THE USE OF FLUORESCENT DYE AND SITE CHARACTERISTICS TO EVALUATE SURFACE EROSION ON HARVESTED AREAS IN THE VERNON FOREST DISTRICT, B.C.

By

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Abstract

Surface erosion on forest lands can cause stream sedimentation and reduce site productivity. In the North Okanagan downstream irrigation and municipal demand require low sediment levels in their water. Higher elevation forest lands have shallow soils developed from nutrient-poor glacial till. To evaluate erosion occurrence on forest lands a research project was initiated in the summer of 1984 on 10 sites in mid-elevation, recently harvested cutblocks in the Vernon Forest Region.

The objective of the study was to evaluate surface erosion and relate erosion intensity to site characteristics. Two separate methods were used to accomplish this. Line transects sampled soil disturbance and examined causal factors for erosion occurrence. Fluorescent dye plots, established on four of the 10 sites, examined rate, distance and patterns of downslope soil particle movement.

Transects were surveyed in a grid pattern across the cutblock and results indicated areal distribution of disturbance. Soil disturbance at the sample point was recorded using 10 classes ranging from bare soil and litter disturbance to deep gouges and deep deposits of soil. Assessment of care-in-logging and identification of existing and potential erosion sites completed the site evaluation.
Day-Glo fluorescent pigment was used to tag soil in situ. Dye was applied in August, 1984, in one metre strips across the slope on plots varying in aspect, slope and disturbance. Field measurement of soil movement was completed in the spring of 1985, shortly after snowmelt. Tagged particles were located and illuminated at night by ultraviolet light. A hand held mineral lamp provided sufficient illumination and fluorescence was recorded on color film. Soil-movement ratings, based on visual perception of particle movement, were assigned to each plot. These ratings were compared to plot and site characteristics to identify possible erosion trends.

The results of this study support the consensus of research results reported in the literature. The major sites of erosion are skid trails and the road system. Steep slopes, fine soil, north aspects and compaction increase potential erosion. Fluorescent dye is an effective soil particle tag allowing distance and pathways of movement to be identified. Day-Glo fluorescent pigment in a solution of acetone was fully satisfactory in adherence to the particle and in persistence under prevailing climatic conditions.
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Chapter 1

INTRODUCTION

The forest lands surrounding the Okanagan basin are important in a number of ways. The high elevation forest contains the headwaters of most streams in the basin and this snowmelt supplies the spring and summer flows of area streams. These streams support fish populations, supply water to meet irrigation needs and municipal demands, replenish aquifers and maintain the level and quality of area lakes, a major recreation and tourism resource. The timber from this forest land supports the extensive forest industry which forms an important component of the regional economy. The Okanagan Timber Supply Area covers 2.5 million hectares and contains 1.7 million hectares of productive forest land. Six percent of the population in the area is employed in the forest industry and a further 10 percent are employed indirectly (Robinson 1985). The harvesting schedule of this industry is based on the concept of a continuing productive forest resource to maintain supply at the current levels. This assumes undiminished productivity of the cutblock.

Forests play an important soil protective role and deforestation can promote surface erosion (Gray 1969).
Bormann and Likens (1979) at Hubbard Brook Experimental Watershed (eastern United States) found that deforestation altered the natural "particle-matter transport" in two ways: (1) by changing the hydrologic characteristics of the ecosystem (increasing velocity of peak streamflow and time of flow at high velocities), and (2) through increases in erodibility of the ecosystem. This study examines the latter.

A fully-forested site usually has little erosion. The vegetative surface is able to absorb most of the incoming precipitation and high infiltration rates combined with translatory flow prevents surface runoff. Removal of surface vegetation disturbs the soil surface and exposes it to the erosive energy of raindrops and overland flow. Rainsplash can move soil particles, compact the surface layer and clog pores thereby reducing infiltration and promoting overland flow.

Surface soil erosion poses a multiple threat to the forest ecosystem: (1) to the future forest productivity and present regeneration on site (2) to the quality of streams draining the watershed (sedimentation) and (3) to human lives and structures (Gray 1969).

In the North Okanagan most soil parent material is nutrient-poor glacial till. On forest lands much of the site nutrients are contained in the surface centimetres of soil. Loss of this soil can severely impact site
productivity. High elevation forest land is characterized by shallow soils and limited nutrients so any loss of soil or production potential may be significant.

Water quality is an important issue in the North Okanagan. Increased sediment levels in the streams draining the forest area diminish water quality and can cause problems with drinking water supply, instream biology, and irrigation works downstream.

In view of the impacts of surface erosion, this research project was initiated to determine if surface erosion on these harvested lands is significant and, if so, to identify those factors influencing the erosion process. Site parameters to be examined on cutover areas included slope angle, aspect, ground disturbance, vegetative cover, soil texture, and slope position.

Road construction associated with timber harvesting has a greater impact on soil stability than vegetation removal alone. Gray and Megahan (1981) identified possible synergistic and cumulative impacts on stability of road construction and vegetation removal which are difficult to distinguish or separate. The present project examined erosion on actual cutblocks but an evaluation of erosion occurring on roads accessing the sites was also included.
Another component of this study was development and evaluation of a method using fluorescent dyes to chart soil movement. A soil-tagging technique was proposed to allow color stratification of soil particles by location and to chart the pathway of movement and distance travelled downslope.

Accurate measurements of soil erosion are difficult to obtain. Existing methods measure only net soil movement, not the rate of particle movement or pathways of movement. Cost, time, and perspective may limit application of these methods. The fluorescent dye application method applied here promotes ease of application, relatively low cost and minimum dependence on structures or site modification.
Chapter 2

OBJECTIVES

The objective of this study is threefold:

1. To identify and determine to what extent erosion is occurring on cutover areas in this region by visual inspection (transects) and monitoring of fluorescent dye plots.

2. To relate erosion intensity to site characteristics including aspect, slope, ground disturbance, vegetation, soil texture and logging method.

3. To develop and test a method of fluorescent dye application to tag soil particles and allow distance and pathways of downslope movement to be determined.
Chapter 3
LITERATURE REVIEW OF SURFACE EROSION

Surface erosion involves the movement of individual detached particles downslope either by raindrop splash (sheet erosion) or in suspension by flowing water (rilling or gullying) (Dyrness 1966). Mass wasting involves simultaneous movement of large quantities of soil under the influence of gravity and is often lubricated by large amounts of water (Dyrness 1966).

Both of the above processes operate to varying degrees within the forest system. Erosion may be said to be the result of the action of the climate on the soil with the results being modified by the topography and the vegetation cover. Differences in any of these bring about differences in the erosion hazard (Anderson 1951).

Smith (1984) identified the potential impact of surface erosion as (1) reduction of site productivity (loss of nutrients in soil fines), (2) impeding of regeneration (abrasion, loss of soil support, physical displacement of the seedling), (3) destruction of roads and other structures, and (4) sedimentation of water courses with resultant downstream impacts.
Smith and Wischmeier (1962) identified four basic factors affecting surface erosion: rainfall characteristics, soil erodibility, topography and plant and litter cover. This discussion groups erosion factors into vegetation, slope, precipitation and soils.

FACTORS INFLUENCING SURFACE EROSION

Vegetation

Vegetation is an important factor in controlling erosion (Rutter 1967). A fully vegetated site is rarely eroded as ground cover stabilizes the soil and mitigates other erosive agents especially raindrop impact. A dense vegetative cover reduces the impact of rainfall on the soil, increases absorption, checks the speed of flowing water and binds the soil (Agriculture Canada 1961).

Swanson and Swanston (1977) describe the stabilizing effect of forest vegetation: "Forest vegetation exercises some control over the amount and timing of water reaching the soil and the amount held in storage as soil water and snow. Forests regulate hydrology through a combination of interception, evapotranspiration and influence on snowmelt rates. In general these hydrologic influences of vegetation are thought to enhance slope stability" (Swanson and Swanston 1977, pg. 115).
Vegetation reduces soil moisture because it has a substantial demand to satisfy evapotranspiration. Soils with lower antecedent soil moisture have a greater infiltration capacity and thereby reduce overland flow. Within a forest, overland flow is rarely observed. Once the soil water capacity is satisfied, translatory flow predominates as infiltration capacity is maintained.

Vegetation contributes organic matter to the soil and allows a litter layer to develop. This organic matter helps bind soil particles together and increases the moisture holding capacity of the soil. Lowdermilk (1934) found that the beneficial effects of litter cover were due not so much to its water absorbing capacity, but rather to its action in protecting the soils from the destructive action of raindrops.

Crockett and Shelford (1982) identified five ways that a natural vegetative cover increases site stability (thereby decreasing erosion). These are:

- Increase in cohesion by vertical and horizontal anchoring of the soil mass.
- Increase in surface roughness, reducing wind speeds at the surface and limiting slope length.
- Interception of rainfall, decreasing impact velocity of water on the ground surface.
- Decrease in runoff due to increased surface storage in the canopy and litter, increased surface roughness and increased infiltration rates.
- Addition of organic matter to the soil, increasing aggregate stability and moisture-holding capacity.
Within forested sites the vegetative species has little influence on erosion. The main influence is the presence or absence of vegetative cover and degree of disturbance of the litter layer. Once a significant amount of vegetative cover is removed, stability of the soil is reduced. Bailey (1941) stated that all vegetated slopes are a manifestation of adjustment between aggradation and degradation forces in which the plant cover is the key to stability. Depletion of the vegetation reverses the gradational processes and accelerates soil removal and runoff.

Orr (1979) in research on forest burns in South Dakota found that 60 percent ground cover density (live vegetation plus litter) was the minimum necessary for soil stabilization. On steeper slopes in mountainous regions, Meeuwig (1971) found that 90 percent ground cover was necessary.

Slope

Slope has a very significant impact on the erosive potential of a site. Slope steepness and length of slope influence soil erodibility directly by influencing the velocity of soil runoff (Brown 1980). Surface soil erodes when the energy of flowing water exceeds the forces holding the individual soil particles together. The slope determines the energy of the flowing water (Krag 1980).
"The velocity of overland flow varies as the square root of the slope gradient and the energy of overland flow varies as the square of its velocity. Overland flow will move down a 40 percent slope at twice the velocity of that on a 10 percent slope. By doubling the velocity, the energy of the flow will be increased about 4 times; the size of particle that can be transported will be increased about 64 times (sixth power of velocity); and the quantity of material of a given size that can be carried is increased about 32 times (fifth power of velocity)" (Farmer and van Haveren 1971, page 2).

The above values are based on the concepts of competance of a flow, a measure of the size of particle which the flow can move, (proportional to the sixth power of velocity), and carrying power, the ability to carry particles in suspension (proportional to the fifth power of velocity).

Slope has an integral relationship to vegetative cover. The effectiveness of cover depends on the slope gradient; the effects of cover are greater on steeper slopes. Similarly, slope becomes increasingly important as cover decreases (Meeuwig 1971). Slope, as a part of overall topography, can influence soil development and subsequently erosion. Slope, aspect, and elevation modify the radiation, temperature, and moisture levels of the general climate. As a result, the weathering of parent material and composition of plant communities may also be modified (Brown 1980).

Precipitation

Rainfall is a major factor in erosion. Erosion occurs when the force exerted by rainsplash or flow exceeds the resistance of the soil. Rain impact dislodges particles and pulverizes materials. If conditions are right, runoff
removes soil by suspension and erodes new material by hydraulic action. On some surfaces rain impact may help to seal the surface, thus decreasing infiltration, increasing runoff, and promoting erosion (Rutter 1967).

Rainfall intensity is important in erosion. Unless the rainfall is intense enough to detach and transport soil particles it is unlikely to cause erosion (Gleason 1953). The kinetic energy of the rainfall varies with drop velocity and mass. The transport of detached particles in overland flow is controlled by runoff amount and turbulence, both of which are, to some extent, functions of rainfall intensity (Dyrness 1966) and the infiltration rate. The infiltration rate (the speed at which water can be absorbed into the soil) dictates the importance of rainfall intensity. If the infiltration rate is high, all the available water can be absorbed by the soil, thus preventing erosion (Rutter 1967).

Soil Properties

Inherent in the erodibility of soil are the properties of the soil itself. A soil's texture, structure and chemistry affect its erodibility. The ease with which particles are dislodged and become available for erosion is determined by the binding strength of the soil. Meeuwig (1971) identified organic matter as the most important soil parameter influencing erosion.
Soil texture is the proportion of variously sized particles, (sand, silt and clay) in the soil composition. This particle size distribution affects erosion rates. Silt-size particles are more easily detached and moved than larger particles. It also influences permeability and vegetative growth which have a direct impact on erosion. The influence of texture on soil erodibility is complex. Much of this complexity arises because of the influence of organic matter content on texture. Organic matter decreases erosion of clay soils and tends to increase erosion of sandy soils (Meeuwig 1971). The adverse effect of organic matter in sandy soils is believed to be linked to water repellance occurring in sandy soils with high organic matter content. Therefore a soil's susceptibility to erosion is dependent on particle size distribution in conjunction with organic matter content.

Soil particles are usually clumped together as aggregates. Aggregation is the most important soil property governing resistance to erosion in many soils (Bryan 1969). The percentage of organic material, carbonates or moisture present in the soil all influence the level of aggregation. When stable aggregates develop, potential erodibility decreases because these larger particles are more difficult to dislodge and transport. The stability of these aggregates is determined by "cementing agents" such as calcium carbonate, organic matter, and colloids. Clay
minerals are important due to their water absorption and expansion properties, as are the kind and amount of soluble salts present (Rutter 1967).

Soil compaction is a significant problem in ground based forest harvesting procedures. Compaction reduces pore space, increases bulk density and reduces infiltration rate, subsurface flow and rooting depth. Measurements of bulk density on skid roads, 25 years after harvesting, showed little or no recovery from compaction (Schwab and Watt 1981). Decreasing infiltration can promote overland flow and compacted areas (e.g. skidder tracks) channel surface flow thus increasing velocity, depth and energy of flow.
SURFACE EROSION CYCLE

Detachment-Overland Flow

Overland flow arises from an inability of the land surface to absorb water or to permit water to move to lower depths, that is, insufficient infiltration (Pierce 1967). It occurs on hillsides during a rainstorm when surface depression storage and either soil moisture storage (with prolonged rain) or the infiltration capacity of the soil (with intense rain) are exceeded (Morgan 1979). Development of overland flow is influenced by: "soil texture, soil depth, soil structure, soil porosity, antecedent soil moisture, presence of rock outcrops, amount of incorporated organic matter, presence of surface humus layers and litter, slope and shape of the land, smoothness of terrain and microtopographical features, amount and type of vegetative ground cover, rainfall rate and duration, presence of snow or ice cover, type and extent of soil frost and air temperature" (Pierce 1967, pg. 248).

Two types of overland flow are recognized. (1) Overland flow as originally defined by Horton (1945) occurs when the rainfall intensity (or rate of snowmelt) exceeds the infiltration rate of the soil. This excess becomes Hortonian overland flow. (2) Saturation overland flow encompasses both direct precipitation onto saturated areas
and return flow (subsurface flow which returns to the ground surface). Rainfall onto saturated areas cannot infiltrate the soil (full soil storage) and therefore forms overland flow. Return flow (and some throughflow) can also form surface runoff although some researchers (such as Hewlett 1982) do not recognize this as true overland flow. The dynamics of overland flow encompass these infusions of subsurface flow as well.

Overland flow is both unsteady and spatially varied since it is supplied by rain (or snowmelt) and depleted by infiltration, neither of which is necessarily constant with respect to time or location (Emmett 1978). Hortonian overland flow, produced by precipitation excess (precipitation intensity - infiltration capacity), is generally seen as being produced rather uniformly over whole catchment areas, as neither precipitation intensity nor infiltration capacity vary greatly over small areas (Pearce 1976). Saturation flow results from local, temporary saturation of the soil profile up to the ground surface. It can occur in very localized areas of saturation and is therefore more variable, in time and space, than Hortonian overland flow. Hortonian overland flow generally prevails in drier climates, in areas where vegetation is limited or removed and on cultivated areas. In many soils it is the properties of the surface and not the complete soil which determine the frequency and amount of runoff (Bryan 1976).
The hydraulic characteristics of overland flow depend on precipitation (type, intensity, duration), texture and type of soil (infiltration capacity), antecedent soil moisture condition, density and type of vegetation, topographical features (number and size of surface depressions and mounds), slope steepness, and length of slope (Emmett 1978). Thus, no simple description of the hydraulics of overland flow is possible on natural hillsides. Hydraulic parameters vary rapidly over time and space.

Overland flow generally consists not of a uniform sheetflow of water but rather of unchannelled water flowing in an anastomosing pattern (Morgan 1980), resulting from topographic irregularities. Horton (1945) stated that hydraulic conditions do not permit the occurrence of shallow steady flow on steep slopes, but rather the runoff is concentrated in a succession of more or less uniformly spaced waves.

Overland Flow in Forest Watersheds

Overland flow in natural watersheds is generally considered by hydrologists as an objectionable characteristic. Pierce (1967) cites two main reasons for this. Firstly, overland flow can concentrate in defined channels and cause greater peak flows in a shorter time than
water infiltrating and passing through the soil layers before entering streamflow. Secondly, high velocity overland flow can cause erosion damage.

Forest lands are generally areas of high infiltration, minimal overland flow and little surface erosion. Soil under undisturbed forest usually has very high infiltration capacities, in excess of usual rainfall intensities. Conditions favoring high infiltration include porous channels due to root and animal activity, incorporated organic matter in the surface layers and accumulation of organic debris (Pierce 1967). Under normal forested conditions a layer of plant litter in addition to living vegetation protects the soil from the erosive energy of raindrops and limits overland flow. Even removal of the forest canopy will have minimal impact if the forest floor is left undisturbed; infiltration remains high and overland flow does not occur (Rothacher 1965).

Disturbance in a watershed often exposes mineral soil and reduces infiltration. When this is significant enough to allow overland flow, surface erosion problems can result. As the soil resource is the fundamental component in a forest ecosystem and stream sediment can have widespread impacts, the occurrence of overland flow and its erosion is undesirable.

Disturbance in a forest watershed can take many forms. Fire can destroy vegetation, cause surface sealing, limit infiltration, and expose soil to raindrop impact.
Compaction, whether by humans, cattle, vehicles, or machinery reduces pore space and hence infiltration capacity. Forest harvesting operations can disturb the natural forest floor and vegetation removal decreases evapotranspiration losses, thereby increasing soil water and decreasing storage capacity. More significant is the exposure of mineral soil to raindrops which detach soil particles and break down soil structure. Logging roads and skid trails concentrate water and can promote overland flow. Hornbeck and Reinhart (1964) suggested a criterion for evaluating the effects of land use on a watershed is the change in infiltration rate resulting from a specific use.

**Detachment—Rainsplash**

Rainsplash erosion is the transport of soil in the absence of overland flow by water droplets that are ejected from the soil surface following raindrop impact. Splash erosion rates are generally low. The major role of rainsplash is the detachment of soil particles prior to their removal by overland flow. Although splash itself may not be an erosion problem, many of the particles detached by splash are removed by overland flow. Morgan (1978) has shown that 12 percent of the variation in soil transport by overland flow is accounted for by splash detachment which, after the volume of runoff and slope angle, was judged the most important factor influencing erosion by overland flow. The impact of rain on bare soil can cause cratering which
compacts the surface (decreasing infiltration), and can dislodge soil particles which are elevated and, in large part, moved downslope. The steeper the slope, the greater the distance moved, although splash is not usually significant in isolation as a transport agent. When the surface is covered by increasing depths of overland flow the effects of rainsplash on soil is decreased but raindrops on the surface layer of water increase turbulence and increase the erosive capacity of the flow. Intense rains contain more large drops which are more effective in compacting and dispersing the soil. Such rain is also more likely to produce overland flow and will generate greater depths of flow. As flow depth increases from zero, soil loss by splash increases. Then, as flow depth begins to exceed raindrop diameter, the entrainment potential of splash can be expected to decrease and the potential entrainment and transport capabilities of wash to increase (Kilinc and Richardson 1973).

Transport - Rainsplash and Overland Flow

Meeuwig and Packer (1976) found that overland flow is not very effective as a soil-detaching agent unless concentrated in rills or gullies, but the presence of overland flow increases the effectiveness of raindrops as detaching agents. If the soil surface is saturated and covered with a film of water the raindrops striking it tend to rebound and to dislodge and transport soil particles. If
the soil is only moist, the raindrops tend to penetrate the soil, dissipating at least part of their kinetic energy as frictional losses. Young and Wiersma (1973) found that the interaction of rainsplash and sheetwash (overland flow) is important; each process acting separately is less efficient at moving soil particles than when the processes are acting together.

Morgan (1979) identified two types of transporting agents, those which act areally and contribute to the removal of a relatively uniform thickness of soil and those which concentrate their actions in channels. The first group includes rainsplash and overland flow, while the second covers water flow in small channels, rills, or the larger gullies and rivers. At low intensities of erosion, removal is more or less uniform and at higher intensities braids, rills or small gullies play an increasingly important role (Kirkby 1980).

Concentration of running water into rills increases erosion power and may account for the bulk of sediment transported from a hillside if such flow occurs. Raindrops have the potential, from an energy standpoint (greater velocities), to be more erosive than overland flow, but most of this energy is used in detachment and little is left for transport, leaving this to overland flow. On many natural hillsides actual flow consists of a disturbed, irregular and discontinuous series of surges which are likely more effective in entrainment than continuous flow (Bryan 1974).
On natural slopes the uneven surface produces variations in flow thickness and thus in erosive capacity. Where there are marked fluctuations in flow thickness, some depressions may be eroded at a higher rate, initiating small channels in which the flow and transportation become progressively concentrated (Carson and Kirkby 1972). This initiates rilling. Although rills do not form on all slopes, where they do form, erosion is several times the level of simple sheetflow.

Deposition

The final step in the erosion cycle is deposition. Deposition occurs when the energy of the transporting agent diminishes until it is unable to support the detached particle. A particle may be detached, transported, and deposited many times as it moves down the hillslope. General areas of more permanent deposition include ditches, culverts, streambanks, and stream channels where the soil forms part of the sediment load.

Forest harvesting operations often leave a buffer strip of vegetation along streams. This strip is designed in part to trap overland flow and promote deposition of sediment before the runoff reaches the stream. In areas where erosion is not severe, such amelioration techniques can control the problem of sediment input to streams although organic matter loss from the site may still be significant.
Roads constitute a major source of sediment for streams. Up to 90 percent of sediment from forest land that reaches stream channels originates on roads (Hewlett 1982). This may arise from improper design which allows runoff to concentrate and flow directly to the stream channel, poor road stream crossings and drainage systems, or road cuts which intercept subsurface flow routes and then allow subsurface flows to become overland flow. Studies have shown that, with proper design and construction, roads can have a minimal impact on stream sediment loads. Rothwell (1977) found water quality unchanged before and after logging in a subalpine watershed in Alberta. This was attributed to careful planning, specifically, location of roads away from stream channels, avoiding steep road gradients, minimizing road-stream crossings, and scheduling operations when runoff, soil moisture, and rainfall were at minimum levels. In addition to these design factors, careful supervision of the construction phases is necessary to avoid mistakes and ensure adherence to specifications.

An overview of the erosion process showing interrelationships among the factors influencing surface erosion follows (Figure 1). Developed by Novak and van Vliet (1983) for illustration of the erosion process on an agricultural site, this flow chart is modified to indicate specific processes and impacts which occur in the surface water erosion process on the forest land base.
Figure 1. An illustration of the physical processes operating in surface water erosion and the natural site characteristics and management which impact this process.
THE ROLE OF FORESTS IN EROSION

An Historical Perspective

It is relevant before making any assessment of the present knowledge of erosion, to consider the development of this science (Hudson 1971). Studies of the effects of erosion on early civilizations have shown that a major cause of the downfall of many empires was soil degradation (Lowdermilk 1953).

Much of the Mediterranean region was once a lush, forested region. In 400 B.C. southern Italy was a land of forests that covered the southern end of the Italian peninsula. Today the forest of ash, evergreen oak, laurel and myrtle survives only in the relatively high, inaccessible Calabrian mountains. Between the sixth and fourth centuries B.C., the extensive mountain forest of Greece dwindled, leaving forest only in remote areas (Thirgood 1981). Originally 60 percent of the country was covered by fine forests. Now only 5 percent is so covered (Osborn 1948).

The Bible describes Palestine as a green and fertile land. By the nineteenth century Palestine was described in very different terms. Lynch, an American, noted in 1849 "the first thing . . . which strikes a visitor from the western world, is the absence of forest trees" (in Thirgood 1981).
Even with the present understanding of soil erosion and knowledge of causal factors, the erosion cycle continues to operate in the Mediterranean. The Food and Agriculture Organization warns that the present expansion of civilization, overgrazing and deforestation may undermine future stability (Sen 1959).

In the Mediterranean area deforestation and lack of proper land management led to severe surface erosion. Soil loss reduced the productive capability of the land base and left an arid, denuded landscape which is today unable to meet the needs of its population. As a whole, Europe, with a moderate climate, stable governments, and good agricultural practices has little severe erosion. However, extensive deforestation in the high mountain forests of the European Alps in the 19th century led to severe loss of life and property from debris torrents, avalanches, and floods. Only a relatively dense population to be protected in the Alps made it worthwhile (for the governments concerned) to spend money on torrent control (Keller 1970). Forests became recognized as valuable not only economically but in a protective function.

Forest management in the Alps expanded to evaluate the benefits from the forest in a protective role as well as timber production. In unstable areas where forests were necessary to stabilize the slope, protection forests were established, recognizing that the maintenance of slope stability in many cases exceeded the returns from logging.
Management techniques included reforestation of cutover lands, afforestation of many previous clearings (especially at climatic timberline), and restriction of land use to suitable sites. "During the period of taking stock the idea of soil conservation has developed further, and from being confined to erosion control has expanded to become linked with the idea of rational utilization of the environment" (Fournier 1972 pg. 14).

Colonization throughout the United States seemed to proceed with an idea of "conquering" the land rather than adapting to the natural system. Land use practices, including deforestation, land clearing, and overgrazing, often led to accelerated erosion. Colonization in Canada occurred with much the same deforestation but a lesser population influx protected much of the forest area from exploitation.

Migration westward in North America was gradual and the population densities were quite low. The timber reserves were generally exploited for logging but an abundant supply and lower levels of forest clearing prevented widespread deforestation. Early logging methods which included hand falling and horse skidding, mainly on snow, had little disturbance, thus little accelerated erosion occurred.

With the continued exploitation of the mountain forests of the western United States, floods, debris torrents, and mudflows caused damage similar to that in the European Alps. Lower population densities limited the loss of life and
property but the problem still existed. Sears (1955), recognizing that deforestation precipitated (in part) these destructive events, remarked, "while this is assumed as a basic element in national forest policy far greater funds are expended upon efforts to control floods after water has reached the river channels than are devoted to securing proper land use on the tributary uplands to retain the water where it falls. This is an interesting aspect of a technological culture whose emphasis is on engineering rather than on biological controls" (Sears 1955, pg. 480).

**British Columbia - Present Perspective**

Mr. W. Young, former chief forester of British Columbia, in an address on "Forestry and Soil Productivity in B.C." (1983), stated that "We, in B.C. need every bit of forest land we have to meet the demands put on it by society - not the least of which is to supply timber to meet the needs of industry." He identified several soil management problems which reduce productive forest land area and stated, "the greatest threat is erosion - soil loss" in connection with forest logging operations.

High elevation forests (1200-2000 metres) contain most of the timber cut on the coast in British Columbia and the major reserve of sawtimber in the Interior occurs in this zone (Weetman 1983). Forest operations at these elevations
must overcome climatic and topographic stresses. Young (1983) stated that "nowhere else in the world does terrain pose such difficult problems for loggers . . . foresters . . . and soil scientists." Soil degradation occurs through fire, soil compaction, and nutrient depletion on landings but the major threat identified by Young was erosion on forest land. This included mass-wasting caused by harvesting unstable slopes, surface erosion leading to gully erosion and, (singularly most important), the construction of forest roads.

The Canadian Forestry Service has produced a situation appraisal of forest operations in British Columbia. It gave a general, concise overview of provincial erosion hazards:

"The diversity of topography, geology, soils, vegetation, and climate in British Columbia, together with historic attitudes and economics have resulted in a variety of timber management practices. This combination of factors has produced a marked regional variation in impacts on the soil and water resources, and, by implication, a need for local or regional information concerning these impacts or interactions. In very general terms it can be stated that:

- The significance of impacts may increase from south to north as the climate becomes more rigorous.

- Accelerated erosion occurs to some extent wherever there is logging, with variations resulting from differences in intrinsic soil erosion hazard and standard of logging practice.

- The greater the areal extent of disturbance the greater the impact. The extent of disturbance is a function of harvesting method, logging technique, road density and slope.
- The degree of impact on the stream environment tends to be inversely related to the distance between the activity and the water course.

- The logging practices used in steep terrain in the Interior tend to be more destructive than on the coast because of the type of equipment used" (Finnis et al. 1973).

Ballard (1983) attempted to assess "how serious and how extensive are various kinds of forest soil degradation associated with timber harvesting and site preparation in British Columbia." No quantitative values were available but an identification of the major erosion problems in the various regions was obtained. In the Kamloops, Nelson, and Cariboo regions timber harvesting impacts in terms of compaction, puddling, and surface erosion were rated relatively important. Nutrient losses from harvesting and slashburning, as well as degradation from mechanical site preparation, were also important impacts. Mass-erosion was a localized concern in several regions but its major impact was in the Prince Rupert region, notably in the Queen Charlotte Islands.

The mandate for forest management by the British Columbia Ministry of Forests is, in part:

"to plan the use of the Forests and range resources of the Crown so that the production of timber and forage, the harvesting of timber, the grazing of livestock and the realization of fisheries, wildlife, water, outdoor recreation and other natural resource values are coordinated and integrated, in consultation and cooperation with other ministries and agencies of the Crown and with the private sector . . . "(Section 5, Subsection C, MOF Act).
The British Columbia Ministry of Forests interim guide to logging on severe sites (B.C.M.O.F 1968) stated that:

"to maintain reasonable site productivity, by minimizing erosion and encouraging regeneration, adjustments in stand treatments and logging techniques are needed on any site where extremes of climate, edaphic or topographic features are encountered. Because of site variability, silvicultural treatment must be determined on the basis of site specific recommendation for all forest units under management and pre-logging examination is essential."

These governmental directives, as well as designation of some high elevation sensitive sites to Environmental Protection Areas and other land off-limits to harvesting in Provincial and National Parks, has protected British Columbia. The hazard for erosion is only presently accelerating to dangerous levels. Logging operations are expanding to more marginally stable slopes as our wood supply diminishes.

Smith (1962) stated the relationship between silviculture and watershed management becoming of primary importance. In British Columbia regeneration, or lack thereof, is a prime silvicultural consideration. Maintenance of site productivity is important, as is the stability of the soil. Management alternatives to limit erosion can often increase regeneration success. Selection logging, if properly planned, can maintain site stability and also promote natural regeneration in some species. Patch or strip clearcutting provides more favorable microsites for seedlings, especially on southern slopes.
In most instances, forest management should minimize erosion, especially if other non-timber values accrue to the land. "We cannot however, condemn forest practices merely because they cause soil degradation. The appropriateness of forest practices can only be determined by comparing costs and benefits of different management options" (Ballard 1983, pg. 175). The problem a land manager faces is that values for benefits and costs of non-timber options are difficult, if not impossible, to quantify. Evaluations are therefore both subjective and difficult. Recognizing the importance of the forest land base in British Columbia, it is imperative that soil degradation be evaluated in conjunction with various management options.
Chapter 4
LITERATURE REVIEW OF FLUORESCENT DYE

Studies of water or soil movement are difficult because distinguishing characteristics rarely allow differentiation between the substance in its original site and after movement. Water and soil "tracers or tags" serve as labels on the substance and allow movement to be observed and documented.

Normal color (non-fluorescent) dyes have been used both to "tag" soil particles and to monitor water flows. These labels give a new color to the sample substance. The resolution, or ability to distinguish labelled particles, in this method is limited by the difficulty in visual detection of tagged particles or slight fluid color changes once mixing has occurred. To improve resolution a tag dependent upon more than visual detection was developed. This technique uses radioactivity to tag particles or to act as tracers in water studies. Detection of particle and fluid movement is successful with this method. The use of radioactivity is limited because it is expensive, potentially hazardous, and frequently the subject of public concern. A technique which overcomes these limitations, yet has high resolution, is the use of fluorescence to monitor or illustrate movement. This method has many applications in soil and water studies.
The appearance of normal color arises from selective absorption and reflection of segments of white light in the visible spectrum. The portion reflected yields the characteristic color while the portion absorbed is dissipated as heat. Fluorescence results from the emission of radiant energy as a molecule drops from an excited or higher energy level to its previous state. The input of ultraviolet light (wavelengths below the visible spectrum) allows a fluorescent molecule to accept an extra photon, thus increasing its energy level. This energy state is unstable and shortlived. As the molecule returns to its original state it emits radiant energy. This emission is called fluorescence and has a longer wavelength than the incident ultraviolet light. This means that the input of ultraviolet light, which is, essentially, invisible to the naked eye, results in the emission of visible light. Thus, when the surrounding particles are unable to be seen (i.e. at night) fluorescent particles will emit light and are therefore easily distinguished. It is this emission of visible light from ultraviolet input which allows fluorescence to be used successfully as a tracer in sediment, soil, and water movement studies.

Smart and Laidlaw (1977) summarized the use of fluorescent dye tracing techniques in hydrology. They found a multitude of uses: for surface water studies, where fluorescent dyes are commonly used for dye dilution gauging; for the calibration of structures, where current metering is
difficult; and, for time-of-travel studies. The tracing of karst groundwater has also been accomplished using dyes. In soil water studies water soluble dyes have been used to identify the occurrence of overland flow, to trace water transmission routes in the soil, and to evaluate infiltration. Fluorescent particles index soil movement and aid in the evaluation of wave action on beaches. The magnitude and location of these transport forces can be illustrated by differential movement of particles color-stratified by size and original location.

SOIL PARTICLE TAGGING

Overview

In evaluating surface erosion most studies use measurements of soil and water collected at the bottom of the slope, the plot boundary, or the watershed outlet. These data illustrate soil loss from the area but tell little about the point source of the eroded material or the patterns of soil movement within the area (Young and Mutchler 1969). Labelling soil particles allows origin and rates of movement to be charted.

In soil studies, colored dyes are of limited value because of the difficulty in distinguishing marked and unmarked particles on the basis of color alone. This is especially evident when an analysis of large numbers of particles is necessary. The use of radioactive compounds is
always subject to public concerns and possible health hazards. Other factors limiting this procedure are high cost, difficulty in tagging particles, and no visual record of tagged particles. Fluorescent dyes are relatively simple and inexpensive to use. They are environmentally safe and allow easy differentiation between tagged and unmarked particles. Large volumes of sediment can be tagged reasonably quickly and a variety of "colors" can be prepared to separate particle samples. The stability of fluorescent dye under environmental conditions is still partially unknown, although different application techniques yield different persistence times. Difficulties in detecting fluorescence will sometimes exist, often due to environmental conditions.

A variety of marking compounds and colors exist, which allow stratification of particle sizes and slope location. When labelling particles with a fluorescent coating four points should be considered:

1) The characteristics (density, size and surface texture) of the natural or introduced particles should not be significantly altered by application of the marking compound.

2) The tagged particles should be readily distinguished from unmarked particles.

3) The procedure should be relatively quick and easy.

4) The tagged compound should be persistent although the desired length of time will depend upon the objectives of the project.
The review of research using fluorescence in particle movement studies is divided into three sections: the original marking of beach sands; the introduction of fluorescent particles (glass or natural material) to a soil system; and the tagging of actual soil particles either by spraying in situ or extraction, marking and replacement.

Beach Sands

The original extensive study of sediment transport using fluorescence was conducted by the Institute of Oceanology of the Soviet Union (Zenkovitch 1958, in Wright 1962). Two fluorescent compounds were used, anthracene, which fluoresces yellow-green under ultraviolet light, and lumogene which fluoresces red-orange. These were combined with a variety of substances, agar-agar, bone-glue, gum and starch, adjusted to dissolve at a predetermined rate (from 1 week to 3 months) in sea-water.

Yasso (1962) evaluated commercially available daylight and near-ultraviolet fluorescent dyes in surface coatings on sediments. Many of these coatings were visible both in daylight and under ultraviolet light allowing day and nighttime evaluations. Wright (1962) conducted tests to develop the simplest possible technique for marking beach sand with an ultraviolet-sensitive dye. It was found that the choice of dye and marking technique was interdependent. Many of the available dyes would fluoresce properly only in solution
in specific solvents or would react with potential coating materials or were soluble in water if attempts were made to apply them directly to grain surfaces.

The most successful results were obtained with anthracene, a readily available organic chemical (a coal-tar derivative). Later experiments concentrated on developing suitable techniques using this fluorescing agent. A simple technique was developed. Sand was scooped from the surface along surveyed lines, rapidly marked in a shaker with the fluorescent compound, and returned to the same location. The dispersal of marked sediment was checked after dark with an ultraviolet lamp and samples were collected for quantitative analysis in the lab.

Yasso (1962) developed a field photometer to sample light intensity from the surface distribution of marked particles over a given sampling area, thereby supplanting or eliminating the conventional counting procedure. This procedure was helpful as it is difficult to sample a uniform layer of sediment by mechanical means. Also, the use of a photometer yields results estimating the relative abundance of marked particles in a fraction of the time needed for counting.

Yasso (1964) used a time-integration sampling technique with color-coded sizes of fluorescent tracer particles to determine the nature of size-velocity relationships in wave action. The procedure involved removing sediment from the foreshore zone, sieving it into four size classes and
coating these with a mixture of Switzer Day-Glo acrylic laquer and American Cyanamid beetle resin. Each size class was coated with a different daylight and ultraviolet fluorescent dye color. The coated sediment was dumped onto the foreshore just before a wave came in and then the area was sampled for marked sediment concentration both onsite and with a smaller subsample in the lab.

**Introduced Fluorescent Particles**

Fluorescent glass particles and willemite, a naturally fluorescing ore, have been used in soil studies to trace movement and to identify overland flow velocity-particle size relationships.

Young and Holt (1968) and Young and Mutchler (1969) used fluorescent glass particles to trace soil movement. These glass particles have a density similar to natural soil particles and are assumed to react the same. This experimental technique was developed in German erosion studies. Ordinary soda glass is impregnated with sodium diuranate, a commercially fluorescing agent identified as "uranium yellow." Other fluorescing agents may be substituted to vary the fluorescence characteristics and the amount of agent used depends upon the degree of fluorescence desired. The mixture is heated until molten and then the glass is cooled, crushed and sieved to the desired particle size distribution.
Young and Mutchler (1969) used fluorescent glass particles to evaluate soil movement on irregular slopes. The use of fluorescent particles (of similar density and size as existing soil) and microrelief measurements allowed soil loss, the point source of eroded material, and onslope soil erosion patterns to be evaluated. Two lines of glass particles were placed across the slope. Collecting troughs were established at the base of the slope and after each half hour increment of simulated rainfall the silt-laden runoff was collected and analyzed in the lab for fluorescent particles. The velocity of the runoff occurring from the simulated rain was measured by the advance of uranine (a fluorescent dye) injected into the flow at various points.

The use of fluorescent particles allows erosion plots to yield data on more than net soil loss. Plots "seeded" with differentiated fluorescent particles illustrate how various portions of the slope contribute to total sediment yield and chart the movement of the fluorescent particles downslope.

Fowler and Berndt (1969) and Helvey and Fowler (1979) used a natural ore containing fluorescent Willemite (zinc silicate with a manganese activator) as an indicator of soil movement. The ore was crushed and graded to sizes representing the existing soil onsite. When illuminated under ultraviolet light Willemite glows yellow-green.
Helvey and Fowler (1979) "salted" 10 plots with size-graded fluorescent material to index movement of particles of various sizes. Each plot varied in surface soil disturbance and was salted in three separate sections, one each with fine, medium, and coarse-grained particles. Rates of movement under different disturbance levels and maximum downslope movement were determined.

Application Onto Natural Soil Particles

Application of dye directly onto soil particles ensures that tagged particles replicate soil properties on the site. Striffler (1969), in Colorado, evaluated alpine soil movement by establishing erosion transects using fluorescent dyes. Sites varied in aspect, slope position, and slope length. Particles were tagged with fluorescein, a fluorescent dye to index soil movement. Small microplots were fitted with soil collectors and particles were analyzed for fluorescence in the lab.

The procedure included spraying a water stable fluorescent dye (fluorescein) directly onto the soil surface or excavating soil particles from a 2.5 cm by 2.5 cm trench across the slope, sieving into size classes, dyeing each size class a separate, distinct color (fluorescent), and replacing them in the trench.

Small metal collection troughs were also imbedded in the slope to collect surface runoff and sediment accumulations. Fluorescent dye of various colors was
sprayed along the transects at intervals upslope from the collector to allow the identification of a particle's original site and thus the distance moved.

Striffler found such particle tagging with fluorescent dyes simple and inexpensive, yet effective. The dye remained sufficiently visible for night illumination over a two year period.

In conjunction with Striffler, Zoghet (1969) established further erosion transects. He used Day-Glo fluorescent pigments mixed with acetone to tag particles either in situ or after excavation. Five different fluorescent pigments were used allowing both a quantitative and qualitative index of soil movement.

Spraying of the soil surface in situ has the advantage of no soil disturbance. However, as it is impossible to coat the complete soil particle, some particles may not be detected after downslope transport. Excavation of particles allows the complete surface to be marked but when replaced onto the slope, the tagged particles may not reflect the actual surface soil stability. Zoghet found that daytime differentiation of particles tagged with Day-Glo pigments was possible in the early stages of the experiment but that this color faded after time. Night-time illumination was successful even after a full year on the site.
DAY-GLO FLUORESCENT PIGMENT

A daylight fluorescent pigment has the same reflection properties as a non-fluorescent color but is also able to absorb wavelengths from the lower end of the spectrum (ultraviolet) and convert these to visible light of a similar wavelength as the reflected light. A bright non-fluorescing color might reflect 90 percent of a color present in the exciting spectrum but in combining reflected and emitted light a fluorescent color can reflect 200 to 300 percent (Day-Glo Tech. Bull, no date).

These extra-bright pigments were first developed in the 1940s for use in military signal paint. Much of the impetus for development of commercial availability was in silk screen process paints.

Day-Glo daylight fluorescent pigments are transparent organic resin particles containing dyes. The fluorescence of these organic dyes is associated with the individual dye molecules and the organic resin acts as a carrier for the dye molecules allowing them to go into solution.

The physical structure of the pigment is amorphous or non-crystalline. The compound is a fine powder which disperses easily in most media. Day-Glo pigments are not resistant to strong solvents but are stable to indoor and
outdoor light. Direct sunlight may change their color characteristics depending on pigment (concentration and color), vehicle/binder (dissolving solvent) used, and thickness of application. The manufacturer recommends outdoor exposure tests to test lightfastness. For properties of the dyes and toxicity values see Appendix A.
Chapter 5

METHODS

STUDY SITE

This study is located in the North Okanagan area of Interior British Columbia (Figure 2). It is part of the Vernon Forest District within the Kamloops Forest Region. The overall project area is bounded by Trinity Valley on the north, Beaver (Swalwell) Lake on the south, Winfield and Vernon on the west and Lumby on the east. Study sites are located in mid-elevation forest areas harvested within the previous four years.

General information on the study area was obtained from field surveys conducted in the summer of 1984, government maps (forest regions, topographic and surficial geology) and published reports. Reports compiled by Willington et al. (1973), Hawthorn and Karanka (1982) and British Columbia Ministry of Environment (1981) give information on the hydrology of the region. Sprout and Kelley (1960) completed a soil survey of the North Okanagan which briefly considered forested regions while Clement (1981), in detailing vegetation resources of the Vernon Map Sheet, determined the relationship of vegetation to other environmental components including topography, soils, and climate.
Figure 2. Location of Study Area.
Climate

The North Okanagan is characterized by moderate precipitation, warm to hot summers and cool winters. The study area is located in a transition zone between the Interior rain shadow (east of the Coast Mountains) and the wetter west slopes of the Monashee Mountains. An increasing precipitation gradient exists south to north and west to east. Most precipitation is supplied by low pressure systems passing from west to east. During the summer months these systems are widely spaced and any precipitation occurring is from localized convectional cooling, generally intense thunderstorms. Spring and fall rain storms also track from west to east, while winter storms usually extend southward from the Arctic.

Precipitation also increases with elevation and temperature decreases (Figure 3). Willington et al. (1973) state that at any latitude through the Okanagan basin precipitation on the ridge tops (1000+m) may be as much as double that occurring at the lake elevation. The highest accumulation of precipitation, rain and snow, occurs in the Monashee Mountains. The proportion of annual precipitation in the form of snow is 50 percent at the lake level (valley bottom) and a larger percentage at higher elevations (Willington et al. 1973).
Throughout much of the area moisture availability is a limiting factor in vegetative growth. The southern half of the study site is located in the Dry Interior Forest Region while the north is in the Interior Wet Belt (Figure 4). In the Dry Interior Region mean annual precipitation ranges from 260 - 450 mm and mean annual snowfall in the valley bottoms is 70 - 200 cm. In the Interior Wet Belt precipitation increases to an average of 425 - 1100 mm and snowfall to 120 - +350 cm (Clement 1981).
Figure 4. Regional climate reflected in forest regions.
Higher incoming radiation results in lower snow accumulations on south and west-facing slopes (especially in the Dry Interior Region), higher potential evapotranspiration (PET) and moisture deficits (PPT - PET) may occur. Site specific climatic data is based on the identified vegetation biophysical(1) zones (Table I).

Physiography

The study area lies within the Interior system of the Canadian Cordillera. It straddles the Thompson Plateau (north) and the Okanagan Highlands (south) physiographic regions (Holland, 1976). The Thompson plateau is characterized by gentle or moderately-sloping plateaus while differential weathering in the Okanagan Highlands produces gentle step-like slopes.

The area is underlain by gneissic bedrock, granitic plutonic (acidic) bedrock and basaltic (basic) bedrock. Surficial geology deposits were mapped by Fulton (1975). Most forested areas occur on undifferentiated morainal deposits from the Pleistocene Ice Age although younger erosional features are also forested.

The study area encompasses a wide range of elevation from the Coldstream valley (600 m) to high peaks (1650 m). The elevation of the study sites is 800 - 1000 m in the northern half of the area and 1200 - 1400 m in the south.

(1)Biophysical classification is differentiation of landscape units on the basis of geology, terrain, climate, soil and vegetation (Walmsley and van Barneveld 1977).
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<th>TRINITY VALLEY</th>
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<th>BEETLE CREEK</th>
<th>BEAVER LAKE</th>
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<td>IWB SALMON ARM</td>
<td>DI VERNON</td>
<td>DI VERNON</td>
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<td>(IwC)</td>
<td>(ID)</td>
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<td>hot,dry</td>
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</tr>
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<td>cool,moot</td>
<td>cool,dry</td>
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<td>900-1300</td>
<td>700-1500</td>
<td>700-1100</td>
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<td>-200/+100</td>
<td>-200/+100</td>
<td>-200/+100</td>
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<td>60-100day</td>
</tr>
<tr>
<td>growing season precipitation</td>
<td>250-350mm</td>
<td>200-300mm</td>
<td>200-250mm</td>
<td>&lt;250-300mm</td>
</tr>
<tr>
<td>possible limits to productivity</td>
<td>leached soils</td>
<td>short growing season</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Soil Types - Orthic Dystric Brunisols - Orthic Gray Luvisols -

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Eluviated Dystric Brunisols</th>
<th>Bruinisolic Gray Luvisols</th>
<th>Orthic Dystric Brunisols</th>
<th>Orthic Eutric Dystric Brunisols</th>
</tr>
</thead>
</table>

(1) growing degree days - The accumulated difference between the mean daily temperature and standard base temperature of 5 degC on days when the mean daily temperature is above 5 degC.

(2) climatic moisture deficit/surplus - The algebraic difference between May to September precipitation and potential evapotranspiration. Deficits (negative) and surpluses (positive).

(3) freeze-free period - The greatest number of consecutive days in a calendar year free of a temperature of 0 degC or less (B.C.M.O.E. 1978).
Soils

The soils of this area originate from glacial deposits. The parent material is generally nutrient poor, with most of the nutrient capital of the site concentrated in the organic matter of the upper few centimetres of soil (Smith 1984). The soils in forested areas are generally dry during the summer; however, they have greater moisture content and lower average temperatures than soils in the surrounding agricultural areas. Many soils are slightly acidic. Sprout and Kelley (1960) classified the major forest soil as a Podzol. In this early soil survey Podzolic Grey-Wooded soils were mapped (with limited field sampling) in the forest areas adjacent to agricultural lands. In a more extensive and recent study, Clement (1981) mapped Brunisols and Luvisols in the area (Table 1).

The Dry Interior is characterized by Eutric Brunisols which are basic and poorly developed, and Gray Luvisols which have leached surfaces and accumulations of clay and minerals in the lower horizons. The Interior Wet Belt is characterized by Gray Luvisols and Dystric Brunisols at lower elevations which characteristically exhibit leached surfaces and minimal accumulation of clays and minerals. Humo-Ferric Podzols are found at the higher elevations (above 1380 m) and exhibit leached upper layers and high accumulations of iron and aluminum (Clement 1981).
Vegetation on many sites serves to control soil erosion, especially on steeper slopes and areas of fine textured soils. The runoff from snowmelt and intense rainstorms can cause problems. In some areas climatic moisture deficits and high soil and air temperatures make regeneration difficult and thus make surface soils less stable.

Vegetation

The study area encompasses a variety of forest types (Table 1). The major tree species are Interior Douglas-fir (ID) (*Pseudotsuga menziesii* var glauca), Engelmann spruce (eS) (*Picea engelmannii*), lodgepole pine (lP) (*Pinus contorta* var latifolia), western red cedar (wC) (*Thuja plicata*), western larch (wL) (*Larix occidentalis*) and alpine fir (alF) (*Abies lasiocarpa*).

The vegetation is significantly different between the Dry Interior and the Interior Wet Belt as a result of temperature and precipitation differences. The Dry Interior is characterized by Interior Douglas-fir in the valleys in association with ponderosa pine (*Pinus ponderosa*) at low elevation, changing to lodgepole pine as elevation increases. A belt dominated by western red cedar forms a transition to the Interior Wet Belt and moister, cooler conditions.
Clement identifies the major understory (indicator) species as Soopalallie (*Shepherdia canadensis*), heart-leaved arnica (*Arnica cordifolia*) and pine grass (*Calamagrostis* spp.) in the Dry Interior portion of the study area. In the Interior Wet Belt portion, characteristic shrubs and herbs are Utah honeysuckle (*Lonicera utahensis*), Oregon boxwood (*Paxistima myrsinoides*), California filbert (*Corylus cornuta* var. *californica*), western thimbleberry (*Rubus parviflorus*), blue-bead clintonia (*Clintonia uniflora*), northern twinflower (*Linnaea borealis*) and large-leaved rattlesnake orchid (*Goodyera oblongifolia*). The major silvicultural system of forest management employed in the area is clearcutting and single or group tree selection, especially in Douglas-fir and ponderosa pine types. Insect and pathogen attacks of forest vegetation vary in scope and location. Recent mountain pine beetle outbreaks have led to salvage cuts south and east of the study area.

**Hydrology**

The study area comprises of a number of basins. Beaver Lake sites in the south drain into Vernon Creek, which flows into the Okanagan Basin, while Beetle Creek, Deafies Creek and Trinity Valley sites drain north to the Shuswap River.
The streamflow hydrograph is snow dominated and follows the general pattern for interior Canadian rivers with sharp spring snowmelt peaks and low summer flows illustrated by the Coldstream Creek hydrograph, a basin situated just west of the study area at slightly lower elevations than the study sites (Figure 5).

Snow accumulation (snow water equivalent) increases with elevation and most snowmelt runoff originates at higher elevations than the study sites (Figure 6).

Fish and Wildlife

The study area contains many small lakes, some maintaining good rainbow trout populations. The streams draining the area are important salmonid producers (anadromous salmon and kokanee).

A variety of habitats exist for wildlife in this area. There are mule deer, moose, some sheep, and black bear populations.
Figure 5. Coldstream Creek hydrographs (Hawthorn and Karanka 1982).

Figure 6. Snow water equivalent (April) versus elevation for seven Okanagan snow courses (B.C.M.O.E. 1981).
SELECTION OF METHODS

Fowler and Berndt (1969) identified a "need for easy to use methods of recognizing or identifying active erosion, determining its cause and appraising relative erosion rates in mountain watersheds" (pg. 1). This study incorporates two relatively easy-to-use methods to evaluate erosion on harvested areas: (1) erosion transects, an established method previously used in British Columbia and (2) fluorescent dye, a relatively new method untested in Canadian conditions. The first method, sampling soil disturbance with line transects, was applied in the summer of 1984 to 10 sites which differed in slope, aspect, soils, location and type of logging, to examine causal factors for erosion occurrence. The second, spraying fluorescent dye to label soil particles, was applied to four of the 10 sites to examine rate, distance, and patterns of downslope soil particle movement.

EROSION TRANSECT STUDY

Estimates of soil disturbance on harvested sites, together with topographic, soil, and climatic information, are recognized as indicators of potential erosion and sedimentation (Bockheim et al. 1975). On a harvested area, soil disturbance varies in location and intensity across the
Figure 7. Location of the study sites. (Triangles indicate fluorescent dye plots).
cutblock. It is not uniformly or randomly distributed, which precludes many sampling techniques. The line transect method allows the areal distribution of various disturbance classes to be determined. In British Columbia, Bockheim et al. (1975), Smith and Waas (1976) and Schwab and Watt (1981) have used this method.

Site Selection

Ten study sites were located on recently harvested areas through the study area (Figure 7). The sites included two selectively logged areas on the Beetle Creek Road and clearcut sites near Deafies Creek, Trinity Valley Road and Beaver (Swalwell) Lake. The sites varied in aspect, soil type and degree of slope. Transects were located in two climatic zones and on both selection and clearcut harvested sites (Figures 8 and 9).

Field Methods

Erosion transects were done by a three-person crew. Transects were laid out in a rectangular grid pattern on the cutblock to estimate general site parameters. The survey procedure resembled that followed by Schwab and Watt (1981), Smith and Wass (1976) and Bockheim et al. (1975). The transect lines were run along a bearing perpendicular to the overall site contours. Lines ran up and down slope and sample intensity varied with cutblock size. Sample points were established every 10 to 25 metres depending on transect
Figure 8. Trinity Valley #2 Site.

Figure 9. Beaver Lake #1 Site.
length, to obtain a minimum of 100 points per cutblock. Ground disturbance was rated subjectively from no-disturbance to a very-deep-gouge or very-deep-deposit of soil at the point. Although subjective, little variation in crew members' ratings was found. Disturbance categories were based on depth, type, and extent of ground disturbance (Table II).

Table II. SOIL DISTURBANCE CATEGORIES
(modified from Schwab and Watt 1981)

At the point directly below meter mark on chain record:

ND - no disturbance
NBS - natural bare soil
BS - mixture of mineral soil and humus
SG - shallow gouge (mineral soil exposed to 5 cm depth)
DG - deep gouge (5-25 cm depth)
VDG - very deep gouge (over 25 cm depth)
SD - shallow deposit (mineral soil deposit to 5 cm depth)
DD - deep deposit (5-25 cm depth)
VDD - very deep deposit (over 25 cm depth)
L - litter disturbed and slash piles

Along the transect line skid trails were recorded on a sketch map. Local slope percentages (point to point) and ground vegetation were recorded and a few random soil samples (3-4 per site) were collected. At the edge of the cutblock a perpendicular offset of 25-50 m (distance determined by cutblock size) was traversed and the line reversed downslope. This continued until the cutblock was
covered. In the very large selection cutblock two randomly selected areas were sampled in this manner.

Analysis

A written report was completed for each cutblock including general site parameters as aspect, slope, map location, cutblock size, number and size of landings and streams draining the area. Field transect information was compiled to give percentage and degree of ground disturbance. Line profiles were drawn, a rough map of the cutblock including streams, skid trails, haulroads and landings was sketched, and a list of ground vegetation included. A site evaluation was completed for each of the sites based on an area reconnaissance which noted erosion occurrence, deposition sites, stream location, possible sedimentation sources, and buffer strips. Erosion occurrence is a subjective evaluation based on visual evidence of soil movement including rills, gullies, deposition areas and bare soil. Site evaluation included a care-in-logging assessment comparing harvesting operations and disturbance levels among sites. Surface soil samples were hand-textured in the lab.

The analysis of site data utilized distribution of disturbance classes, the written site evaluation, a site description, line profiles, and a photographic record. Average data values, variability in site evaluation and site specific features were used to identify trends and draw preliminary conclusions.
FLUORESCENT DYE STUDY

This study method used Day-Glo fluorescent pigment to label soil particles and ultraviolet light to identify soil movement. This procedure, the spraying of fluorescent dyes onto soil particles, is quite new and few examples exist in the literature. No literature describes research studies using fluorescent dyes under Canadian climatic conditions and only one study (from the United States) uses a similar method. Therefore many unknowns exist, including:

- Will the dye degrade in sunlight?
- Will fluorescence persist after freezing and snow cover?
- What solvent should be used to bind the dye to the soil particles? How should such be applied?
- Will application change the characteristics of the soil particles (size, density, shape)?
- What level of ultraviolet illumination is necessary to detect particles? Is a hand held field lamp sufficient?
- Can movement patterns be recorded on film? If so what color and speed of film is best?
- What size of particles will hold the dye and remain visible for measurement?
Selection of Fluorescent Dye

In a soil movement study conducted in Colorado, Zoghet (1969) used Day-Glo fluorescent pigment in a solution of acetone and Striffler (1969) used fluorescein in solution with xylene (personal communication 1984). Both reported satisfactory results applying dye to soil in situ.

Field tests with Day-Glo Saturn yellow fluorescent pigment in acetone and fluorescein in xylene were conducted on soil samples from the Deafies Creek #2 site. Twenty grams of fluorescein were mixed with 200 ml of xylene and applied to one soil sample. Twenty grams of Saturn yellow pigment were mixed with 200 ml of acetone and sprayed on a second soil sample. Both samples tested positively for fluorescence under night-time ultraviolet illumination.

The test boxes of soil were set outside for three weeks and were subject to high temperature, long hours of sunlight, and periodic heavy rains. At the end of this time the Day-Glo pigment yielded satisfactory illumination under ultraviolet light but the fluorescein mixture was found to have degraded (likely due to sunlight). Therefore, dye application of Day-Glo fluorescent pigment mixed with acetone was chosen.

Site Selection

In late August 1984, four study sites were selected for fluorescent dye application. The sites varied in aspect and slope but all were located within walking distance of major
roads to allow night-time access and access shortly after snowmelt in the spring of 1985. The study sites chosen were Trinity Valley #1 and #2 and Beaver Lake #1 and #4.

The number of dye plots established on each site varied. Trinity Valley #2 has 15 dye plots, Trinity Valley #1 has 11, Beaver Lake #4 has 6 and Beaver Lake #1 has 6. The numbers reflect somewhat loosely the variation in site conditions seen on the cutblocks. The location of dye plots was quite arbitrary.

Plots were established both in upper slope positions and lower slope positions, on heavily disturbed and compacted skid trails and in relatively undisturbed areas beside them, and on a variety of slopes and aspects. Locations generally free of ground vegetation were chosen to ensure proper adherence of the dye to soil particles. A clinometer was used to measure immediate slope above the plot.

Field Methods

Application of Dye

During August, 1984, various applicators were tested for an even distribution of measured solutions of pigment on the dye plots. The volatile nature of acetone limited the available sprayers, for safety reasons, to those which did not have a build-up of high pressure. The final
selection was a hand-held pump-type sprayer, although its durability was marginal due to the corrosive properties of acetone.

Dye was applied directly to soil, precluding further disturbance of soil and site alteration. Lines of pigment were sprayed perpendicular to the slope (Figure 10). The dye solution consisted of one gram Day-Glo fluorescent pigment (Saturn yellow) in 10 ml acetone to cover 25 cm² surface area (similar to Zoghet 1969). Templates of wood lined with sponge were used to ensure proper application rates and area boundaries. Dye strips were one metre long and five centimetres wide, marked with metal pins and tied into site features.

Two plots were established on level ground to evaluate raindrop splash and pigment deterioration over time. On selected areas fluorescence was tested after dye application and a photographic record of the application process and fluorescence was compiled.

Field Measurement - Spring 1985

In spring 1985, shortly after snowmelt, the field plots were visited at night to evaluate the fluorescence of the dye and quantify soil movement. A hand held MSL-48 battery operated mineralight was used for ultraviolet illumination (Figure 11). Downslope movement of particles was identified and measured. A comparison evaluation of movement was also recorded by rating sites on a scale of 1 to 10, based on a
Figure 10. Field application of fluorescent dye.

Figure 11. Illumination of fluorescent dye strips with hand held mineral lamp (Natural light is causing much of this illumination).
visual perception of movement. Each of the dye strips was photographed under ultraviolet light using a tripod and various film colors and types. Color and black and white prints and 100, 400 and 1600 ASA film were compared to determine which was most effective for use in photographic record.

Nails sprayed with fluorescent paint were used to indicate and locate particles downslope and allow measurement of distance moved in daylight conditions.

Analysis

Movement Rating

The soil movement occurring on dye plots was ranked from most to least, based on the number of individual soil particles moved and the distance moved downslope (soil-movement-rating).

The site variables distinguishing each plot were evaluated and trends relating degree of movement to particular site variables identified.

Photographic Record

The various films and photographic methods used were judged for effectiveness in capturing the fluorescence and in documenting movement.
Chapter 6
RESULTS AND DISCUSSION

EROSION TRANSECT STUDY

Site Evaluation

Trinity Valley #1

The cutblock selected is part of a progressive clearcut extending across the contour and upslope. Logging was done in the winter and this block contained windrowed slash. No slashburning had yet taken place. Older surrounding cuts had been burned and some areas had been planted.

Bedrock was close to the surface throughout the cutblock. Bare rock was visible in some areas and in others was covered by thin soil and ground vegetation (mainly herbs and mosses).

The average slope was 30-35% and 15% of the site was revegetated. There was little indication of erosion on the site although the spur road into the site was severely eroded and skid roads showed evidence of rilling (Figure 16 pg. 92).

Soil-disturbance and bare-soil values for TV #1 were 77% and 66% respectively (Table III). TV #1 had the highest value for soil disturbance classed as shallow-deposits (48.4%) (Table IV). With bedrock close to the surface there is less moisture storage capacity. Therefore, shallow soils
### TABLE III. OVERALL SITE CHARACTERISTICS FROM LINE TRANSECT DATA

<table>
<thead>
<tr>
<th></th>
<th>% Size</th>
<th>Slope Aspect (ha)</th>
<th>Dist Soil Disturbance</th>
<th>% Bare Soil</th>
<th>Soil Texture</th>
<th>Care** in Logging</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beetle Creek</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82-L-2-e(32) 1 27</td>
<td>SW 186</td>
<td>SW 186</td>
<td>26</td>
<td>22</td>
<td>f-s-loam</td>
<td>8.0 selective</td>
</tr>
<tr>
<td>82-L-2-e(20) 2 25 gen</td>
<td>NW 45</td>
<td>NW 45</td>
<td>29</td>
<td>24</td>
<td>g-s-loam</td>
<td>8.5 selective</td>
</tr>
<tr>
<td><strong>Deafies Creek</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82-L-7-d(25) 1 20</td>
<td>SW 17</td>
<td>SW 17</td>
<td>69</td>
<td>68</td>
<td>si-loam</td>
<td>4.0 clearcut</td>
</tr>
<tr>
<td>82-L-6-a(13) 2 25</td>
<td>SW 15</td>
<td>SW 15</td>
<td>67</td>
<td>62</td>
<td>si-loam</td>
<td>4.5 clearcut</td>
</tr>
<tr>
<td><strong>Trinity Valley</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82-L-7-d(45) 1 35</td>
<td>W 15</td>
<td>W 15</td>
<td>77</td>
<td>66</td>
<td>loam</td>
<td>5.0 clearcut</td>
</tr>
<tr>
<td>82-L-7-d(23) 2 45</td>
<td>SE 10*</td>
<td>SE 10*</td>
<td>50</td>
<td>46</td>
<td>loam-sl</td>
<td>9.0 clearcut</td>
</tr>
<tr>
<td><strong>Beaver Lake</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82-L-3-c(39) 1 10</td>
<td>S 16</td>
<td>S 16</td>
<td>44</td>
<td>44</td>
<td>si-loam</td>
<td>6.0 clearcut</td>
</tr>
<tr>
<td>82-L-3-c(34) 2 10</td>
<td>NW 12</td>
<td>NW 12</td>
<td>64</td>
<td>64</td>
<td>si-loam</td>
<td>4.0 clearcut</td>
</tr>
<tr>
<td>82-L-3-c(31) 3 8</td>
<td>SW 15</td>
<td>SW 15</td>
<td>37</td>
<td>28</td>
<td>si-loam</td>
<td>7.0 clearcut</td>
</tr>
<tr>
<td>82-L-3-c(53) 4A 50</td>
<td>SW 7.5</td>
<td>SW 7.5</td>
<td>60</td>
<td>43</td>
<td>si-loam</td>
<td>7.0 clearcut</td>
</tr>
<tr>
<td>82-L-3-c(53) 4B 20</td>
<td>SW 7.5</td>
<td>SW 7.5</td>
<td>53</td>
<td>28</td>
<td>si-loam</td>
<td>7.0 clearcut</td>
</tr>
</tbody>
</table>

* area traversed (approximately 25% of total cutblock area)

** subjective evaluation by crew supervisor

82-L-2-e Forest Cover Map Location (32) Cutblock number

*** % Dist (Soil disturbance) and % Bare Soil from Table IV.
have greater risk of becoming saturated during rainfall or snowmelt and yielding overland flow. There is an older clearcut located immediately upslope of TV #1 which may input sediment to the site.

Gray and Megahan (1981), in a study on similar textured shallow soils in the Idaho batholith, found that after burning there was a significant increase in surface erosion on previously stable sites. The burning upslope of TV #1 might increase sediment input from the upper clearcut.

The fact that this site was winter logged was reflected in lower values for deep-deposits and shallow and deep-gouging (8.4% & 9.5%) (Table IV). TV #1 had a high amount of disturbance (lowest no-disturbance value 23.2%). This is somewhat unexpected in view of the relatively coarse-textured soil and winter logging. The high disturbance value can likely be attributed to the low assessment of care-in-logging (5.0)(Table III) and to the fact that the site forms part of a progressive clearcut. Rothwell (1978) stated that progressive clearcuts maximize the potential for soil disturbance, overland flow, and erosion.

Slope gradient becomes increasingly important as vegetative cover is reduced (Meeuwig and Packer 1976). TV #1 had less cover than TV #2, therefore soil movement might be expected to be greater, as was shown.
TABLE IV. LINE TRANSECT DATA

Soil disturbance classes for study (percentage of cutblock area)

<table>
<thead>
<tr>
<th>Disturbance Class</th>
<th>Trinity Valley</th>
<th>Deafies Creek</th>
<th>Beetle Creek</th>
<th>Beaver Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>No disturbance</td>
<td>23.2</td>
<td>45.1</td>
<td>30.9</td>
<td>33.3</td>
</tr>
<tr>
<td>Natural bare soil</td>
<td>/</td>
<td>3.5</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Bare soil</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Shallow gouge</td>
<td>6.3</td>
<td>4.4</td>
<td>9.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Very deep gouge</td>
<td>3.2</td>
<td>3.5</td>
<td>4.8</td>
<td>6.5</td>
</tr>
<tr>
<td>Shallow deposit</td>
<td>48.4</td>
<td>23.9</td>
<td>32.1</td>
<td>32.3</td>
</tr>
<tr>
<td>Very deep deposit</td>
<td>8.4</td>
<td>10.6</td>
<td>21.4</td>
<td>16.0</td>
</tr>
<tr>
<td>Litter &amp; slash</td>
<td>10.5</td>
<td>8.0</td>
<td>1.2</td>
<td>4.3</td>
</tr>
</tbody>
</table>

% Bare Soil
66.3 45.9 67.8 62.3 22.1 24.2 44.0 63.6 27.6 43.2 27.9

% Disturbance
76.8 50.4 69.0 66.6 26.0 29.2 44.0 63.6 36.8 60.2 52.9
Trinity Valley #2

This cutblock was relatively steep (45% average slope) and care in logging was rated high. Patches of advanced regeneration were left undisturbed and skid roads generally ran parallel to contours. Skidder use was confined to the skid roads and the steeper skid roads were "put-to-bed" with water bars (soil mounds) established at intervals along their length.

No streams crossed the block and little erosion or rilling occurred on the block. This was influenced at least in part by the moderately coarse soils (loam-sandy loam texture).

TV #2 had values for disturbance and bare soil of 50% and 46%. It was one of the steepest sites, yet also one of the most stable, reflected in disturbance values (high no-disturbance value 45.1%) and care in logging (9) assessment. In a ground based skidding operation on steep slopes, safety and operational constraints limit skidder movement to established skid roads. This results in a reduction in disturbance between the skid roads and, on a cutblock basis, less area will be disturbed.

TV #2 had a higher proportion of disturbance classed as deposits than as gouges. It has a coarse textured soil and was therefore more resistant to gouging, especially when compacted on a skid trail.
The water bars established on TV #2 diverted runoff onto the undisturbed cutover. This prevented accumulation of runoff on skid roads and landings (Rothwell 1978).

**Deafies Creek #1**

This small cutblock was oriented perpendicular to the contours. There were few defined skid trails and skidder tracks disturbed much of the area with very deep gouges and deposits. Most damage occurred on moderate slopes where skidder movement was unconfined. The road system was rilled although culverts were established and flow through them was occurring. The overall drainage in the road system was insufficient, mainly due to the road switchbacks which intercepted subsurface flow.

Overall site evaluation indicated a moderate amount of erosion on site. Much of the sediment input to Deafies Creek would originate on the road system.

DC #1 had high disturbance and bare-soil values, 69% and 68% respectively. Thirty-two percent of the site was under shallow-deposit and 21% deep-deposit (Table IV). These values are quite high. It is likely that soil eroded from the road system and from skidder disturbance on the cutblock supplied much of this sediment. The gentle slopes at the base of the cutblock served as a deposition zone for sediment from upslope and allowed the build-up of deep deposits.
The low values for gouging on this site may reflect the presence of sheet erosion rather than indicating that no gouging took place. If overland flow was occurring, especially with the erodibility of the silt loam soil onsite, shallow gouges would be obliterated.

The low care-in-logging value (4) (Table III), reflected the unconfined skidder movement and lack of drainage on the road system. Erosion and damage to water quality is greatly reduced by providing effective drainage of skid trails and skid roads to eliminate concentration of overland flow (Meeuwig and Packer 1976).

Deafies Creek #2

This small cutblock was oriented perpendicular to the contours and was mostly gently sloped. A small creek ran through the center of the cutblock draining into Coldstream Creek. Much of the lowlands (20-25%) was marshy, resulting in deep ruts from skidder movement. The creek was diverted because of channel disturbance. The roads in the area exhibited moderate rilling.

The major disturbance was in the marshy lowlands but erosion there was limited because of low slopes. Much of the cutblock (aside from roads and landings) was revegetated with herbs and forbs.

DC #2 had 67% disturbance and a low assessment of care-in-logging (4.5). There were significant shallow and deep-
deposits (32% and 16%). The high disturbance from skidder movement in the lowlands would supply sediment. Deafies Creek sites had high gouging in comparison with many of the other plots. This resulted, in part, from the finer silt loam soils on site and the fact that it was summer logged (Schwab and Watt 1981).

The high amount of disturbance in the lowlands and in the diversion of the creek channel did not appear to be actively eroding as overland flow was limited by low slope angles. It is likely, however, that spring runoff will move much of this sediment and incorporate it into the sediment load of the stream. Rothwell (1978) identified skidding along or across creek bottoms or draws as a cause of erosion and deterioration of water quality.

**Beetle Creek #1**

This large cutblock was selectively logged. Little site disturbance occurred and only slight soil movement occurred on skid trails. This minor damage was confined to fairly steep slopes (greater than 30%) with gouges (and rills) on short lengths of trail. Most skid trails were put to bed before the landing at the base of the slope. The soils are fairly coarse (fine sandy loam), promoting infiltration and resisting compaction.

This cutblock had low disturbance (72% no-disturbance), as expected on a selectively logged site. The only
significant disturbance value was 6% shallow-gouging onsite which likely reflected the rills developing on some skidroads.

B.C. #1 was the only site recording a bare-soil class (6.3%) which reflected a mixture of mineral soil and humus. This might represent, at a lower intensity, the process which forms the shallow-deposits on other sites. With little movement onsite, this bare soil can remain stable, while on more active sites it would evolve to form shallow deposits or shallow gouges.

The existence of bare soil might also result from the difficulty in revegetating southwest slopes in the Dry Interior Region (Clement 1981). The more northerly aspect of #2 might allow similar areas to establish vegetative cover.

Beetle Creek #2

This large cross contour cutblock was harvested using shelterwood and seed tree methods. A few old skid trails ran up natural gullies and concentrated surface drainage. Although some skid trails were established straight upslope with no diversion of overland flow, little erosion was occurring. The soils were relatively coarse textured (gravelly sandy loam). The identified erosion was associated with the road and its drainage (culverts).

There was very little gouging on this site (1%) which
reflected care-in-logging (8.5), selection logging methods, and coarse textured soils, which all minimize disturbance levels.

**Beaver Lake #1**

This was a small strip clearcut, part of an older, very large progressive clearcut. High water table and clay soils in a portion of the cutblock caused some problems with rutting, drainage and blowdown. The drainage channels were somewhat obscure and were crossed several times by skidders. Much of the area had revegetated with moss and grass. Cattle movement had compacted and potted portions of the cutblock.

The low disturbance value may reflect, in part, revegetation which occurred on the wetter sections. Hills (1971) indicated pockets formed by hoofprints may increase surface storage on site which would limit overland flow and reduce disturbance.

**Beaver Lake #2**

This cutblock was cut, in part, with a feller buncher and some hand falling. The mechanized harvesting caused severe soil disturbance over much of the block. Most of the erosion occurred on less steep slopes accessed by the feller buncher. Though the soil was highly disturbed, little evidence of erosion was observed.

BL #2 has the highest shallow-gouge incidence (19%). This likely resulted from mechanized harvesting on a silt
loam soil. The weight of machinery, unconfined skidder movement on the shallow slopes and the movement of logs could cause this.

Northwest slopes in the Dry Interior climatic zone have more revegetation due to increased moisture availability. The higher levels of disturbance on this slope may be stabilized with vegetation and the low slope angle will limit erosion by overland flow.

**Beaver Lake #3**

This relatively flat cutblock had limited disturbance. Lack of drainage culverts on the haul road system accessing this site caused severe rilling and partial road collapse. The area below the road system was more disturbed with less revegetation but erosion was still low.

Sixty percent of this cutblock had no-disturbance. The disturbance which did occur was on the cutblock surface below the actively eroding road system. The higher disturbance and lower revegetation below the road likely resulted from increased overland flow and sediment input from upslope.

**Beaver Lake #4A**

This small clearcut was cut in winter and rises steeply from the landing. Significant accumulations of slash were left onsite and skidders were confined to established trails. Sidecuts of skid trails and the entire skid trail
and road system exhibited erosion but the rest of the cut was stable.

Even with significant erosion occurring, 38% had no-disturbance. This is a result of skidder movement being confined to trails. The high value for shallow-deposits (23.9%) likely resulted from erosion on skid roads. The high amounts of slash left from winter logging would trap sediment and increase the deposition.

The amount of shallow-gouging was fairly high (11.5%) and likely reflected the rills forming on skid trails. The value for deep-gouging was low, as expected in winter logging.

**Beaver Lake #4B**

This cutblock was upslope from #4A and was a gently sloping plateau. Much of the area had poor drainage (swamp). Significant ground cover vegetation was left and winter logging minimized disturbance leaving a fairly stable site.

BL #4B had twice as much soil disturbance as bare-soil classes (53% vs 28%). This is indicative of winter logging and the protection of the snow cover during operations. It also had little gouging. Deep disturbance in the form of gouging is greatest in summer logging and deposits form a greater proportion of total disturbance in winter (Schwab and Watt 1981).
Comparison Among Sites

Observation and site evaluation indicates that the major disturbance factor within a cutblock was random skidding. However, soil disturbance values did not necessarily correlate with erosion occurrence. It was shown that disturbance on gentle slopes caused little erosion (BL #2). This is likely due to lack of overland flow as a transport agent, therefore the second step of the erosion cycle was limiting.

High slope angles, especially in fine-textured soils, showed significant erosion (BL #4A). On coarser textured soils, where skid roads were put-to-bed, erosion rates on clearcuts were low (TV #2). The density of skid trails was generally correlated with increased erosion, especially if roads were located across the contours and allowed to channel flow.

Logging in high moisture areas can cause severe disturbance. The high disturbance values of DC #2 and BL #2 illustrate this. Disturbance in creek beds will likely directly increase sediment levels, especially in storm and snowmelt runoff. The lower disturbance values for BL #4B, a high moisture site, illustrates a management option, winter logged, that reduces site impact.

Many of the cutblocks limit sediment movement from the cutblock by leaving buffer strips of forest vegetation along stream channels. This appeared to be successful and
deposition of sediment on ground vegetation at the edge of the strip (personal observation in DC #1) showed its role in slowing overland flow and capturing sediment.

Much of the erosion comes directly from the road system as evidenced by deep rilling and roadbed failure (BL #3 and DC #1). Skid trails on cutblocks were also erosion sites (see discussion of fluorescent dye erosion plots).

The selectively logged sites showed little, if any, erosion. This can be attributed to preservation of vegetation cover, coarse textured soils which resist compaction and promote infiltration, and minimal site disturbance. It is expected (as per Rothacher 1965) that maintaining vegetation will reduce erosion. The Beetle Creek sites illustrated this. Evaluation of BL #4 also supports this statement. Although erosion rates were high, the erosion was taking place on the skid trails not the actual cutover. Preservation of ground vegetation (in winter logging) and leaving slash on the site is believed to have stabilized this area.

The relationship between slope and the various disturbance classes for clearcut sites varies (Figure 12). The shallow-deposit class was shown to increase in percentage with increasing slope (Figure 13) although neither were statistically significant. Identification of those sites which lie below the regression line (Figure 13), indicated that sites with lower care-in-logging have higher shallow-deposits on an equal slope.
Figure 12. Distribution (cutblock area) of disturbance classes (shallow + deep gouge, shallow + deep deposit) with increasing slope on clearcut sites.

Figure 13. Distribution of shallow deposit disturbance class with increasing slope.
Steeper slopes require increased care in logging (Figure 14). This trend, although not statistically significant, was also reported by Schwab and Watt (1981) who attributed it to the physical and safety constraints which limit skidder movement in operation on steep slopes. Below 35% slope the relationship between care-in-logging and slope varied. When evaluated as a group, selective sites, winter-logged sites and those sites steeper than 35% showed high care-in-logging.

At a given slope, those sites with coarser soils have less disturbance and lower bare-soil percentage than those with fine soils (Figure 15). Beaver Lake 4A presents an anomaly to the above trend. It had steep slopes but lower soil disturbance and bare soil percentage than the other fine soil plots. This is likely explained by the fact that Beaver Lake 4 was winter logged. It may also be influenced by the organic matter content of the soil.

Table V shows average values of proportion distribution among disturbance classes for this study and compares this with other studies reported in the literature. Such a comparison must be evaluated with care, as site variability and differences in definition of disturbance class will affect values. The mean no-disturbance value of 46.2% (range of 23 to 59) was lower than values of Schwab and Watt (1981) (55.9%) but of similar magnitude. Schwabb and Watt (1981) established line transects on harvested sites in the Cariboo Forest Region of British Columbia. Their study most
Figure 14. Assessment of care-in-logging variation with increasing slope.

Figure 15. Distribution of bare soil and soil disturbance values with increasing slope.
closely replicated the present study. The values of Bockheim et al. (1975) were considerably lower (12.5%). Total area of disturbance was 65% in this study and 62.6% in the study by Schwabb and Watt. The value of Bockheim et al. was 87.5%. Shallow-disturbance was greater in this study and deep-disturbance less than those reported in the literature. The close agreement with total disturbance values of Schwabb and Watt and the lack of soil disturbance classed as deep-deposit in the present study, suggested some variation in estimating depth of disturbance, particularly in shallow-deposits. Bockheim et al. presented average values from studies in the United States utilizing a similar method. The range of values was large but overall averages were lower than those of the British Columbian studies (Table V).
### TABLE V. Comparison of soil disturbance class distribution found in present study and from other regions as reported in the literature

<table>
<thead>
<tr>
<th>Disturbance Class</th>
<th>Present Study %</th>
<th>Schwab &amp; Watt*</th>
<th>Bockheim et al.**</th>
<th>Avg. values+ in literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>No disturbance</td>
<td>46.2 ++</td>
<td>55.9</td>
<td>72.5</td>
<td>/</td>
</tr>
<tr>
<td>Shallow gouge %</td>
<td>39.4</td>
<td>16.3</td>
<td>11</td>
<td>12.2</td>
</tr>
<tr>
<td>Shallow deposit %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep Gouge %</td>
<td>15.6</td>
<td>27.8</td>
<td>58.5</td>
<td>24.5</td>
</tr>
<tr>
<td>Deep Deposit %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total soil Disturbance</td>
<td>65</td>
<td>62.6</td>
<td>87.5</td>
<td>50</td>
</tr>
</tbody>
</table>

++ Data are averaged and are presented as a percent of land area.

* Schwab and Watt (1981) Cariboo Forest Region, B. C.

** Bockheim et al. (1975) Vancouver Forest District, B.C.

+ averages from data in literature and presented in Bockheim et al. (1975)

Garrison and Rummell (1951) Eastern Oregon & Washington
Woolridge (1960) North Central Washington
Dyrness (1965) South Central Oregon
FLUORESCENT DYE EROSION STUDY

Movement Ratings - Site

Trinity Valley #1

TV #1 had a medium-textured soil (loam) and moderate (15-35%) slopes. North aspects had higher soil-movement ratings (average rating 2.9) (Table VI) than south aspects (avg. 2.2), although slope was the same. This agreed with Hart (1984) who found that higher antecedent moisture levels on northfacing slopes had a strong effect on surface erosion rates.

To evaluate slope position, plots were located in a series downslope on the same cutblock. The three sets of plots all showed increasing soil-movement-ratings from the upper plot in the series to the plot furthest downslope. This may indicate lower slope positions contribute more sediment to the erosion process or that sediment deposited on the lower slope is more easily moved. Such results are expected because as overland flow is channelled and flows downslope, its depth and ability to detach and transport particles increases.

Trinity Valley #2

TV #2 had a coarse textured (loam-sandy loam) soil and slopes of 10-32% above the plots. Movement ratings were quite uniform over the block. Average slope was higher on south aspects than on north (28% vs. 23%) but soil-movement
TABLE VI. FLUORESCENT DYE PLOT CHARACTERISTICS AND SOIL-MOVEMENT-RATINGS

DYE PLOT DATA

<table>
<thead>
<tr>
<th>TRINITY VALLEY #1</th>
<th>TRINITY VALLEY #2</th>
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<tbody>
<tr>
<td>Aspect Slope</td>
<td>SMR</td>
</tr>
<tr>
<td>%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>N27W -</td>
</tr>
<tr>
<td>2</td>
<td>N63W u</td>
</tr>
<tr>
<td>3</td>
<td>N31W u</td>
</tr>
<tr>
<td>4</td>
<td>S70W -</td>
</tr>
<tr>
<td>5</td>
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<td>7</td>
<td>N06W -</td>
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<td>8</td>
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</tr>
<tr>
<td>9</td>
<td>N45W d</td>
</tr>
<tr>
<td>10</td>
<td>N35W d</td>
</tr>
<tr>
<td>11</td>
<td>S66W -</td>
</tr>
<tr>
<td>avg. 25.6</td>
<td>2.6</td>
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</table>

<table>
<thead>
<tr>
<th>BEAVER LAKE #1</th>
<th>BEAVER LAKE #4A</th>
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</thead>
<tbody>
<tr>
<td>Aspect Slope</td>
<td>SMR</td>
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<tr>
<td>%</td>
<td></td>
</tr>
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<td>1</td>
<td>S20W -</td>
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<td>2</td>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
<td>S80E -</td>
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<td>5</td>
<td>S80E u</td>
</tr>
<tr>
<td>6</td>
<td>S -</td>
</tr>
<tr>
<td>avg. 21.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

- no relation to previous plot location
- u located upslope from preceding plot
- d located downslope from preceding plot

SMR  Soil-movement-rating
ratings were the same (2.4 vs. 2.3) (Table VI). The rate of movement on the cutslope was the same as that on the skidroads. It would be expected that lower cutslope compaction would limit overland flow and hence soil movement. In this study the coarse soils required significant overland flow or rainfall intensity to move soil particles. The establishment of waterbars prevented channelling of overland flow and the coarse soils promoted infiltration so it is unlikely overland flow occurred with sufficient erosion potential to move much soil.

Plot 14, with a soil movement rating of 2.0 on a level surface, indicated rainsplash erosion played a dominant role in the erosion process on site. This was expected, as summer rains are usually high intensity thunderstorms that can cause severe erosion problems (Clement 1981, Helvey and Fowler 1979).

Beaver Lake #1

BL #1 was a fine textured (silt loam), less steep (5-30% slopes), south facing cutblock. Little movement was observed and the main disturbance factor was rainsplash and some trampling by cattle.

The soil movement rating for plot 1 on the cutslope was higher than the adjacent plot on the skid road. This may result from animal browsing or a looser soil surface on the uncompacted cutslope, allowing easier movement by raindrops.
Beaver Lake #4A

BL #4A was a fine textured (silt loam), relatively steep (20-40% slope) cutblock and dye plots were generally on northern aspects. This site had the highest soil movement ratings in the study. Plots 1 and 2 were severely disturbed both by overland flow and vehicle tracks (Figure 17). Soil movement ratings on all skid road plots were high but the cutover value was low. This dye plot on the cutover surface had the steepest slope (40%) on the site with highest soil movement ratings, yet its soil movement rating was only 2 (comparable to a level plot in TV #2). Young and Mutchler (1969) on a South Dakota site with a silt loam soil found that soil loss from a slope depended on steepness of a short segment immediately above point of measurement. The cutover plot indicates that on harvested sites the disturbance factor was more important than slope alone. Bockheim et al. (1975) concluded that exposed mineral soil is likely the best index of harvesting disturbance and hence erosion susceptibility and forest regeneration potential. Results from this study indicated degree of slope may be more important in comparing soil movement of plots located on skid roads but disturbance values were more significant when comparing cutover surface to skidroads.
Comparison of Movement Ratings Among Sites

Beaver Lake #4 had the highest average soil-movement-rating (4.7) and Beaver Lake #1 had the lowest (1.3). Trinity Valley #1 (2.6) had more movement than #2 (2.3) (Table VI). In general, northfacing slopes appear to have more movement (3.3) than southfacing slopes (2.0) and areas on cutovers (2.1) had less movement than plots on adjacent skidroads (2.9).

Sixty-seven percent (8/12) of plots on slopes 30% or more had soil-movement-ratings of 3 or greater. Those four plots with ratings less than 3 were on the more stable cutblocks and had SW or SE aspects. Fourteen plots had a rating greater than or equal to 3 and all of these plots were located on skid trails. Only three of these plots were on SW or SE aspects. The soil-movement-ratings for plots located on the cutslope beside skid trails were all 3 or less though slopes ranged from 25-40%.

Fourteen sets of dye plots were established. These were groups of two or three plots in which one plot was located downslope of another. None of the soil movement ratings for these sets decreased from the upslope plot downslope to the next plot(s). Those sets of plots with no change in soil movement rating downslope were located on TV #2 and BL #1 the more stable sites.

The relationship of increasing soil movement ratings with increasing slope (Figure 18) was based on observations of the fluorescent dye line. The lower slope of the
Figure 16. Rilling on skid road in Trinity Valley #1.

Figure 17. Vehicle disturbance on skid road, Beaver Lake #4A. Nail (beside stone) locates dye plot.
regression line for skid trail plots indicated that movement on skid trails increased at a greater rate with increasing slope. This was expected because compaction of the skid trails can increase overland flow which is very dependent on slope length (regression is significant at the 85% level).

Fowler and Berndt (1969), in a similar study in northeast Oregon, found surface water released by snowmelt was the major cause of soil movement. Dye plots in the present study were established at the end of the summer so most of the movement was attributable to snowmelt runoff. Although measurements from the fall of 1985 would be necessary to determine the movement as a result of summer storms the results indicated significant movement with snowmelt. The snowpack was likely greater on the Beaver Lake sites (higher elevations). The sites were still snow covered in April when measurement of dye plots was completed on Trinity Valley sites. This increased depth and duration of snowpack may influence the high erosion ratings on BL #4A.

Bethlahmy (1967) found in Idaho that runoff and erosion were greater on southwest than on northeast exposures, the opposite of the results of this study. This is easily explained when site characteristics are identified. In his study, southwest facing plots averaged 41.9% bare ground while northeast plots averaged only 2.7%. He also hypothesized that if northeast and southwest exposures were equally bare, overland flow would be equal.
Figure 18. Changes in soil-movement ratings with increasing slope.

Statistics:

'All' regression is significant at 90% confidence level
\[ r^2 = 0.88 \]

'Skid' regression is significant at 85% confidence level
\[ r^2 = 0.76 \]
In the present study, skid trails were equally bare independent of aspect. Increased soil movement on northfacing slopes was not unexpected. If infiltration rates are similar, and it is likely skidroads are fairly uniformly compacted, antecedent moisture levels will be greater on northern exposures because of reduced solar radiation input. With less storage, overland flow will occur sooner on northfacing slopes causing greater amounts of movement.

Some general trends evidenced by this study (recognizing the small sample size and high variability of sites) are:

- steeper slopes lead to higher rates of soil movement
- skidroads have more erosion than cutslopes
- northwest and northeast aspects have more soil movement than southern aspects
- silt loams generally have increased movements when compared with sandy loams, especially at higher slope angles.
- rainsplash appears to be a significant erosion agent (evidenced by rating on TV #2 plot 14).
Photographic Record of Beaver Lake #4A

Photographs provide a visual record of the fluorescent dye plots. Figure 19 records the illumination of the dye strip by ultraviolet light. This plot was located on a skid road disturbed by vehicle tracks and shown in Figure 17. The left portion of the dye strip was disturbed by tire tracks and some dyed particles were removed from the site.

Figure 20 illustrates daytime visibility of the Day Glo pigment. The normal color had degraded over the winter but was still easily visible, especially when concentrated in the dye strip. The fluorescent color appeared unchanged over the study period.

Figures 21 and 22 show daylight and ultraviolet photographs of the same plot. Overland flow is occurring on the dye strip (from melting snow) but particles remain visible through the thin sheet of water. Marking downslope movement with nails coated with fluorescent spray paint is useful to locate particles for photography. It is also useful when the sediment load of the water reduces light penetration and fluorescing particles would not be easily seen on a photo.
Figure 19. Fluorescent illumination of Beaver Lake #4A Plot 2 illustrating downslope movement of particles.

Figure 20. Beaver Lake #4 Plot 4 illustrating active erosion (on left of photo).
Figure 21. BL #4A P1 3
Sediment deposition from overland flow. Nails on right side indicate particle movement (Fig. 22).

Figure 22. Ultraviolet illumination of BL #4A P 3
Much of plot is under water. Light color of the water reflects sediment load.
These photos illustrate the illumination and the movement of soil particles on the dye plots. Although photography is not required to obtain soil movement ratings, photos can be useful records of site processes and allow later comparison among plots.
Addressing the Project Unknowns

In outlining the fluorescent dye method a list of project unknowns was listed (Page 62). The factors are discussed here based on results of the fluorescent dye plots and on observations made during the study period.

The persistence of Day-Glo pigment was fully satisfactory nine months after application. It was stable in sunlight and also through winter freezing and under the snowpack. The choice of acetone as the vehicle for solution provided excellent adherence. The application was a thin layer which had little impact on size or density of soil particles (site observations and Zoghet 1969). A hand held ultraviolet lamp provided ample strength of ultraviolet illumination, although the use of more than one lamp would illuminate more area, giving a better photographic record.

Black and white photography effectively showed ground surface roughness and soil particles but was insufficient in daylight or night evaluation of fluorescence. Color photography was found to be most suitable. The high speed (1600 ASA) film was unnecessary and resulted in overexposure or a coarse-grained photo. The resolution and clarity of 400 ASA was found to be suitable. Photos were taken on a tripod at a height of 0.5 metres with a 30-60 second exposure time. Particles visible by eye were generally easily captured on film, provided that the position of the ultraviolet lamp for photography illuminated that portion.
The ultraviolet lamp illuminated fluorescent particles under flowing water and even through a thin snow cover.

The width of the dye strip was constant on all sites and provided a term of reference for comparison between photos but the inclusion of a fluorescent ruler on the edge of the photo would aid evaluation.

The major limitation to direct application of fluorescent pigment to the soil was the large amount of very small soil particles and organic matter which accepted the dye and was fully illuminated by the ultraviolet lamp. The large numbers of particles precluded a quantitative estimate of the number of particles moved. It is likely necessary to excavate a soil sample and sieve to various sizes of particles. The small organics could then be excluded from dye application and other particle sizes could be color stratified to allow size-velocity relationships (particle size-overland flow velocity) to be documented. This excavation would disturb the soil surface but dye application could then coat the entire particle preventing "loss" of particles because the fluorescent tag is turned to the underside of the particle.
Chapter 7

SUMMARY AND CONCLUSIONS

SUMMARY

Erosion Transects

Site characteristics influencing surface soil movement on harvested areas in the North Okanagan were identified by line transect data. Slope was an important characteristic. On gentle slopes high disturbance levels caused little erosion. On steep slopes, especially finer textured silt loams, significant erosion was taking place. The major erosion sites were not the harvested land itself but rather skid trails and roads built to extract the timber. Some harvesting operations on steeper slopes successfully controlled erosion by installation of water bars (TV #2). Another significant factor limiting erosion was "care-in-logging." This factor correlated well with Rothwell's (1977) identification of careful planning as the major component in road construction to minimize water quality deterioration.

Some trends in the results appear evident although of little statistical significance. The area under shallow deposits increased with increasing slope. Sites with lower care-in-logging values had higher amounts of soil deposits which may result from overland flow and deposition onsite.
Northern aspects, steep slopes and finer soils were identified as having higher erosion rates on skid trails. The cutover surface had less soil disturbance and erosion rates were low.

Coarser sandy loam soils showed less disturbance than finer silt loams on similar slopes. High moisture sites were susceptible to deep gouging and high soil disturbance although low slope angles often limited erosion.

Disturbance levels in clearcuts varied greatly but progressive clearcuts appeared to have more soil movement than other sites while selection harvesting had the least disturbance.

Fluorescent Dye Plots

The fluorescent dye plots yielded information on the erosion process occurring on the slope. Soil movement ratings were higher on steeper slopes and on northfacing slopes. The relationship between soil-movement-rating and slope was linear showing higher ratings on steeper slopes.

The movement of the tagged particles was indicative of erosion processes occurring on the site. Rainsplash erosion occurred at all locations. Overland flow also caused erosion especially on steeper slopes and on fine soils.
Fluorescent Dye Method Evaluation

The fluorescent dye application was stable under climatic conditions of the study area for at least nine months. As little degradation of fluorescence was noted, it is likely persistence is considerably longer than nine months. The application of Day-Glo fluorescent pigment in acetone thinly coated the surface with little impact on size, density or texture of particles and gave stable adherence of the dye to soil particles. The fluorescence was easily visible with a hand held ultraviolet mineral lamp.

Although some modifications were suggested, this method for application of fluorescent dye to index soil movement was recommended. Spraying dye on soil in situ tagged very fine organic and soil particles which "clutter" the field of view under ultraviolet illumination and make measurement difficult. To quantify movement and determine particle-size relationships the extraction of a surface soil sample and sieving to size classes was recommended.
CONCLUSIONS

Surface Erosion

Surface erosion is an active process on the forest land base of the North Okanagan. The major sites of erosion are skid trails and the road system constructed in harvesting operations. The data collected in this study confirmed the general consensus of research results recorded in the literature.

The trends in soil movement on the study sites showed:
- slope is a significant component in erosion on disturbed sites.
- erosion is much higher on skid trails than on the surface of the cutover.
- more erosion occurs on fine, silt loam textured soils than on loams and sandy loams.
- soil movement increases downslope.
- water bars are effective in limiting soil movement on skid roads.
- selection logging practices cause less erosion than clearcutting.
- it is the road system, not the actual cutover surface, which has the highest erosion.
Fluorescent Dye

Day-Glo fluorescent pigment in solution with acetone is useful as a soil tag. Such labelling of soil particles does not significantly alter physical properties of the particles, is stable under sunlight and persists for at least nine months.

Using normal color film and an ultraviolet mineral lamp for illumination, a photographic record of fluorescence can be obtained.

Excavation and sieving of particles is recommended on forest harvested sites to reduce the large numbers of very fine materials (largely organic matter) which clutter the downslope viewing field and makes quantification of soil movement difficult.

Fluorescent dye is an inexpensive, easy-to-apply soil tag which effectively illustrates soil movement and allows rates of soil movement, sources of eroding material and pathways of movement to be observed.

Soil movement on actual cutovers in this region is relatively low, indicating little loss of productive potential from surface erosion of this soil. The erosion process was most active on skid roads, access roads, and landings, all site disturbances resulting from the harvesting system. On many sites, harvesting operations resulted in significant soil movement. It was shown that
with high care in logging steep sites can be harvested with little impact on the soil movement process onsite if proper planning and skid road maintenance is completed.

Soil movement is not necessarily indicative of sediment levels in area streams. The proximity of stream courses to the cutblocks and the drainage channels established will influence this. Although a detailed stream course evaluation was not completed, it was noted that runoff from some cutblocks flowed directly into a stream. In a region with high water values and a need for high quality water to satisfy the needs of downstream users, such indicators of erosion should initiate action to stabilize the soil surface.

Selection logging methods promote surface soil stability. They are, however, not universally applicable. Much of the forest in this region will be clearcut harvested for both economic and silvicultural reasons. Modification of size and shape of clearcuts, and care in site preparation and road location can reduce disturbance levels. Such clearcut harvesting methods still have potential to adversely influence soil stability but proper planning, and careful logging and road construction can reduce this impact and maintain soil stability.
Chapter 8
RECOMMENDATIONS

Some modifications to the fluorescent dye methods used in the study are recommended. This method for fluorescent dye application might follow the steps listed below:
1) excavate soil upslope and sieve into desired size classes. Each class can be sprayed with a different Day-Glo pigment in solution with acetone. Different slope locations can also be color-stratified.
2) replace the extracted soil and attempt to recreate former conditions.
3) monitor downslope movement with a hand-held mineral light.
4) photograph fluorescence.
5) quantify movement downslope and location of particles (especially medium and larger sizes) by marking with color coded nails. In daylight a sketch of movement pathways and distances downslope can be obtained.

Forest Management Uses

The ease of application and relatively low cost of fluorescent dye methods support their use in erosion assessment of roads and skid trails. Much of the erosion on roads begins as shallow sheetflow. Although sheetflow is capable of transporting sediment, the erosion problem is minor until the flow is channelled and rilling and gullying
take place. On roads, if rills are identified early in their formation and the overland flow pattern disrupted, erosional impact can be reduced. Spraying fluorescent dye on cut and fill slopes and on parts of the actual road surface would illustrate movement occurring before significant rilling had taken place and allow use of simple, inexpensive measures to stabilize the surface. Although night illumination is necessary for quantitative results, Day-Glo pigment is easily visible in daylight and acts as an extra bright normal color dye to tag particles. This means that much of the monitoring would require no night-time illumination.

An interesting and useful follow-up to this study would be to revisit the study sites and evaluate persistence of fluorescence and soil movement after two to three years. This would yield necessary data on persistence and stability of this fluorescent dye under local climatic conditions.
LITERATURE CITED


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--- 1984. personal communication.


APPENDIX A

PROPERTIES OF DAY-GLO FLUORESCENT PIGMENT

COLORS

<table>
<thead>
<tr>
<th>Color</th>
<th>A</th>
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PHYSICAL PROPERTIES AND CHEMICAL NATURE

Specific Gravity: 1.36
Average Particle Size (microns): 3.5 - 4.0
Softening Point: 115-120°C.
Decomposition Point: 195°C.
Oil Absorption (g/100g pigment): 47

TOXICITY

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<th>A.</th>
<th>AX</th>
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