams chosen for this study may be divided into four distinct provinces, with a range of characteristics included for each district. The four provinces represented include low gradient coastal streams, high gradient coastal streams, Cascade Mountain Range streams in volcanics, and Cascade Range streams in granitics.

Each of the four provinces represented may be distinguished by one or more unique stream channel characteristics. For example, low gradient coastal streams are characterized by a gradient of less than three percent, with relatively small average gravel sizes. High gradient coastal streams have gradients greater than three percent, with relatively coarse cobble sizes. Three percent slope was arbitrarily chosen as the dividing point because it appeared to represent a natural breaking point for the streams sampled.

The Cascade Range streams in the Willamette and Umpqua

TABLE I: DESCRIPTION OF TEN SAMPLE STREAMS.

Stream Name (Ranger Dist)	Watershed Size (ha)	Distinguishing Features
		Low Gradient Coastal
Flynn Creek (Alsea)	220	Low gradient; Coast Range; Light debris loading.
Gopher Creek (Alsea)	1225	Low gradient; Coast Range; Light debris loading.
		High Gradient Coastal
Bear Creek (Alsea)	565	High gradient; Coast Range; Moderate debris loading.
Mill Creek (Alsea)	240	High gradient; Coast Range; Heavy debris loading.
Mill Creek (Waldport)	455	High gradient; Coast Range; Moderate debris loading.
		Cascade Range - Volcanics
Mack Creek (Blue River)	585	High gradient; Cascade Range; Light debris loading.
Mack Tributary (Blue River)	90	High gradient; Cascade Range; Heavy debris loading.
Watershed II (Blue River)	95	High gradient; Cascade Range; Moderate debris loading.
		Cascade Range - Granitics
Jim Creek (Roseburg)	940	High gradient; Cascade Range; Moderate debris loading.
No Man Creek (Roseburg)	580	High gradient; Cascade Range; Light debris loading.

National Forests represent high gradient streams, with relatively large cobble sizes. The streams selected on the Umpqua National Forest are based in granitic material, while the Willamette National Forest streams are based in volcanic substances, such as breccea, tuff, or basalt.

Field Measurements And Techniques

A 250 foot (76.2 meter) section of eight of the ten sample streams was selected for the desired conditions. Each section was then subdivided into 25 foot (7.62 meter) sections. These divisions, which were marked with metal tags, provided a simple reference for sample location and measurement points. A 25 foot (7.62 meter) wide zone, with its center at the center of the water, was considered for each stream. This sample zone provided a 6250 square foot (580.6 square meter) study area for each of the eight streams.

Two of the ten sample streams were examined using 150 foot (45.7 meter) sections. Use of longer sections would have been unprofitable, as the reaches examined were bounded on each end by bedrock channels, which are not succeptable to debris intrusion. For these two streams, the total study zone was 3750 square feet (348.2 square meters).

Streambed Sampling

This study was based on samples taken by freezing a core of the streambed around a pipe, which had been driven into the streambed. These cores provided an "undisturbed" sample of the streambed gravels, saturated pore space, and intruded organic material. Two techniques were used during the course of this study to obtain the frozen cores. Although the cores produced are identical, each of the two techniques has both advantages and disadvantages.

The first technique for frozen core sampling was designed by Ryan (1970), and developed for use at Oregon State University by Ringler (1970). This sampler consists of two parts, as shown in Figure One. The outer (large) section consists of a bucket-like container 20 cm high and 16 cm in diameter. A four cm diameter iron pipe is attached to the center of the bottom of the bucket, so that liquids can flow from the bucket into the pipe. The pipe is threaded so that it can be removed from the bucket. The tip of the pipe is formed into a solid point which may be driven into the streambed. The length of pipe used is dependent on the length of core desired.

The inner section of this sampler consists of a smaller bucket-like container which is eight cm high and 12 cm in diameter. A 1.25 cm diameter copper tube is attached to the center of the bottom of the container so that liquid may flow through the container, into the copper tube. The end of the copper tube is open.

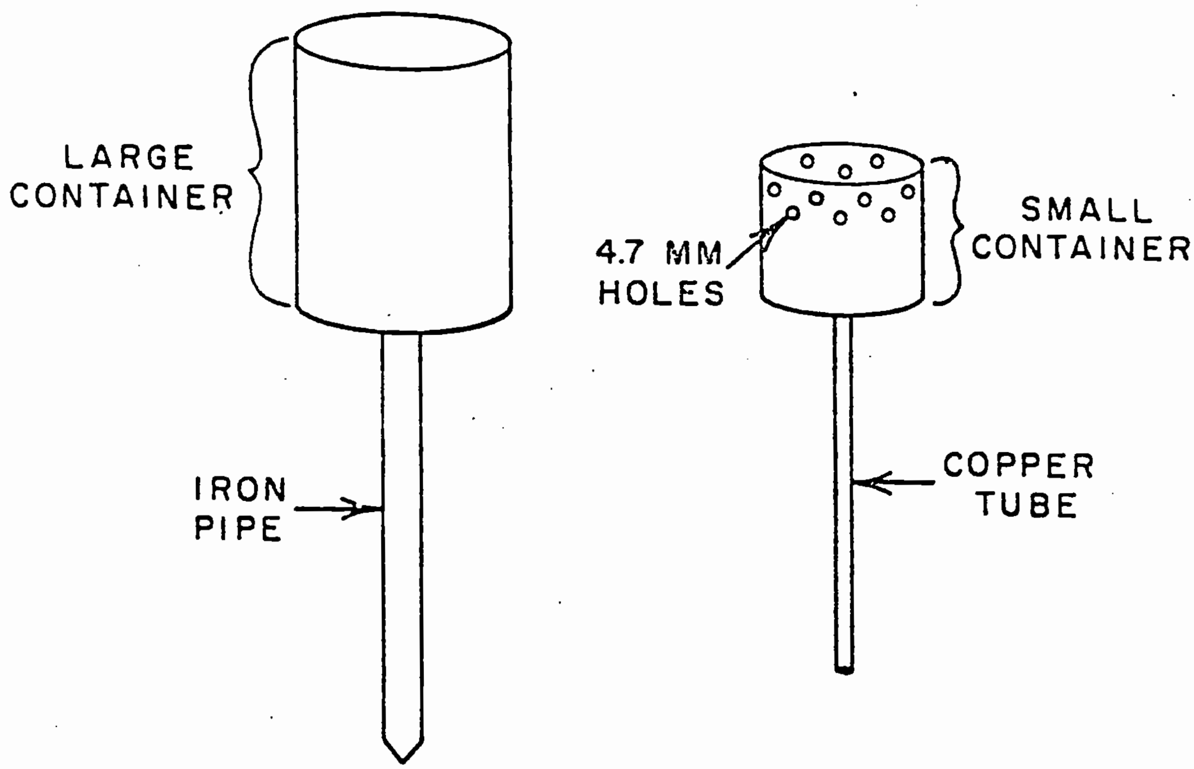

Figure 1: Frozen core sampler. (developed by Peter Ryan, Canada Department of Fisheries, Vancouver, British Columbia.)

To obtain a sample, the iron pipe is driven into the streambed to the desired depth. The large container is then attached to the top of the pipe, and acetone is poured in until the large container is approximately one-third full. The inner section is then lowered into the outer section so that the copper tube extends down into the iron pipe. Dry ice is placed in the small container. The dry ice cools the acetone to -80° C. The cold acetone flows down the copper tube into the iron pipe, forcing the relatively warm acetone up the iron pipe into the large container, where it may be re-cooled by the dry ice. In this manner, the acetone is circulated through the system, causing the layer of streambed in contact with the pipe to be frozen into a core. This technique requires about one hour, and six to ten kilograms of dry ice, to form a core approximately 20 cm. in diameter.

This technique has several distinct disadvantages. First of all, a relatively large amount of equipment and material is required for each core. This problem is especially significant if the equipment must be carried for any distance over rough terrain. Secondly, the containers are subject to leaks. This significantly increases the amount of acetone required per core. In addition to increased costs, the cores obtained may be smaller or lost entirely if the sampler is not operating properly. Finally, this approach is relatively expensive. In addition to construction and maintenance of the samplers, dry ice and acetone were consumed in large quantities.

Due to the significant problems associated with obtaining frozen cores by the dry ice method, a second technique was suggested by George Wingate, Watershed Extension Specialist, Oregon State University, Corvallis, Oregon. This approach used liquid nitrogen, which was slowly poured into a pointed iron pipe which had been driven into the streambed. The liquid nitrogen was rapidly volatilized, producing temperatures of -180° C. within the pipe, and freezing a core approximately 20 cm. in diameter in about 15 minutes.

The liquid nitrogen technique offers several significant advantages over the dry ice method. First, the amount of equipment needed is substantially reduced, with no significant maintenance requirement. Second, the liquid nitrogen required per core is much less expensive than the equivalent dry ice and acetone. Finally, this technique takes only one-fourth the time needed for the dry ice method.

On the other hand, the liquid nitrogen technique also has several disadvantages. The most significant problem is that the nitrogen is difficult to handle and transport. Care must be taken to avoid exposure from spilling or splashing nitrogen. In addition, heavy insulated tanks are used to transport the material, so that a fork-lift is required for loading and unloading the primary storage tank into the transport vehicle. Finally, expensive Dewar flasks are required for transferring the nitrogen from the tank to the sample site. These flasks are fragile and must be handled carefully, although no damage was incurred in this study.

After a core was frozen onto a pipe, it was extracted from the streambed (Figure Two) and sectioned into layers of 15 cm. Generally the cores used for this project were 45 to 60 cm long. Each section was placed in a plastic bag, labeled, and returned to the lab, where it was stored in a cold room for later laboratory analysis.

Before leaving this discussion of frozen core sampling, it should be noted that roughly one in four samples did not produce a frozen core. This problem was encountered with both sampling techniques. There are several possible reasons for this failure. First of all, it is essential that all pore space near the pipe be filled with water. If the bed material around the pipe is not saturated, the core may be unable to form. A second, more significant problem is related to subsurface flow. If subsurface flow rates are high, warmer water may flow past the pipe before a core is able to form. This problem is especially significant for high-gradient, porous streambeds.

It should also be noted that frozen core sampling is biased against streambeds with average cobble sizes greater than 15 cm. Cores in these areas tend to become frozen among large cobbles and are difficult to extract and separate. Under these conditions, irregular or partial cores were sometimes formed. Partial cores were sectioned and analyzed in the same manner as complete, regular cores whenever possible.

Figure 2: Frozen core after extraction from the streambed.

Dissolved Oxygen Sampling

Intragravel water samples were extracted from two cm diameter plastic standpipes which had been driven into the streambed at the core sample points. The standpipes were constructed by fastening pointed metal tips in the ends of one meter long P.V.C. pipes. Numerous 0.5 cm diameter holes were drilled through the pipe from near the point to approximately 10 cm above the metal tips. The pipe was driven into the streambed until the 10 cm layer of holes was at the intragravel layer being sampled.

Immediately after the pipes were driven to the desired level in the streambed, muddy water in the pipes was removed and discarded. The pipes were allowed to stabilize for 24 hours. Three-hundred ml samples were then removed from the standpipes by applying suction. The dissolved oxygen in these samples was analyzed in the field using a technique described by the Hach Chemical Company (1975). Dissolved oxygen concentrations were calculated to the nearest 0.1 p.p.m., and converted to percent saturation using a table of temperatures with their associated saturation oxygen concentrations. This conversion eliminated the effects of water temperature differences on the dissolved oxygen levels observed in different samples.

The method used for obtaining intragravel water samples was subject to several problems. Standpipes frequently filled with sediment or muddy water to the degree that no dissolved oxygen analysis could be completed. This obstacle resulted in a very small sample of usable dissolved oxygen values. Of course, streambeds characterized by high concentrations of fines are most susceptible to this problem. Several steps could be taken as a means of overcoming this problem. Smaller holes in the standpipes, as well as a smaller diameter pipe, could possibly prevent sediment entrance and settling.

It is important to insure that the entire sample taken comes from the desired intragravel layer. It is difficult to prevent surface water from running down the outside of the standpipes, especially when 300 ml. samples are required. It is recommended that sampling devices and chemicals be modified to use smaller samples, such as the mechanism described by Harper (1953). Carefully constructed and installed standpipes, coupled with improved analysis techniques, should help to minimize the problems encountered in this study.

Stream Description Methods

The organic debris which accumulates above the bed in a stream channel may have a direct influence on the concentrations which accumulate within the streambed gravels by providing a source of material and by modifying flow conditions. Surface organic debris was measured considering two basic size classes. Large material included all pieces with a diameter greater than 10 centimeters. This size group includes pieces such as tree boles, root wads, and large branches. Each piece within the study zone was considered individually, with small end diameter, large end diameter, and length measured for each piece. These values were then converted to volumes using Smalian's Formula:

$$V = ((A_1 + A_2)/2) \times L$$

Where V = Volume of the large piece

A_1 = Small end area

A_2 = Large end area

and L = Length of the piece.

Determination of which pieces should be measured required some personal judgement, especially when dealing with pieces that had only one end in the stream channel, or pieces which were suspended over the stream. Generally, all pieces were measured which could potentially enter the channel under high flow conditions. Judgement was also required during the measurement of irregular pieces, such as root wads. In each case, an attempt was made to arrive at average dimensions, which would yield a reasonable estimate of the true volume.

Small organic debris, such as twigs or small branches, was considered in three diameter classes: Zero to one cm., One to three cm., and Three to ten cm. An estimate of the volume of this material was obtained using a line intersect method, as described by vanWagner (1968) and Brown (1971). Cross sections were established every 10 feet (3.05 meters) along each study zone. Three random sample points along each cross section were chosen in advance. At each of these points, the number of organic pieces which intersected a metal frame was counted. The number of intersections from each size class was converted to a volume estimate using an equation modified from vanWagner (1968) and listed by Lammel (1972):

$$V = \frac{\pi^2 n \bar{d}^2}{8L}$$

where V = Volume of material per unit area

n = Number of intersections for any size class

$\bar{d}$ = Average diameter for a given size class

and L = Length of sample frame (30 cm).

Average diameter values were obtained after measuring approximately 750 randomly selected pieces from a wide range of stream conditions. The average diameters obtained for each of the three size classes were:

0.48 cm. for debris zero to one cm. in diameter

1.83 cm. for debris one to three cm. in diameter

and 5.25 cm. for debris three to ten cm. in diameter.

The small surface debris measurement techniques used for this project require a large sample size if accurate estimates are to be obtained. Therefore, only one volume was calculated for each stream for each of the size classes. This value represents the average debris loading for that entire sample stream. In other words, a single value, based on measurements over the entire stream sample should provide a more accurate estimate than if values had been calculated for each 25 foot long zone. This is because values calculated for the smaller sections could only be based on a relatively small number of measurements.

Table II provides a comparison of the surface debris volumes for each of the 10 sample streams examined. Volume measurements were converted to mass units assuming a specific density of 0.58 grams per cubic centimeter, with an average moisture content of 10 percent, as listed by Lammel (1972).

The stream gradient may also have a significant influence on organic debris intrusion into natural gravel streambeds. Therefore, the stream gradient at each core sample point was measured using a hand-held abney. Estimates of stream gradient are assumed to be within plus or minus one percent.

Laboratory Methods

The frozen streambed cores obtained in the field provided "undisturbed" samples of the streambed. That is, the proportions of gravel, water, or organic material in the sample were equal to the proportions in the streambed at the sample point. Therefore, each of the samples could be analyzed in the laboratory to yield a great deal of information. The laboratory procedures described in this section are modified from the techniques described by Garvin (1974).

Each frozen core layer was placed in a metal pan and weighed to the nearest 0.1 gram on an Ohaus balance. The

TABLE II: SURFACE ORGANIC DEBRIS LOADING OF SAMPLE STREAMS
(All values in g/cm^2 of streambed)

Stream Name	0 - 1 cm.	1 - 3 cm.	3 - 10 cm.	Small Total	Large Debris
Bear Cr.	0.032	0.076	0.158	0.266	1.42
Flynn Cr.	0.044	0.057	0.125	0.226	2.97
Gopher Cr.	0.021	0.040	0.158	0.219	0.30
Jim Cr.	0.256	0.063	0.151	0.240	8.35
Mack Cr.	0.023	0.036	0.151	0.210	6.90
Mack Trib.	0.137	0.247	0.947	1.331	11.21
Mill (Al)	0.035	0.077	0.184	0.295	8.16
Mill (Wd)	0.046	0.063	0.381	0.490	4.27
No Man Cr.	0.023	0.020	0.026	0.069	0.00
WS II	0.050	0.077	0.565	0.692	5.92

samples were then oven dried for 24 hours at 100° C., and re-weighed. The difference in weights was equal to the water that had been in the sample. Assuming all pore spaces were completely saturated, and that water density equals one gram per cubic centimeter, the mass of water in grams equals the volume of pore space in cubic centimeters.

After the water had been removed from the sample, the remaining inorganic and organic solids were dry sieved. Sieve sizes included 25.4 mm., 16 mm., 9.51 mm., 4.0 mm., 2.0 mm., 1.0 mm., and a pan. The percent of the sample that would pass each successive sieve was then calculated. These figures, in turn, were used to calculate the weighted average diameter (by weight) of the solids in a given sample. In some cases, it was observed that one or two large cobbles could bias the average value. As a means of overcoming this problem, the median solid size (by weight) was calculated. That is, 50 percent of the weight of the sample was composed of particles larger than the median, with the remaining 50 percent smaller.

Figure three shows an elutriator which was developed to facillitate the removal of organic material from the core sample. This device consists of a five gallon tank which has two metal tubes protruding from one centimeter above its bottom. One of these tubes is attached to a water supply, while the other is attached to an air regulator. In addition, a manometer is attached to the elutriator for monitoring changes in the water level in the tank.

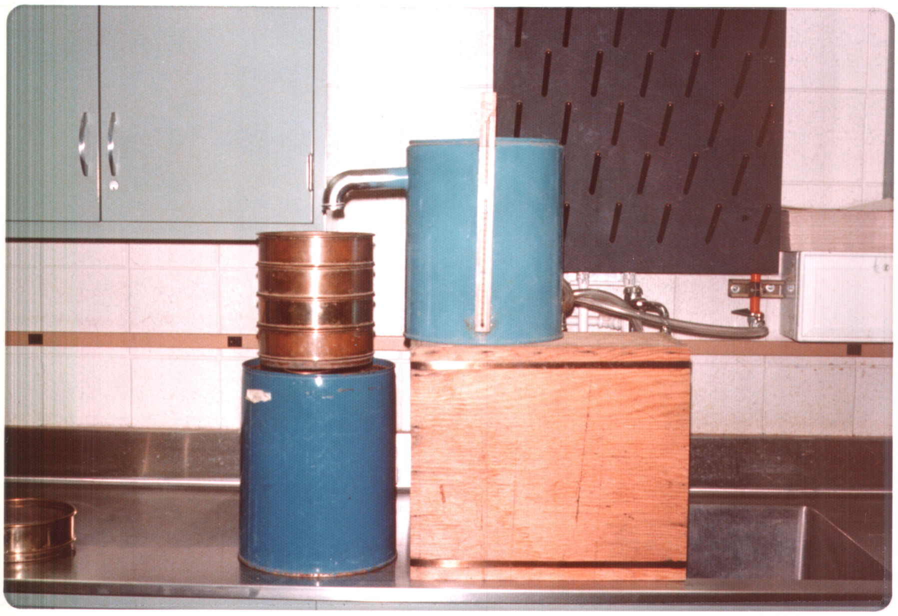

Figure 3: The Elutriator.

After the solid portion of a sample had been dry sieved, the solid volume was obtained by placing the sample in the elutriator, which had been partially filled with water. Using basic water displacement techniques, the change in water height after addition of the sample, multiplied by the surface area of the tank, equals the volume of the solids in the sample. This value was used to calculate the porosity of the sample section using the following equation:

$$P = (V_p / (V_p + V_s)) \times 100$$

where P = Porosity (percent)

V_p = Volume of pore space (cm^3)

and V_s = Volume of solid material (cm^3).

The organic material was then separated from the inorganic solids by running water and bubbling air through the elutriator. The lower density organic material was carried from the tank by water flowing through a 3.5 cm. diameter curved pipe, which protruded from near the top of the elutriator tank. In order to facillitate complete separation, the solids in the tank were stirred regularly. Occasionally, the air and water regulators were turned off, allowing any organic material held in suspension to float to the water surface, where it could be skimmed off.

The elutriator technique was designed to remove as much of the organic debris as possible. There were some cases, however, when it was very difficult to obtain complete separation. This problem was especially prevalent when extremely large amounts of detritus were present, or when there was a large percentage of fine inorganic sediment in the sample. Under these conditions, it was generally necessary to run the elutriator for twice the normal time to get satisfactory separation.

As the organic material was washed from the elutriator tank, it passed through a wet-sieve series, including 16.0 mm., 4.0 mm., 1.0 mm., 0.25 mm., and 0.075 mm. sieves. All material passing the 0.075 mm. sieve was collected in a large container.

The organic material from each sieve was placed in a labeled crucible and oven dried for 24 hours at 100° C. After removal from the oven, the crucibles were allowed to adjust to room temperature. After cooling, the crucibles were weighed to the nearest 0.001 gram on a Mettler balance. The crucibles were then placed in a muffle furnace at 600° C. for six hours. At this temperature, all the organic material in the crucibles was volatilized. After cooling, the crucibles were again weighed. The volatilized weight, subtracted from the oven dry weight, yielded the weight of the organic material in a given size class.

The water and material passing the 0.075 mm. sieve was weighed, and a 300 ml. sample was extracted and weighed. The subsample was filtered through Watman No. 42 Ashless filter papers, where particulate matter was collected. These filters were dried and weighed, then volatilized and re-weighed. The oven-dried crucible weight was adjusted by subtracting the oven-dried filter paper weight. The volatilized weight was then subtracted from the corrected oven dry weight to yield the weight of the particulate organic material present in the subsample. This value was multiplied by the ratio of the weight of the total water collected in the tank to the weight of the 300 ml. sample. The new value represents the total weight of the particulate organic matter in the core sample.

The weights of the organic material from each of the size classes were used to calculate the weighted average of the organic material sizes in each of the samples. In addition, the organic debris weights were used to calculate the following debris concentrations: (a) grams of organic material per liter of pore volume in the streambed, (b) grams of organic material per liter of solid volume in the streambed, and, finally, (c) the grams of organic material per liter of total core volume. These values were used as dependent variables during the development of debris accumulation prediction models.

It is probable that the factors affecting the accumulation of large pieces of debris may be different from the factors affecting small and particulate material. Therefore, the organic material found within each streambed was divided into two general size classes. Large material included all debris greater than four millimeters in diameter, while all material that passed a four millimeter sieve was considered as fine, or particulate debris. The organic debris from each of these two size classes was converted into debris concentrations with respect to pore volume, solids volume, and total streambed core volume. These concentrations, along with the concentrations of total debris loading, were used as dependent variables for model development.

Statistical Methods

The Statistical Interactive Programming System (SIPS), a package of statistical programs developed at Oregon State University, was used to analyze the data obtained from stream measurements and laboratory analysis of frozen core samples. Stepwise multiple regression techniques were used to develop predictive models for the following dependent variables:

Y_1 Grams of organic material per liter of pore volume.

Y_2 Grams of organic material per liter of solids volume.

Y_3 Grams of organic material per liter of total volume.

Y_4 Grams of small organic material (less than four mm. in diameter) per liter of pore volume.

Y_5 Grams of small organic material per liter of solids volume.

Y_6 Grams of small organic material per liter of total volume.

Y_7 Grams of large organic material (greater than four mm. in diameter) per liter of pore volume.

Y_8 Grams of large organic material per liter of solids volume.

Y_9 Grams of large organic material per liter of total volume.

Y_{10} The average organic piece diameter (mm.).

The independent variables used during model development were:

X_1 Depth of the sample in the streambed (cm.).

X_2 Average solid size (mm.).

X_3 Median solid size (mm.).

X_4 Mass per unit area of surface debris zero to three cm. in diameter (grams per cm. squared).

X_5 Mass per unit area of surface debris three to ten cm. in diameter (grams per cm. squared).

X_6 Mass per unit area of surface debris greater than 10 cm. in diameter (grams per cm. squared).

X_7 Streambed porosity (percent).

X_8 Stream gradient (percent).

Each of the variables used to develop the debris intrusion models was manipulated to account for any interactions between variables, or transformed to reduce the effects of any non-linear relationships. In addition, any variables which did not make a significant contribution to the model were eliminated from the analysis. In this manner, models were developed which provided the simplest and most efficient means of predicting organic debris concentrations in natural gravel streambeds.

V. ANALYSIS AND RESULTS

The values obtained by stream measurements, and by laboratory analysis of frozen core samples, are characterized by very high variability, as shown in Table III. The organic debris concentrations, which were used as dependent variables for model development, exhibit large ranges of values, and very large standard deviations. This variability has made it very difficult to accurately predict debris accumulation levels within gravel streambeds.

The values obtained to index the field characteristics which may affect subsurface debris accumulation also exhibit a wide range of values. This is desireable, as it is important to represent the wide range of characteristics which may be observed in the field. It must be emphasized that the models developed from this data are based on a sample size of only 144 observations. However, these models should provide an initial analysis of the stream characteristics that appear to influence organic debris accumulations in natural gravel streambeds.

Subsurface Debris Accumulation Models

It was observed on scatter diagrams that subsurface debris concentration is a non-linear function of porosity. Several

TABLE III: BASIC STATISTICS FOR EACH VARIABLE.

Variable Name	Mean	Std. Dev.	Minimum	Maximum	Range
Dependent Variables					
g/l pore (Total OM)	29.26	52.92	1.35	439.93	438.58
g/l sol. (Total OM)	22.06	50.35	0.65	358.95	358.30
g/l tot. (Total OM)	12.13	25.13	0.47	197.67	197.20
g/l pore (Small OM)	10.44	5.68	0.91	34.01	33.10
g/l sol. (Small OM)	6.11	5.37	0.24	31.83	31.59
g/l tot. (Small OM)	3.89	2.85	0.19	15.46	15.27
g/l pore (Large OM)	18.86	51.62	0.00	428.63	428.63
g/l sol. (Large OM)	15.89	47.56	0.00	349.73	349.73
g/l tot. (Large OM)	8.31	24.13	0.00	192.59	192.59
Average OM Size (mm)	3.78	5.17	0.06	19.25	19.19
Independent Variables					
Sample Depth (cm)	24.49	13.55	8.00	52.00	44.00
Ave. Solid Size (mm)	15.53	5.88	1.88	31.36	29.48
Med. Solid Size (mm)	15.42	8.99	0.63	30.16	29.53
0-3 Surf. OM (g/cm^2)	0.126	0.097	0.04	0.384	0.341
3-10 Surf. OM (g/cm^2)	0.295	0.272	0.03	0.947	0.921
Lge Surf. OM (g/cm^2)	4.98	3.60	0.00	11.21	11.21
Porosity (%)	33.43	9.28	14.90	63.00	48.10
Stream Gradient (%)	4.31	3.69	1.00	17.00	16.00

transformations of porosity were tested to determine the best relationship available. Porosity, as a percent, squared was found to be the most highly correlated with subsurface debris concentrations. Therefore, porosity squared was used to replace porosity as an independent variable.

It was also observed that median cobble sizes and average cobble sizes were approximately equal. However, in preliminary models, one of these variables was always positively correlated with subsurface debris concentrations, while the other was negitively correlated. Calculations revealed that the second of the two variables added did not contribute significantly to the model. Therefore, it was determined that only one of these two variables should remain in the analysis. Median cobble size was chosen because of the probability that average solid size is biased by the presence of a single, abnormally large cobble in a sample. In addition, median cobble size had the higher correlations with intragravel debris accumulations.

A similar interaction was discovered between the three surface debris loading factors. That is, if the amount of bole-sized material was greater in one stream than another, the twig and branch sized loadings were also higher. Therefore, only one of the three values of surface debris loading could be used in the analysis.

The index for bole-sized material was chosen as the best surface debris factor. Although this variable is slightly less significant than the other two surface debris factors, it provides several distinct advantages. First of all, this factor is the most easily measured. Land managers can obtain an idea of the relative surface debris loading of various streams with quick, simple observations. Secondly, the bole-sized material is the most stable. That is, this material is least lidely to be removed by winter freshets.

Although streams which had been subject to recent sluice-outs were not included in this study, it must be remembered that flood events which are capable of modifying the amounts of twig and branch sized material may also change the subsurface debris concentrations by initiating bed movement. However, since the bole-sized surface material is only slightly less correlated to subsurface debris than the other surface material factors, it appears that the loading of large, above-bed organic material will provide a more effective predictor than twig or branch-sized surface debris.

One observation had such extremely high subsurface debris concentrations present that it was considered an outlier and was dropped from the analysis. While it is essential to examine a wide range of values when considering potential intragravel debris accumulations, it is not practical to accept a biased model on the basis of one extreme observation. After this observation was dropped, 143 observations remained in the analysis.

After manipulation and testing of the measurements, the independent variables remaining in the analysis were:

1. Depth of sample in the streambed
2. Median cobble size
3. Mass of large surface material per unit of streambed surface area
4. Stream gradient

and 5. Streambed porosity squared.

These variables were used to develop the final models for predicting organic debris concentrations within natural gravel streambeds.

The first group of dependent variables examined consisted of the mass of the total organic matter per liter of volume of either the pore space, inorganic solid material, or total core sample. The models obtained for each of these variables were:

(1) Grams of organic matter per liter of pore volume=
-52.84 + 1.67 (Median cobble size)
+ 2.38 (Large surface debris loading)
- 2.00 (Stream gradient)
+ 0.04 (Porosity squared).

(R^2 = 0.362)

(2) Grams of organic matter per liter of inorganic solids=
-73.69 + 1.77 (Median cobble size)
+ 2.14 (Large surface debris loading)
- 1.83 (Stream gradient)
+ 0.05 (Porosity squared).

(R^2 = 0.543)

(3) Grams of organic matter per liter of total sample volume=
-31.13 + 0.81 (Median cobble size)
+ 1.07 (Large surface debris loading)
- 0.92 (Stream gradient)
+ 0.02 (Porosity squared).

(R^2 = 0.479)

The independent variables which are significant at the 80 percent confidence level, listed from the most significant to the least significant, are: Porosity squared, Median cobble size, Surface debris loading, and Stream gradient.

The second group of dependent variables consists of the mass of small organic material (less than four millimeters in diameter) per liter of pore volume, inorganic solids volume, and total core sample volume. The models for prediction of each of these variables were:

(4) Grams of small organic matter per liter of pore space=
2.87 + 0.41 (Large surface debris loading)
+ 0.05 (Stream gradient)
+ 0.0026 (Porosity squared).

($R^2 = 0.401$)

(5) Grams of small organic matter per liter of solids volume=
4.04 + 0.27 (Large surface debris loading)
+ 0.25 (Stream gradient)
+ 0.0064 (Porosity squared).

($R^2 = 0.801$)

(6) Grams of small organic matter per liter of total sample=
2.03 + 0.026 (Depth of sample)
+ 0.23 (Large surface debris loading)
+ 0.19 (Stream gradient)
+ 0.0027 (Porosity squared).

($R^2 = 0.676$)

The independent variables which are significant at the 80 percent confidence level, listed from the most significant to the least significant, are: Porosity squared, Large surface debris loading, and Stream gradient. The model for grams of small organic matter per liter of total sample volume was also significantly influenced by the depth of the sample. This difference in the three models is probably due to differences in the volumes used to calculate the subsurface debris concentrations for small debris. That is, the dependent variable for Model (6) is smaller than for Models (4) or (5). Attempting to predict these smaller values may be responsible for making depth of sample a significant factor in only one model.

The third group of dependent variables consists of the mass of large organic material (greater than four millimeters in diameter) per liter of pore space, solid volume, and total frozen core volume. The models obtained for these variables were:

(7) Grams of large organic matter per liter of pore volume=
-55.10 + 1.65 (Median cobble size)
+ 1.95 (Large surface debris loading)
- 2.53 (Stream gradient)
+ 0.039(Porosity squared).

(R^2 = 0.337)

(8) Grams of large organic matter per liter of solids volume=
-68.13 + 1.73 (Median cobble size)
+ 1.83 (Large surface debris loading)
- 2.06 (Stream gradient)
+ 0.045(Porosity squared).

(R^2 = 0.464)

(9) Grams of large organic matter per liter of total volume=
-30.07 + 0.81 (Median cobble size)
+ 0.86 (Large surface debris loading)
- 1.09 (Stream gradient)
+ 0.021(Porosity squared).

(R^2 = 0.414)

The independent variables which are significant at the 80 percent confidence level, listed from the most significant to the least significant, are: Porosity squared, Median cobble size, Stream gradient, and Large surface debris loading.

A final dependent variable considered was the average diameter of the organic pieces found within the streambed gravels. The model developed to predict this factor was:

(10) Average subsurface detritus diameter=

$$-5.15 + 0.22\ (\text{Median cobble size}) + 0.23\ (\text{Large surface debris loading}) - 0.34\ (\text{Stream gradient}) + 0.0048\ (\text{Porosity squared}).$$

$(R^2 = 0.302)$

The independent variables which are significant at the 80 percent confidence level, listed from the most significant to the least significant, are: Porosity squared, Median cobble size, Stream gradient, and finally, Large surface debris loading.

The average subsurface detritus diameter model was subject to a significant error due to organic pieces that were broken up during sampling or transport. It is probable, therefore, that this model will underestimate the correct average particle size for pieces of organic material.

It was noted in these models that porosity squared was the independent variable which had the strongest correlation with each of the dependent variables. It was hypothesized that the organic material was creating the porosity as it became incorporated into the bed. In an effort to account for this interaction, models were developed which used subsurface debris concentrations divided by porosity as the dependent variables. Other models were developed to predict subsurface debris concentrations multiplied by porosity. In all cases, the models developed to predict these values were of less practical value than the models which used porosity squared as an independent variable. Therefore, the models which have been listed in this report were accepted as the best models for the data available. The possibility of an interaction between subsurface debris and porosity will be further analyzed in the discussion section of this report.

Dissolved Oxygen Analysis

The relationship between the percent of the dissolved oxygen saturation level, and grams of organic material per liter of pore volume, was determined. This relationship is based on 11 acceptable samples, which represent 23 percent of the 15 to 30 cm. deep core samples obtained. The relationship between dissolved oxygen level and subsurface detritus concentration is:

Percent of the Dissolved Oxygen Saturation Level= 83.7 + 0.75 (Grams of organic material per liter of sample pore volume).

This relationship is based on a very small sample size, with an R^2 value of only 0.276. However, it is indicated that, for the samples taken, the dissolved oxygen level tends to increase as subsurface detritus concentrations increase. Ponce (1974) and others, have shown that dissolved oxygen levels can be expected to decrease with increases in organic matter concentration. There are, however, several explanations for this apparent contradiction, which will be examined in the discussion section of this report.

VI. DISCUSSION

Dissolved Oxygen Analysis

The subsurface debris described in this report was composed primarily of highly weathered woody material. Needles or leaf fragments were found in only 16 percent of the samples, and were always brown and highly leached. The condition of the debris taken from the sample streambeds supports the hypothesis that the material had been incorporated in the streambed for at least four months, or since the previous winter's freshets. Based on the dissolved oxygen samples obtained, it appears that this highly weathered material exerts no appreciable B.O.D. on the subsurface dissolved oxygen supplies. This also supports the theory that organic debris incorporated within the streambed gravels produces only a temporary demand on the subsurface dissolved oxygen supply. It is important to remember, however, that even a temporary reduction in subsurface dissolved oxygen levels may have a critical impact on the reproduction of anadromous or resident fish populations if it occurs at the time the developing alevins are dependent on intragravel dissolved oxygen.

It must also be noted that the data presented represents a relatively narrow range of organic matter concentrations. It is unfortunate that dissolved oxygen samples were not obtained at at the core sample points which had extremely high detritus concentrations present, as such data points may have substantially modified the relationship observed.

Intragravel Detritus Diameters

The range of average organic particle diameters for all observations was 0.06 mm. to 19.25 mm. Very large pieces were not measured individually, but were simply considered as greater than 16 mm. during the calculation of the average diameter values. This problem, coupled with the break-up of some material during sampling, transport, and handling may produce a significant error, such that the true average diameter may be considerably higher than 19.25 mm. In fact, many pieces were extracted from the streambeds which were in excess of 150 mm. average diameter.

The size of the organic particles that become incorporated into the streambed may influence the reactions within the gravels. For example, small particles provide a greater surface area than an equal volume of larger particles. This increased solid-water interface tends to increase the potential biochemical oxygen demand which may occur by providing a larger reaction surface. Small organic particles may also decrease the amount of gravels available for spawning by blocking the pore spaces, thus reducing the amount of dissolved oxygen supplied to the redds.

The average particle diameter in streambeds tends to increase with increases in median solid diameter, amount of large surface debris present, and streambed porosity. Detritus size tends to decrease with increases in stream gradient. It is reasonable to assume that larger amounts of surface debris provide a continuous source of large organic particles which may become incorporated into the streambed. It also appears reasonable that streambeds with larger porosities will be capable of incorporating larger pieces of organic material. However, the relationships between porosity, median cobble size, and stream gradient as they relate to intragravel debris diameters are not clear, as several interactions are possible.

It was noted that the average subsurface organic particle diameters decrease with increases in stream gradient. However, median cobble sizes are generally larger for high gradient streams. Since average subsurface debris diameter is positively correlated with median cobble size, and negitively correlated with stream gradient, it appears that there is a contradiction in the prediction model.

In an effort to account for the apparent contradiction in the regression equations, the correlations of the independent variables were tested. It was observed that there was no significant correlation between median cobble size and stream gradient for the samples obtained. Therefore, the models were accepted as shown. Of course, as with any regression equations, the model elements must be utilized as stated, as the signs and coefficients of any one variable are influenced by the other variables.

Intragravel Debris Concentration Models

Factors influencing the accumulation of both small and large organic particles that become incorporated into gravel streambeds have now been discussed. The next step in this report must be a review of the reasons why each of the independent variables analyzed in this research does or does not influence subsurface debris accumulation.

The possible interaction that occurs if intruded organic material creates porosity has already been described. However, including porosity as part of the dependent variable did not improve the prediction models. It must be noted that porosity, as measured for this report, is a function of the water filled pore space. When organic material becomes incorporated into streambeds, it certainly creates voids in the gravels, but these voids are filled with woody material, rather than water. There is, of course, a small error due to the moisture content of the debris. This error becomes slightly larger if the detritus becomes highly decomposed before the streambed settles or is overturned. However, it is assumed that large pieces of organic material may be compared to inorganic cobbles within the streambed. Therefore, porosity was considered as a valid streambed characteristic, and was retained in the analysis as an independent variable.

Median cobble size is a streambed characteristic which is easily measured by land managers. While the influence of this parameter on debris intrusion is uncertain, it is probable that this variable influences streambed overturning, flow turbulence, and intragravel pore space. This factor may be related to other independent variables used in this analysis, specifically streambed porosity and stream gradient. Tests to determine the magnitudes of these interactions revealed that the relationship between stream gradient and median cobble size was statistically insignificant. While the relationship between cobble size and streambed porosity was significant, the correlation was very low. Therefore, median cobble size was retained in the model as an acceptable streambed characteristic.

The relationship between subsurface debris concentrations and surface debris loading has already been described. The accumulation of large surface debris is a factor that is easily measured in the field. This factor is probably related to the supply of organic material available for incorporation into the streambed. In addition, it may influence the flow characteristics of a stream. This index is relatively highly correlated with subsurface debris concentrations. Therefore, the loading of bole-sized surface material was considered an important independent variable in the models for prediction of subsurface organic debris concentrations.

The gradient of the streambed was found to be a significant contributor to all models of subsurface debris concentration. It was noted that concentrations of small debris tend to increase as gradient increases, while concentrations of large and total organic material tend to decrease as stream gradient increases. This difference is probably due to differences in the processes of intrusion for small and large organic debris. Here again, it is impossible to determine the exact processes which cause this discrepancy, due to a lack of past work. It must be noted, however, that there is a very low correlation between intragravel detritus and stream gradient. Therefore, relationships for this factor should be considered as general trends, rather than absolute relationships.

The depth of a sample in the streambed was found to significantly influence only the model for prediction of the concentration of small organic material per liter of total sample volume. For this relationship, it was observed that the amount of small organic debris tends to increase slightly with depth. However, this increase may be due to the breakup of large organic material which has been incorporated for long time periods. This relationship has a relatively low significance, and contributes only slightly to the total prediction model for small debris accumulations. For all other models, the subsurface debris concentrations did not change significantly with changes in depth of the sample. Further research should be considered to further analyze the relationship of these factors.

VII. RECOMMENDATIONS FOR FUTURE RESEARCH

This report has presented the results of a preliminary analysis of the factors which influence detritus accumulation within stream gravels. There has been relatively little work which addresses this problem, and much remains to be done. Hopefully, the methods and other information presented in this report will encourage future work concerning the management of organic material which becomes incorporated into gravel streambeds.

There are several specific problems which warrant immediate attention. The next logical step is to analyze intragravel debris accumulations in stream channels which have been disturbed by logging. Such streams will have extremely high surface debris loadings, at least before yarding. In addition, they will be subject to a direct disturbance during clean-up operations, especially if heavy equipment is used. It will be of value to determine if there are any changes in subsurface debris concentrations, both immediately and with time, after a stream is disturbed by logging.

Future research must examine any additional factors which may influence subsurface debris accumulation. For example, it is possible that stream meanders may have a significant impact on detritus incorporation within streambed gravels. Meanders influence the cross-sectional flow distribution of a stream, which may, in turn, affect debris intrusion.

Difficulties in quantitatively describing the location of a core sample in relation to stream position were encountered in this study, due to low flow rates during sampling. Therefore, the effects of relative stream position were not included in the development of the regression models listed in this report. The impacts of relative stream position on organic debris intrusion should be analyzed in a flume, where flow conditions could be carefully monitored. Although there are many problems associated with attempting to extend work done in an artificial flume to a natural streambed, a flume study would provide an initial analysis of the problem. The results of a flume study could then be examined and verified under natural field conditions.

Additional work is required to examine the impacts of subsurface debris on the fisheries resource. Future work must test the hypothesis that organic debris in streambeds produces only a short-term impact on intragravel dissolved oxygen levels. It would also be of value to know the time required for detritus decomposition within the streambed. This information would enable aquatic biologists to trace the "life-cycle" of intragravel organic material, as well as the interactions of detritus with aquatic organisms at the various stages of decomposition.

A final area for future research concerns the actual intrusion mechanisms of terrestrial organic material. The intrusion processes are still not well understood. This knowledge is essential in research examining the accumulation of subsurface debris, as well as providing a more precise means of analyzing the impacts of this material. It will be of value to compare organic pieces to inorganic streambed gravels. It is possible that these materials respond similarly to the forces of movement within the streambed, although their specific gravities are generally very different.

In conclusion, several ideas have been presented for future analysis of subsurface organic debris. This field has a variety of problems which require further analysis. The impacts of decomposing organic material on anadromous and resident fish populations make the processes of organic debris intrusion and subusrface accumulation an important phenomenon which warrants continued examination.

VIII. SUMMARY

Measurements indicate that subsurface debris concentrations may range from 1.4 to 439.9 grams of detritus per liter of pore volume, with a mean of 29.3 and a standard deviation of 52.9. Material extracted from the streambeds was generally highly conditioned, woody material which appeared to produce no discernable impact on intragravel dissolved oxygen supplies at the time of sampling. Previous work has indicated that the B.O.D. of organic material has generally been met in approximately 60 days.

Models have been developed to predict subsurface organic debris accumulations for natural gravel streambeds. Dependent variables for the models included organic debris mass for small, large, and total organic material per liter of pore volume, gravel volume, and total streambed volume. Independent variables used in this analysis were depth of sample, median cobble size, surface debris loading, streambed porosity squared, and stream gradient.

The models for prediction of the mass of organic material per liter of pore volume are likely to be the most valuable models for use by land managers. These models will enable aquatic biologists to evaluate the potential impacts of intruded organic material on subsurface dissolved oxygen supplies. Of course, an estimate of the B.O.D. of the intruded detritus is essential for an accurate analysis of this problem.

The models developed for detritus mass per liter of total streambed volume are also of potential value, as they provide an index of relative streambed debris loading. These models will provide the most understandable values for comparisons of debris intrusion into the gravels of different streambeds. On the other hand, the models using the volume of solid material for calculation of debris concentrations are of little practical significance. These models were presented in this report simply for comparison with the more practical models. It is uncertain why these models have higher R^2 values than the other models, but it may be due to an interaction between the dependent variable and median solid size or one of the other independent variables.

Three stream characteristics were found which significantly influence intursion of all size classes of organic material. These factors were: The surface organic material present in the stream channel, the Stream gradient, and the Streambed porosity. Although intrusion of all size classes of organic debris are influenced by these factors, the response of small material is apparently different from the response of larger pieces.

The models for concentrations of subsurface debris greater than four millimeters in diameter are very similar to the models for total subsurface debris accumulations. This is because organic material less than four millimeters in diameter generally contributes a relatively small amount to the total subsurface debris concentrations.

The models for total and large debris indicated that concentrations can be expected to increase with increases in median cobble size, surface debris loading, and streambed porosity. Subsurface concentrations can be expected to decrease with increases in stream gradient. In other words, low gradient streams characterized by large median cobble sizes, heavy surface debris loadings, and high streambed porosities are most subject to large subsurface debris accumulations.

The models for debris less than four millimeters in diameter indicate that subsurface concentrations of small material can be expected to increase with increases in surface debris loadings, stream gradient, and streambed porosity. In other words, streams characterized by high gradients, heavy surface debris loadings, and high streambed porosities are most subject to heavy subsurface debris accumulations. There is also an indication that concentrations of small material may tend to increase with depth in the streambed.

Several projects for future research have been suggested. For example, it will be of interest to determine factors that influence intragravel debris accumulation, in addition to those which have already been described. It would also be of value to examine subsurface debris concentrations in streams, both immediately and with time, after a drainage has been logged. A final consideration should be an examination of the actual mechanisms of intrusion. An understanding of these processes will complement the models for subsurface debris accumulation. In conclusion, it must be noted that the impacts of decomposing organic material on the fisheries resource make the mechanisms of intrusion and subsurface accumulation an important management consideration, which requires continued examination.

The models developed in this study cannot be expected to yield accurate values under all conditions, and high variability must be anticipated. However, these models provide a preliminary analysis of subsurface organic debris, as well as a means of estimating intra-gravel debris accumulations. Hopefully, the measurement and analysis techniques described in this report will promote a continued examination of the role of organic material in the small stream ecosystem.

IX. BIBLIOGRAPHY

Bear, Jacob. 1961. On the tensor form of dispersion in porous media. Journal of Geophysical Research 66(4): 1185-1197.

Brown, J.K. 1971. A planar intersect method for sampling fuel volume and surface area. Forest Science 17: 96-102.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience 24: 631-641.

Fair, G.M., and L.P. Hatch. 1933. Fundamental factors governing the streamline flow of water through sand. Journal of American Waterworks Association 25(1): 1551-1565.

Garvin, W.F. 1974. The intrusion of logging material into artificial gravel streambeds. Water Resources Research Institute. No. WRRI-27. Oregon State University. 79 pp.

Hach Chemical Company. 1975. Procedures, chemical lists, and glassware for water and wastewater analysis. 3rd Edition. pp. 2-91 - 2-92.

Harleman, D.R.F., and R.R. Rumer. 1963. Longitudinal and lateral dispersion in an isotropic porous medium. Journal of Fluid Mechanics 16(3): 385-394.

Harper, E.L. 1953. Semimicrodetermination of dissolved oxygen. Analytical Chemistry 25(1): 187-188.

Lammel, Richard. 1972. Natural debris and logging residue within the stream environment. M.S. Thesis Oregon State University. 49 pp.

Likens, G.E., and F.H. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. Bioscience 24: 447-456.

McNeil, W.J. 1966. Effect of spawning bed environment on reproduction of pink and chum salmon. U.S. Fish and Wildlife Service. Fisheries Bulletin 65: 495-523.

McNeil, W.J., and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service. Special Scientific Report: Fisheries. no. 469. 15 pp.

Narver, David W. 1971. Effects of logging debris on fish production. IN: Proceedings of a symposium: Forest Land Uses and Stream Environment. edited by: J.T. Krygier and J.D. Hall. Oregon State University. pp. 100-111.

Ponce, S.L. 1974. The biochemical oxygen demand of finely divided logging debris in stream water. Water Resources Research 10(5): 983-988.

Pyper, J. (M.S.). 1956. Physical and biological features of natural and artificial spawning grounds of Frazier River Sockeye and pink salmon. International Pacific Salmon Fisheries Commission. 98 pp.

Ringler, N.H. 1970. Effects of logging on the spawning bed environment in two Oregon coastal streams. M.S. Thesis. Oregon State University. 96 pp.

Ryan, P. 1970. Design and operation of an In Situ frozen core gravel sampler. Technical Report 1970-12. Canada Dept. of Fisheries and Forestry, Pacific Region. 8 pp.

Saffman, P.G. 1959. A theory of dispersion in a porous medium. Journal of Fluid Mechanics 6(3): 321-349.

Scheidegger, A.E. 1961. General theory of dispersion in porous media. Journal of Geophysical Research 66: 3273-3278.

Silver, S.J., C.E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and Chinook Salmon embryos at different water velocities. Transactions of the American Fisheries Society 92(4): 327-343.

Swanson, F.J., G.W. Lienkaemper, and J.R. Sedell. 1976. History, physical effects, and management implications of large organic debris in Western Oregon streams. U.S.D.A. Forest Service General Technical Report PNW-56. 15 pp.

vanWagner, C.E. 1968. The line intersect method in forest fuel sampling. Forest Science 14(1): 20-26.

Vaux, W.G. 1962. Interchange of stream and intragravel water in a salmon spawning riffle. U.S. Fish and Wildlife Service Special Scientific Report: Fisheries, no. 405. 11 pp.

APPENDIX

APPENDIX I: DATA USED FOR MODEL DEVELOPMENT[1]

g/1 pores (Total OM)	g/1 pores (OM 4mm)	g/1 pores (OM 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm^2)	Porosity (%)	Stream Gradient (%)
High Gradient Coastal Streams								
Bear Creek								
13.763	11.514	2.249	1.72	8	1.87	1.42	40.4	10
11.686	8.764	2.921	4.90	8	23.30	1.42	29.4	5
32.361	9.089	23.271	14.24	8	28.27	1.42	27.4	1
46.287	21.586	24.701	6.50	8	10.80	1.42	36.9	1
13.809	12.602	1.207	1.19	22	9.23	1.42	31.0	10
23.707	11.467	12.240	10.43	22	25.40	1.42	27.9	5
256.470	6.360	250.110	19.25	22	22.23	1.42	55.0	1
67.236	17.540	49.697	10.43	22	0.63	1.42	53.5	1
181.814	11.687	170.127	17.96	38	26.09	1.42	42.3	1
77.667	14.934	62.733	12.09	38	6.98	1.42	42.0	1
50.551	17.753	32.798	11.65	52	25.12	1.42	32.8	1
Mill Creek - Alsea District								
11.185	10.936	0.249	0.25	8	1.96	8.16	22.7	9
18.723	14.619	4.104	2.01	8	17.16	8.16	29.4	6

1 Only the dependent variables for Models 1,4,7, and 10 are presented here.

Appendix I (con't)

g/l pores (Total OM)	g/l pores (OM < 4mm)	g/l pores (OM > 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm^2)	Porosity (%)	Stream Gradient (%)
Mill Creek - Alsea District (con't)								
9.401	8.101	1.300	1.27	8	21.64	8.16	28.0	5
142.239	10.906	131.333	16.88	8	5.87	8.16	34.9	3
13.117	11.093	2.024	3.61	22	19.04	8.16	33.2	6
12.236	11.466	0.770	0.67	22	8.19	8.16	32.3	5
26.216	14.165	12.051	6.39	22	4.24	8.16	35.8	3
8.122	8.079	0.043	0.21	38	15.31	8.16	29.5	6
13.634	11.412	2.222	1.47	38	14.81	8.16	26.3	5
19.539	13.936	5.603	1.85	38	27.08	8.16	25.1	3
9.565	9.565	0.000	0.08	52	12.76	8.16	30.9	6
Mill Creek - Waldport District								
8.764	8.569	0.195	0.26	8	2.37	4.27	44.2	4
10.132	7.923	2.209	2.02	8	11.63	4.27	37.1	4
57.283	17.392	39.891	12.40	8	4.68	4.27	50.0	4
11.866	11.109	0.757	0.53	8	5.99	4.27	31.8	4
10.454	9.737	0.717	0.71	8	28.74	4.27	24.4	4
12.256	11.691	0.565	0.65	8	23.78	4.27	34.2	4

Appendix I (con't)

g/l pores (Total OM)	g/l pores (OM < 4mm)	g/l pores (OM > 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm^2)	Porosity (%)	Stream Gradient (%)
Mill Creek - Waldport District								
6.842	6.805	0.037	0.18	22	9.43	4.27	37.1	4
16.818	9.439	7.379	3.73	22	26.69	4.27	27.7	4
15.913	13.980	1.933	1.28	22	9.67	4.27	55.6	4
9.527	8.673	0.854	0.87	22	13.12	4.27	37.0	4
15.387	11.440	3.947	2.22	22	15.89	4.27	29.7	4
10.832	9.629	1.203	2.26	22	14.64	4.27	34.6	4
5.618	5.618	0.000	0.06	38	25.13	4.27	24.6	4
74.753	9.543	65.210	9.31	38	26.25	4.27	44.3	4
6.546	0.909	5.637	1.42	38	28.97	4.27	20.9	4
11.333	10.541	0.792	0.71	38	28.97	4.27	19.1	4
211.189	15.963	195.226	18.04	38	10.90	4.27	42.0	4
21.887	14.679	7.208	5.56	38	2.38	4.27	48.5	4
			Low Gradient Coastal Streams					
Flynn Creek								
8.138	8.005	0.133	0.21	8	0.77	2.97	51.8	2
29.828	6.340	23.488	14.81	8	14.97	2.97	34.6	2
19.045	7.272	11.773	10.68	8	12.92	2.97	37.8	2
7.590	7.080	0.510	0.87	8	14.75	2.97	34.3	2
9.105	9.030	0.078	0.22	8	7.30	2.97	35.5	1

Appendix I (con't)

g/l pores (Total OM)	g/l pores (OM < 4mm)	g/l pores (OM > 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm^2)	Porosity (%)	Stream Gradient (%)
Flynn Creek (con't)								
7.859	7.472	0.389	0.52	8	5.45	2.97	38.5	1
29.732	16.690	13.049	5.60	8	0.84	2.97	53.5	1
10.353	9.750	0.604	0.63	22	5.34	2.97	37.3	2
8.862	8.437	0.426	0.64	22	7.06	2.97	40.0	2
112.636	9.354	103.282	17.78	22	11.09	2.97	37.7	2
8.706	8.565	0.145	0.41	22	14.80	2.97	32.8	2
10.000	6.095	3.906	3.77	22	14.29	2.97	44.5	1
11.489	9.378	2.113	1.67	22	4.56	2.97	41.1	1
96.139	10.715	85.406	17.05	22	1.00	2.97	49.6	1
10.550	10.452	0.103	0.16	38	9.11	2.97	23.2	2
11.656	10.998	0.665	0.69	38	9.39	2.97	35.0	2
10.454	10.152	0.306	0.34	38	7.71	2.97	34.3	2
9.306	9.200	0.106	0.22	38	15.96	2.97	31.1	2
11.327	11.169	0.147	0.16	38	9.88	2.97	25.2	1
8.787	8.096	0.693	0.97	38	3.76	2.97	42.8	1
49.018	15.454	33.550	7.59	38	0.67	2.97	54.3	1
7.632	7.632	0.000	0.11	52	6.29	2.97	39.2	2
8.296	7.494	0.802	0.91	52	7.76	2.97	37.5	2
6.632	6.632	0.000	0.06	52	6.84	2.97	38.1	1

Appendix I (con't)

g/l pores (Total OM)	g/l pores (OM < 4mm)	g/l pores (OM > 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm^2)	Porosity (%)	Stream Gradient (%)
<u>Gopher Creek</u>								
1.351	1.351	0.000	1.31	8	15.62	0.30	34.8	2
3.264	1.849	1.415	4.04	8	29.26	0.30	26.2	1
4.976	4.790	0.186	0.56	8	24.73	0.30	29.3	1
5.177	5.177	0.000	0.17	8	23.80	0.30	30.5	2
4.087	3.390	0.697	1.96	8	26.23	0.30	30.3	3
2.092	1.513	0.579	2.22	22	25.90	0.30	24.9	2
11.375	11.306	0.071	0.26	22	3.15	0.30	43.6	2
4.212	3.581	0.631	1.64	22	19.37	0.30	31.1	1
5.780	4.825	0.955	1.93	22	24.88	0.30	26.5	1
3.196	3.148	0.048	0.26	22	15.22	0.30	29.7	2
6.698	3.479	3.219	4.03	22	16.22	0.30	32.5	3
1.817	1.240	0.577	5.33	38	16.10	0.30	26.3	2
7.954	7.927	0.027	0.22	38	26.33	0.30	30.0	2
5.962	5.895	0.067	0.21	38	14.57	0.30	32.3	1
1.640	1.445	0.185	1.48	38	8.37	0.30	34.9	1
3.560	3.527	0.033	0.33	38	13.53	0.30	29.9	2
4.655	4.640	0.015	0.08	38	15.94	0.30	30.3	3
11.805	11.805	0.000	0.13	52	18.74	0.30	32.4	2

Appendix I (con't)

g/l pores (Total OM)	g/l pores (OM < 4mm)	g/l pores (OM > 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm²)	Porosity (%)	Stream Gradient (%)
Cascade Mountains - Volcanics								
Mack Creek								
162.174	18.725	143.449	15.47	8	3.89	6.90	51.4	4
13.766	12.159	1.607	1.20	8	12.11	6.90	31.6	4
17.883	14.766	3.117	1.72	8	15.90	6.90	32.4	5
69.197	16.885	52.312	8.55	22	11.01	6.90	44.6	4
12.556	8.789	3.767	3.89	22	28.00	6.90	20.1	4
13.087	12.319	0.768	0.92	22	14.84	6.90	30.0	5
87.109	15.356	71.753	13.49	38	16.67	6.90	37.1	4
12.828	11.331	1.497	1.36	38	18.92	6.90	22.7	4
Mack Creek Tributary								
73.720	18.705	55.015	12.02	8	18.59	11.21	35.9	8
80.349	24.528	55.821	7.79	8	1.25	11.21	63.0	10
22.723	17.850	4.873	2.01	8	12.07	11.21	29.8	10
130.164	16.818	113.364	15.45	8	19.29	11.21	58.7	10
8.777	5.324	3.453	2.34	22	10.67	11.21	39.3	8
13.244	12.409	0.835	0.74	22	24.41	11.21	23.5	8

Appendix I (con't)

g/l pores (Total OM)	g/l pores (OM < 4mm)	g/l pores (OM > 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm²)	Porosity (%)	Stream Gradient (%)
Mack Creek Tributary (con't)								
56.984	16.995	39.989	7.80	22	1.79	11.21	57.7	10
19.624	17.554	2.070	1.19	22	10.38	11.21	34.9	10
111.461	19.407	92.054	13.64	22	3.33	11.21	55.8	10
45.764	25.379	20.385	3.86	22	30.16	11.21	21.7	13
5.912	4.781	1.131	1.06	38	9.84	11.21	33.7	8
32.396	19.579	12.917	4.47	38	18.63	11.21	42.2	10
17.919	17.340	0.579	0.42	38	9.07	11.21	34.0	10
26.431	19.641	6.790	2.39	38	7.79	11.21	43.0	10
19.120	14.731	4.389	2.11	38	25.96	11.21	25.5	13
34.013	34.013	0.000	0.34	38	28.18	11.21	24.7	13
12.755	11.548	1.207	1.08	52	18.25	11.21	34.7	10
Watershed II								
17.098	16.569	0.529	0.35	8	19.57	5.92	37.7	16
20.893	10.390	10.503	8.07	8	29.17	5.92	38.9	17
26.802	20.906	5.902	3.31	8	22.84	5.92	35.5	5
11.720	11.598	0.122	0.16	22	29.70	5.92	21.7	16
20.985	19.703	1.282	0.60	22	29.89	5.92	28.5	17
12.187	11.954	0.233	0.29	22	27.60	5.92	29.4	5

Appendix I (con't)

g/l pores (Total OM)	g/l pores (OM < 4mm)	g/l pores (OM > 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm^2)	Porosity (%)	Stream Gradient (%)
Watershed II (con't)								
25.419	18.017	7.402	5.25	22	20.40	5.92	28.0	4
16.201	16.148	0.053	0.13	38	29.93	5.92	25.0	17
10.985	10.552	0.053	0.44	38	25.53	5.92	29.4	5
19.735	18.790	0.945	0.59	38	17.97	5.92	31.1	4
			Cascade Mountains - Granitics					
Jim Creek								
89.593	5.144	84.449	18.26	8	27.08	8.35	23.2	2
13.387	11.917	1.470	1.00	8	3.99	8.35	34.9	2
4.973	3.783	1.190	2.52	8	1.90	8.35	35.2	2
12.134	11.677	0.457	0.60	8	9.22	8.35	30.0	2
4.664	4.664	0.000	0.29	8	6.94	8.35	25.1	3
5.143	5.143	0.000	0.19	8	25.90	8.35	23.8	5
15.222	8.033	6.589	3.82	22	10.40	8.35	31.5	2
4.558	4.192	0.367	0.85	22	10.09	8.35	29.6	2
3.811	3.667	0.144	0.47	22	1.88	8.35	29.4	2
12.013	11.600	0.413	0.32	22	19.64	8.35	22.9	2
2.174	2.174	0.000	0.13	22	7.31	8.35	25.5	3
7.826	5.605	2.221	4.30	22	26.51	8.35	19.2	5

Appendix I (con't)

g/l pores (Total OM)	g/l pores (OM < 4mm)	g/l pores (OM > 4mm)	Ave OM Diameter (mm)	Sample Depth (cm)	Med. Sol Diameter (mm)	Lar Surf Loading (g/cm^2)	Porosity (%)	Stream Gradient (%)
Jim Creek (con't)								
8.615	8.269	0.346	0.55	38	25.93	8.35	19.4	2
4.694	4.694	0.000	0.08	38	26.96	8.35	18.8	2
3.269	3.005	0.264	1.02	38	21.18	8.35	22.6	2
25.606	20.950	4.656	1.80	38	15.20	8.35	25.7	2
3.677	3.677	0.000	0.08	38	5.75	8.35	27.6	3
35.913	12.641	23.272	10.50	38	26.79	8.35	19.2	5
No Man Creek								
6.191	5.312	0.879	1.34	8	30.01	0.00	28.5	3
5.777	4.847	0.930	1.38	22	24.19	0.00	25.3	3
3.111	3.032	0.079	0.57	22	24.71	0.00	28.1	3
2.071	2.071	0.000	0.27	22	26.54	0.00	28.2	3
12.836	10.991	1.845	1.35	38	15.29	0.00	32.8	3
4.591	4.214	0.377	0.96	38	28.41	0.00	27.9	3
32.735	12.099	20.636	7.65	38	7.65	0.00	28.8	3
2.494	2.358	0.136	0.87	38	15.76	0.00	28.4	3