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FISHERIES RESEARCH INSTITUTE
College of Fisheries
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Seattle, Washington 98195

OBSERVATIONS ON THE EFFECTS OF LANDSLIDE SILTATION ON SALMON AND TROUT RESOURCES OF THE CLEARWATER RIVER, JEFFERSON COUNTY, WASHINGTON, 1972-73

by

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and
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FINAL REPORT, PART I
with a supplemental report by Allen J. Fiksdal,
Washington State Department of Natural Resources

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ABSTRACT

Field investigation of the effects of logging operation-induced landslides on the composition of salmonid spawning gravel, stability of the streambed, concentrations of suspended sediment, populations of fish, and abundance of benthic fauna in Stequaleho Creek and the Clearwater River were carried out during 1972-73.

In Stequaleho Creek and the Clearwater River those gravel areas suitable for spawning downstream of the landslides were found to have significantly greater percentages of the less than 3.36 mm and 0.841 mm fines than the upstream control gravels. However, a high degree of gravel flushing since the landslides was evidenced by the relatively low levels in Stequaleho Creek. Cutthroat trout eggs planted in landslide-affected and -unaffected parts of Stequaleho Creek showed no difference in intragravel survival from eyed egg to hatch. Cross-sectional surveys of the lower Stequaleho streambed detected general streambed instability which may or may not be man-caused. Suspended sediment samples taken from various tributaries in the winter of 1971-72 showed Stequaleho Creek to have the highest sediment levels in most cases. The Yahoo Lake landslide caused additional turbidity in lower Stequaleho Creek occasionally during the summer of 1972.

Juvenile coho salmon and steelhead trout rearing densities were small in lower Stequaleho Creek when compared to densities in the upper Clearwater River during the summer of 1972. Resident cutthroat trout are quite numerous in upper Stequaleho Creek.

The populations of benthic organisms were significantly (1% level) lower in landslide-affected areas of Stequaleho Creek compared to landslide-unaffected areas. However, no significant difference (1% or 5% levels) existed for the Clearwater River above and below the mouth of Stequaleho Creek. When all stations were considered together, strong inverse correlation (June, $r = -0.85$; July and August, $r = -0.95$) was found between mean numbers of total insects per square foot per station and the percentage of sediment less than 0.841 mm in diameter, implying a reduction in the available living space for benthic organisms.

ACKNOWLEDGMENTS

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Mrs. Bette Tuttle (Department of Natural Resources, Forks) and her assistants typed many drafts of this paper.

LIST OF PLATES

INTRODUCTION

In early May 1971, two massive landslides occurred in the watershed of Stequaleho Creek from the failure of sidecast material from logging roads (*see* Plates 1, 2, 3, and 4). Stequaleho Creek is a tributary of the Clearwater River, Jefferson County, Washington (Fig. 1). The creek falls within the Clearwater River Forest management block, under the stewardship of the Washington State Department of Natural Resources (DNR). The slides caused siltation in Stequaleho Creek, as well as in the Clearwater River. According to Wooldridge (personal communication) these landslides occurred at the end of the winter rainy season during a period when the stream was in a receding stage which minimized the flushing action. Surveys made by the Washington State Department of Fisheries on July 7, 20, and 27, 1971 (Deschamps, 1971) showed that the siltation affected the abundance of fish food organisms and covered salmonid spawning beds in Stequaleho Creek and the lower Clearwater River.

During December 1971, the Fisheries Research Institute (FRI) of the University of Washington's College of Fisheries entered into a cooperative research study of the area with the College of Forest Resources (CFR), University of Washington. The project was funded by the Washington State Department of Natural Resources and scheduled to begin January 1, 1972 and terminate June 30, 1973. Its main emphasis was to document the effect of sedimentation from the May 1971 landslides on the Stequaleho Creek fishery resources. Comparative studies were to be conducted in adjacent tributaries and the main Clearwater River since there were no data available on Stequaleho Creek and its fishery resources prior to the landslides.

The criteria used in selecting study tributaries included stream slope, discharge, substrates, fish populations and temperatures.

The following objectives guided this research:

1) Determine the extent and quality of the spawning gravels in Stequaleho Creek and the adjacent study sites;
2) Evaluate streambed stability in Stequaleho Creek and the adjacent study sites;

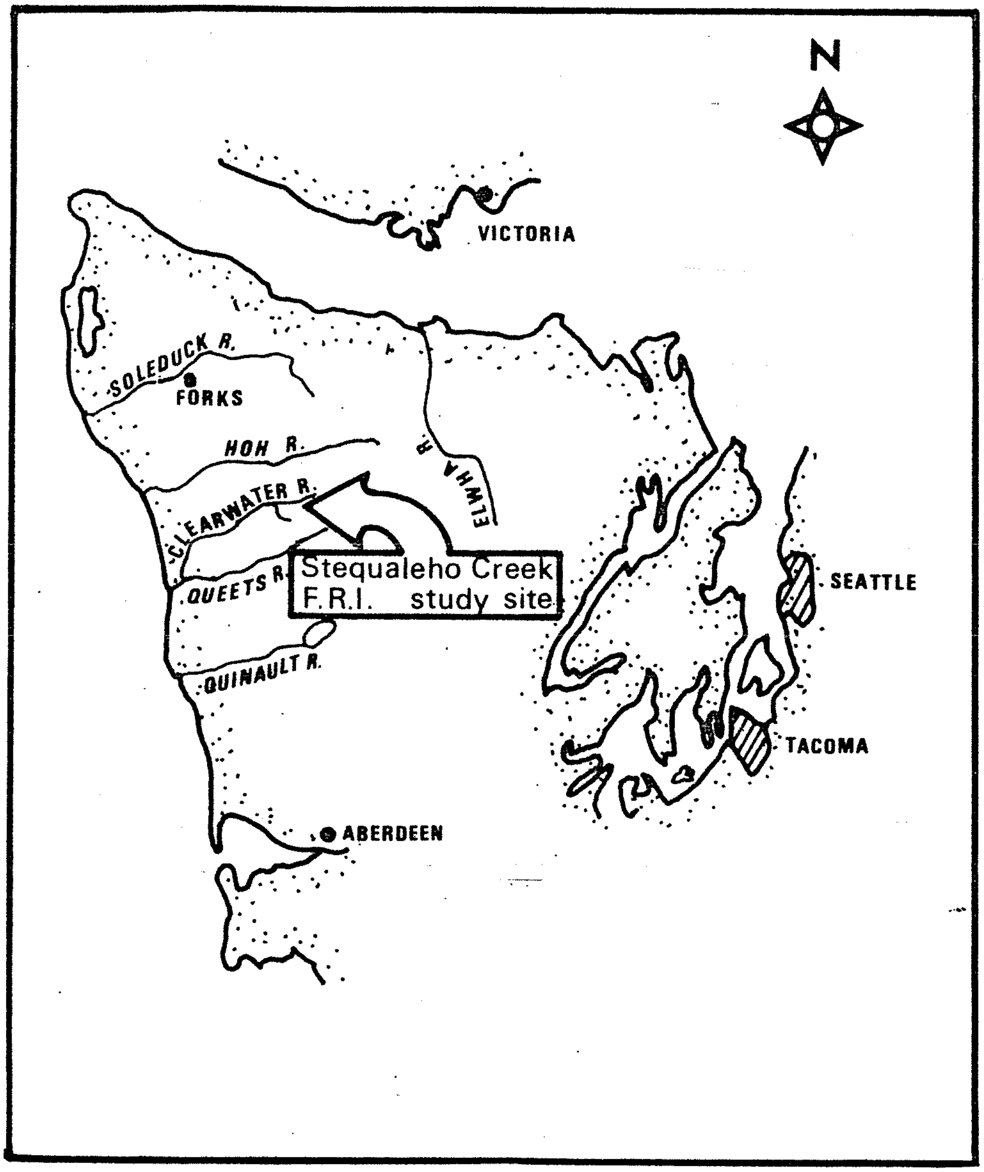


Fig. 1. General location of the Fisheries Research Institute study area in the Clearwater River, Jefferson County, Washington.

3) Determine the extent of suspended sediment concentrations in Stequaleho Creek and the adjacent study sites originating from natural and man-caused soil disturbance;

4) Determine the relative abundance of salmonids and their food organisms (i.e., aquatic insects) in Stequaleho Creek and adjacent study sites.

This report summarizes the findings as of June 30, 1973.

EFFECTS OF SILTATION ON SURVIVAL OF SALMONIDS

Literature Review

There has been widespread research, both laboratory and field studies, on the effects of silt on fish and fish habitat (Cordone and Kelley, 1961; Hollis et al., 1964; Koski, 1972; and Gibbons and Salo, 1973). Studies have been carried out throughout the United States but the major work on salmonids has centered on the West Coast. Documented findings of the physical effects of sedimentation upon fishery resources include the results of studies of: (1) fish pre-emergent life, (2) fish post-emergent life, and (3) benthic fishfood organisms. This literature review is by no means complete, but it is presented to point out that a relationship does exist between unnaturally high amounts of siltation and the degradation of fisheries habitat.

This is a good time to define the terms sediment and silt, for these terms will be used throughout this paper. According to the report of the American Geophysical Union Subcommittee on Sediment Terminology (1947) sediment is a very general term for material ranging in size from very fine clay to very large boulders, while silt refers to sediment smaller than sand but larger than clay (Table 1). In this paper, sediment will still be used in the general sense; but silt will be defined as that size of inorganic sediment considered to be detrimental to fish and insect life. This includes sediment smaller than 3.36 mm diameter.

Table 1. Designated size classes of sediments smaller than very course sand (adapted from American Geophysical Union, Report of the subcommittee on sediment terminology, 1947)

Class name	mm
Very coarse sand	2.000 - 1.000
Coarse sand	1.000 - 0.500
Medium sand	0.500 - 0.250
Fine sand	0.250 - 0.125
Very fine sand	0.125 - 0.062

Coarse silt	0.062 - 0.031
Medium silt	0.031 - 0.016
Fine silt	0.016 - 0.008
Very fine silt	0.008 - 0.004

Coarse clay size	0.004 - 0.0020
Medium clay size	0.0020- 0.0010
Fine clay size	0.0010- 0.0005
Very fine clay size	0.0005- 0.00024

Fish Pre-emergent Life

There has been extensive research on the effects of sediment on the intragravel life of salmonids. During the intragravel life sediment can limit survival by: (1) inhibiting intragravel permeability, (2) physically blocking fry emergence, and (3) crushing eggs during gravel shift.

Wickett (1958) used a standpipe to measure permeability of spawning beds in streams in British Columbia, Canada, where total freshwater survival of salmonids had been measured over a number of years. Wickett found a direct relationship between the average permeability of the beds and survival of salmon.

McNeil and Ahnell (1964) found that in six southeast Alaska streams the coefficient of permeability decreases as the percentage of 0.833 mm fines increases in spawning gravels (Fig. 2).

Vaux (1962) studied the interchange of stream and intragravel water in a salmon spawning riffle. He found that dissolved oxygen is supplied to intragravel water through (1) interchange of water from the stream above and

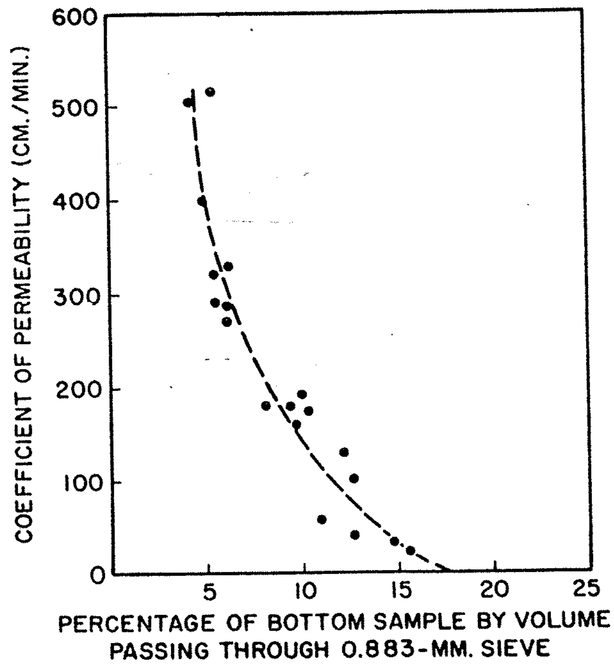


Fig. 2. Relation observed between coefficient of permeability and the fraction by volume of a bottom sample passing through an 0.833-mm sieve (from McNeil and Ahnell, 1964). Curve fitted by eye.

(2) ground water flow. Within the gravel the primary variables that control interchange are gradients in the stream profile, permeability of the gravel bed, and dimensions of the bed.

Sheridan (1962) correspondingly found that the main source of oxygenated intragravel water is supplied through an exchange with the water surface above.

Alderdice, Wickett, and Brett (1958) found that the rate of oxygen consumption for chum salmon was highest but variable during the first one-third of the intragravel development period and fairly constant thereafter. It seemed that the most critical oxygen needs were at time of hatching.

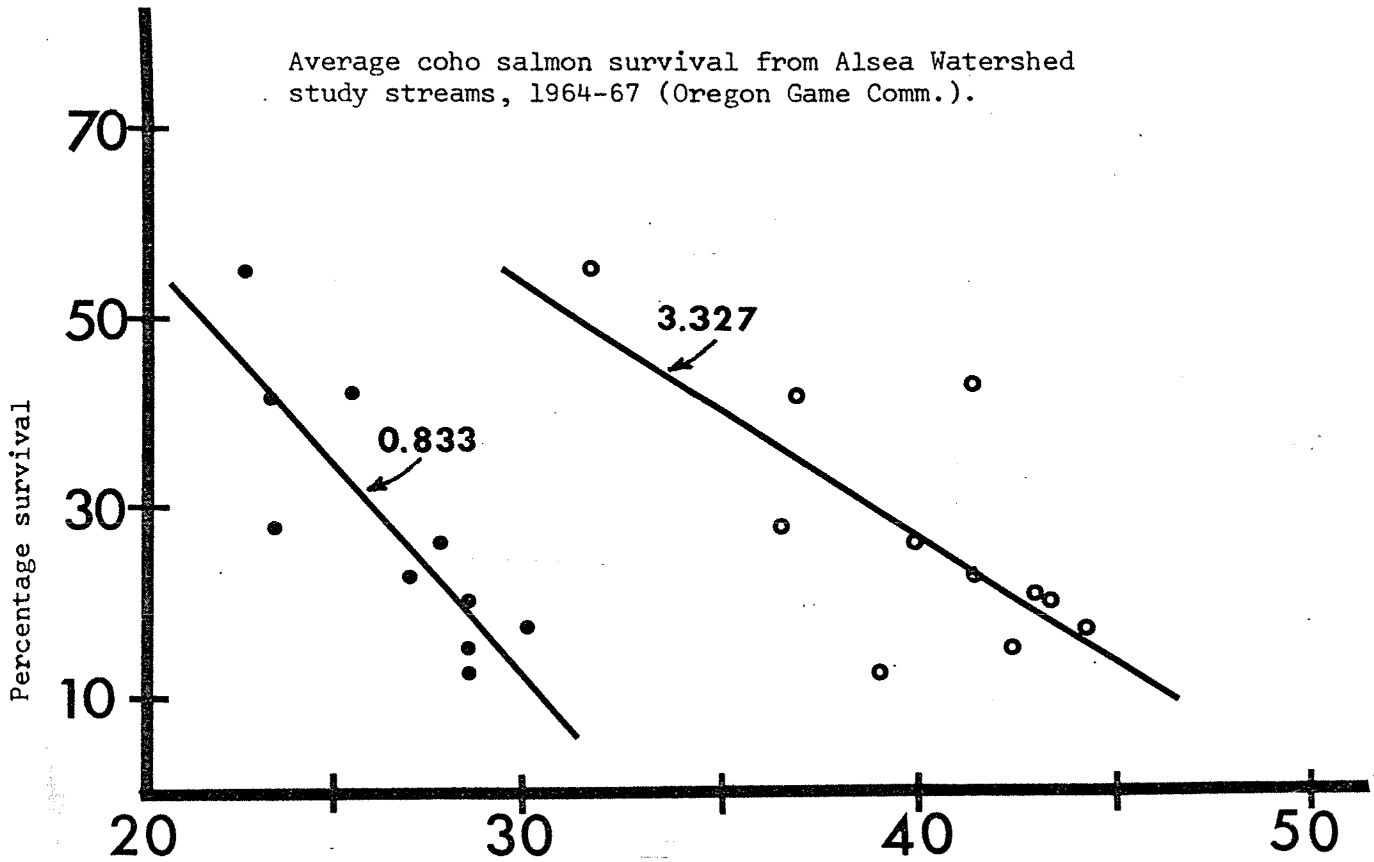
Hays et al. (1951) found that with Atlantic salmon the oxygen level limiting survival was greater for eggs (7.5 mg/l at 10 C) than for the posthatch alevins (4.5 mg/l). Initiation of active respiration across gill membranes was given as the mechanism accounting for the different requirements.

Wickett (1954) pointed out that the delivery rate of oxygen to an egg or larva is a function of water velocity as well as of oxygen content. Others (Coble, 1961; Shumway, 1960) have given experimental evidence that variations in velocity affected embryonic growth, development, and survival in much the same manner as variations in oxygen content.

Considerable research has been carried out on the effects of varying amounts of silt less than 3.3 mm and 0.8 mm diameter in spawning gravels. Cooper (1965) made a very extensive study on the dynamics of sediment transport and its effect on spawning gravel. He explained the relationships between the permeability of the gravel and particle size, porosity and particle shape. Flow of silt-laden water over a gravel bed results in deposition of silt within the gravel, even though velocities exceed those allowing deposition on the surface. His results indicated that the least damaging effects of suspended sediment on salmon enbryos and alevins would occur with a very coarse gravel and the most severe with fine gravel such as found in typical spawning beds. He stressed the necessity for maintaining very low suspended sediment concentration in water flowing over salmon spawning beds.

McNeil and Ahnell (1964) sampled the spawning gravels of six southeast Alaska pink salmon streams and determined the amount of fines passing a 0.833-mm sieve. Generally, they found an inverse relationship between the levels of fines and escapements of salmon.

Probably the most comprehensive studies of the effect of silt on intragravel survival were carried out on coho salmon in the Alsea watershed. During the calibration phase of the Alsea watershed study, it was found that in the natural redds of coho salmon, the gravel composition or silt content was the variable most clearly related to emergence survival. The mean survival from 21 redds was about 27% and ranged from 0 to 78%. The average sediment content of these naturally occurring gravels ranged from about 32% to 42% less than 3.327 mm (22% to 28% less than 0.833 mm). Later, the Oregon Game Commission summarized the Alsea watershed emergence data for the years 1964-67 (Fig. 3). High natural levels of silt were found to correlate strongly with low intragravel survival. Sediment in the gravel less than 0.833 mm had a slightly stronger correlation ($r = -0.83$) than did the percentage of gravel less than 3.327 mm ($r = -0.73$). Koski (1972) pointed out that the amount of 0.833 mm and smaller silt in the Alsea redds had a range of only 8%, but the mean survival ranged from 0.2% to 54%. He stated that "... a 1% increase in sediment less than 0.833 mm resulted in a 4.5% decrease in survival to emergence."



Percent gravel composition less than 0.833 mm r = 0.84
less than 3.327 mm r = 0.73

Fig. 3. Relationship between gravel composition and the average yearly survival to emergence of coho salmon from Deer Creek, Flynn Creek, and Needle Branch during the period 1964-67. (Adapted from Koski, 1972).

Bjornn (1968) worked under experimental laboratory conditions with survival of chinook salmon and steelhead trout in Idaho. He mixed gravel with increasing percentages of granitic sand smaller than 6.35 mm (72% of which was smaller than 2.54 mm) and, as the percentage of fine sediments increased, the salmonid survival decreased. The survival of steelhead was found to be greater than salmon for a given percentage of sand and it was thought that this was reflected by the smaller fry size.

Hall and Lantz (1969) carried out extensive laboratory studies in Oregon with the emergent survival of coho salmon and steelhead trout. They mixed gravel to match that which was found in the Alsea field studies and then added 1-3 mm fines in 10% increments. The survival curves showed a very distinct reduction in survival with increasing amounts of fines, and also a difference in the ability (determined by numbers of emergent fry) of the two species to emerge through the silt-filled gravels. Again, the steelhead fry were found to have better survival at each gravel size category; their smaller size was given as the explanation.

A high portion of the mortality in the redds of coho salmon in Oregon was believed to have been caused by the inability of fry to penetrate through the interstices of the gravel (Koski, 1966). In conjunction with reductions in dissolved oxygen and intragravel water velocity, sediment may form a barrier to fry migrating up through the gravel and actually entomb them within the redd. White (1942) found that where Atlantic salmon (*Salmo salar*) had spawned in gravel with an extensive amount of sand, 80% of the embryos were dead and 20% had produced fry which were unable to emerge through the compact layer. Numerous entombed fry were found in redds even with fairly good emergence.

Phillips (1965) observed that in aquaria coho salmon embryos suffered only low mortality rates prior to hatching in fine gravel, but after hatching, the coho alevins appeared distressed and died a short time later. The restriction of movement was dramatically illustrated by the trail of dead alevins as they struggled toward the surface. The more vigorous died about 2 inches short of emerging.

Royce (1959), in his paper on the possibilities of improving salmon spawning grounds, gave freedom from gravel bed disturbance as a definite advantage of artificial spawning areas. McNeil (1966) made a review of the literature on the effect of the spawning bed environment on reproduction of pink and chum salmon, and he concluded that movement of bottom materials (molar action) during high water was an important cause of mortality, which was most severe where temporarily stationary debris shifted position within the flood plain. Mortality from movement of bottom materials was estimated to exceed 90% in one instance.

The Canada Department of Fisheries and the International Pacific Salmon Fisheries Commission (1966) carried out an effects of log driving study on spawning grounds in the Stellako River, B.C., and concluded that individual grounding logs and moderate hydraulic erosion could cause mortality if erosion extended to the depth of the eggs. Erosion and damage to certain spawning grounds caused a 40% shift in the distribution of sockeye spawners in the ensuing run.

After a severe storm in December 1970, many salmon eggs which evidently had been eroded from the streambed were observed on the flood plain of Big Beef Creek, Washington. Investigators at the FRI Big Beef field station observed that seagulls and ducks fed heavily on the eggs.

Several conclusions may be drawn regarding the requirements of salmonids during their intragravel life: (1) good intragravel survival is dependent on a permeable streambed that allows a good interchange of oxygenated water from the stream above; (2) the rate of oxygen consumption by larvae varies depending on the developmental stage; (3) the oxygen levels limiting metabolic processes and causing mortality approach a maximum shortly before hatching; (4) there must also be sufficient intragravel velocities to allow for normal larval growth; (5) high levels of silt in spawning gravels can reduce the pre-emergent survival of salmon and trout; (6) the degree of reduction in pre-emergent survival for a given gravel composition may depend on the species of salmonids; and (7) shifting and erosion can cause mortality in salmon spawning grounds, either by displacement or crushing of the eggs.

There has been only a limited amount of work done on the effects of streambed instability on intragravel survival. This probably reflects the difficulty in conducting such an experiment; but all the evidence points to this cause as an important factor in intragravel mortality of eggs.

Fish Post-emergent Life

There is a scarcity of information on the direct effects of sediments on post-emergent and larger salmonids. According to Phillips (1970), post-emergent salmonid fry depend on the crevices and interstices in gravel for cover to escape predators, thus an accumulation of sediment eliminates this cover. Rainbow trout fingerlings placed in cages 1-1/2 miles below a gold dredge operating on the Powder River, Oregon, where turbidity ranged from 1,000 to 2,500 ppm, suffered 57% mortality in 20 days as compared to only 9.5% mortality in a group placed in a cage in a clear tributary (Campbell, 1954). The effects of short periods of exposure to low levels of suspended sediments on salmonids probably are not adequately understood at this time.

Effects of Sediment upon Bottom Organisms

An increase in sedimentation can cause a reduction in abundance of aquatic insects. This is of significance since benthic insects are a vital component in the food web of freshwater fishes (Hynes, 1970).

Tebo (1955) observed a reduction in standing crop of bottom organisms in a small North Carolina stream following siltation due to logging. A total of 109 one-sq-ft-bottom samples were collected above and below the sediment source and the reduction was statistically significant in the affected section. Bachman (1958) observed a statistically significant reduction in volume of benthic organisms in an Idaho stream following sedimentation from logging road construction. A similar reduction occurred in the Truckee River, California, following a gravel washing operation (Cordone and Pennoyer, 1960); samples taken below the sediment source contained significantly fewer insects than samples upstream of the source. This difference was observed as far as 10.5 miles downstream from the sediment source. Erosion depositing approximately 10,000 m^3 of sand in a British stream over a period of two years reduced the downstream populations of aquatic food organisms when compared to samples above the sediment source (Nuttall, 1972). In fact, Chironomidae, which often increase in abundance in organic sedimentation, were either absent or occurred sporadically below this sediment source.

Several mechanisms have been proposed to account for a reduction in insect abundance following increased sedimentation. Degradation of habitat can occur by the filling of the gravel interstices with fine particles and thus may cause a reduction in available living space (Phillips, 1970). Clogging of interstices may also affect insect abundance by a reduction in flow of oxygen-enriched water (Ziebell, 1960). Usinger (1971) suggests there may be an abrasion effect or interference with the respiratory structures of insects caused by silt. Streams which rely on primary production as their principal energy source may be affected by a decrease in the photosynthesis process during increased suspended sediment loads, affecting the insect community by decreasing insect food abundance (Hynes, 1960).

HISTORY OF DEPARTMENT OF NATURAL RESOURCES MANAGEMENT OF THE CLEARWATER RIVER DRAINAGE

The principal timber harvesting practice throughout the DNR Clearwater management block is clearcutting in a patchquilt pattern (Fig. 4 and Plate 5). Streamside protection through the use of buffer strips has been the practice for most major rivers and creeks tributary to the Clearwater River but not for all small tributaries and headwaters (Plate 6).

Before 1960, the major logging activity was conducted on privately owned land in the lower area of the Clearwater River drainage below Hunt Creek. In 1960, the DNR began extending its road system into the state-owned upper area. This area is managed by the DNR for the Washington State public school system and comprises 75,500 acres (approximately 79% of the total Clearwater River drainage). The remaining 21% of the watershed is divided into approximately 20 ownerships. Sales of state-owned timber in the upper Clearwater River drainage were slow at first but began to boom after 1966, and the miles of roads increased accordingly (Table 2). By mid-1973, approximately 25.6%

Table 2. Annual DNR numbers of sales, miles of roads, and clear-cut acreage in the Clearwater River basin, 1960-73

Fiscal year sale was made	Number of sales	Miles of road[1]	Clearcut area[2] (acres)
1960-61-62	3	16	850
1963	3	18	1,150
1964	3	15	1,020
1965	4	11	860
1966	4	7	750
1967	8	30	2,000
1968	13	36	2,200
1969	4	14	900
1970	13	41	2,900
1971	10	34	2,000
1972	12	27	2,400
1973 - June	12	26	2,301
TOTAL	89	275	19,331

[1]Management standard and loggers choice roads included (these are estimates made at the time of sale).

[2]Does not include small sales (these are estimates made at the time of sale).

HOH-CLEARWATER VICINITY MAP

STATE OF WASHINGTON
DEPARTMENT OF NATURAL RESOURCES
BERT L. COLE COMMISSIONER OF PUBLIC LANDS

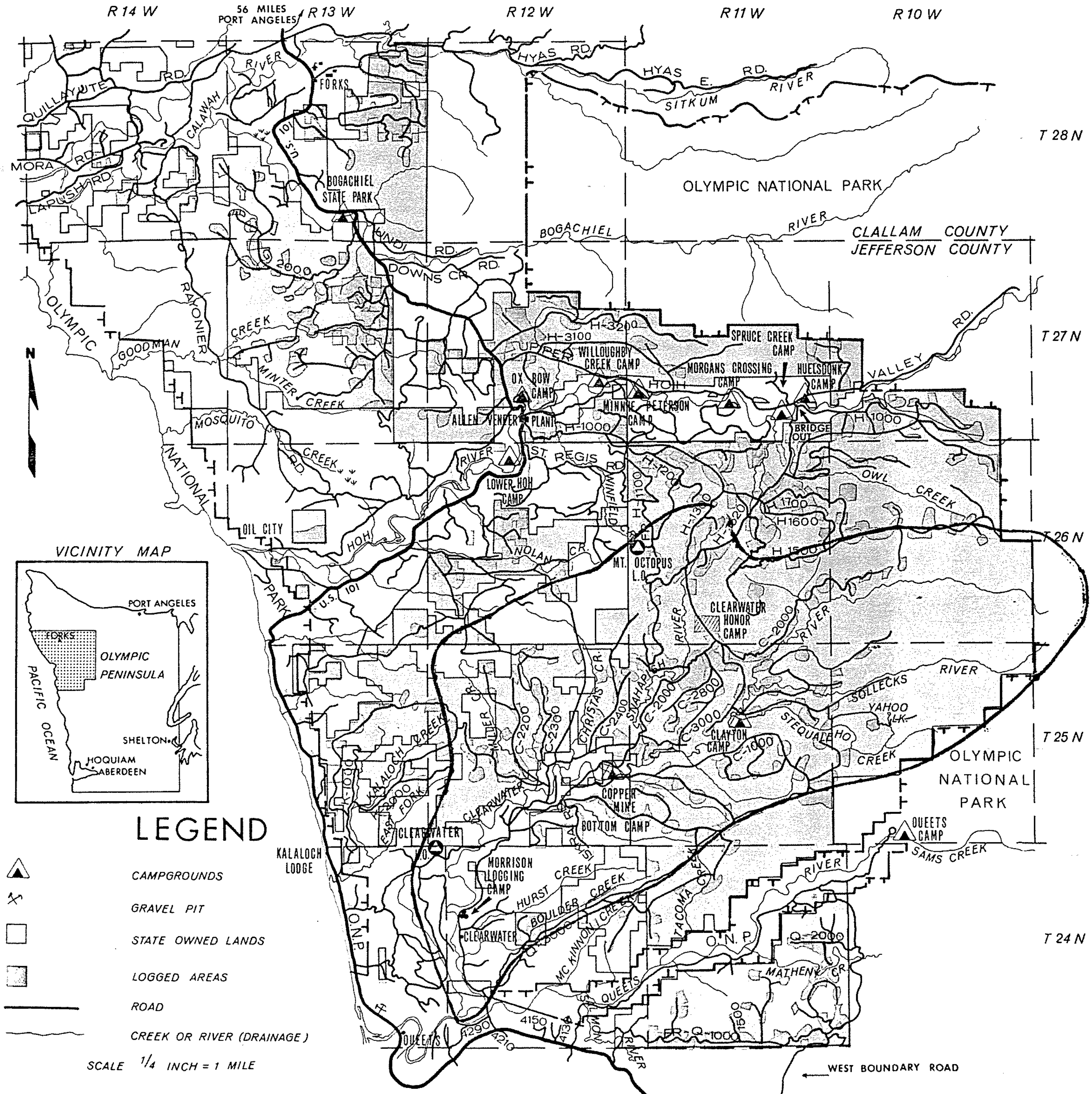


Fig. 4.

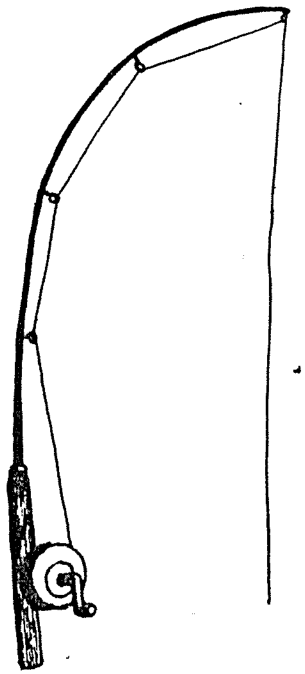
* Roads across National Park not open to hunting.

** Roads across National Park open to hunting, general bull season only.

RESTRICTED AREA — NO HUNTING WITHIN 1000 FEET OF CLEARWATER HONOR CAMP.

September, 1972

GOOD FOREST CAMPING MANNERS
For Developed Recreation Sites



1. Use the fireplaces or stoves provided.
2. Before leaving be sure your fire is out.
3. Use garbage cans for garbage and burn papers in your campfire.
4. Keep your camp clean and leave it clean.
5. Toilets are provided for your convenience. Please help to keep them clean.
6. Do not cut or mutilate trees, shrubs, or flowers.
7. All improvements are property of the State of Washington. Please do not damage or write on them.
8. Discharging firearms in developed recreation sites is so dangerous it has been prohibited.
9. Horses and pleasure driving of motor vehicles are not permitted in developed sites.
10. If you observe any unsatisfactory, unsanitary or dangerous condition, please, report it to the Department.

Vehicles and Road Use - General:

Vehicular travel shall be over roads adequate for ordinary automobiles. Off-road travel is prohibited except on trails or routes designated by the Department. Every motor vehicle shall, at all times, be equipped with an approved spark arresting muffler in good working order and in constant operation. Complete use regulations are available at Olympic Area Headquarters in Forks.

CAUTION HUNTERS !

Please help prevent forest fires by taking these simple precautions:

1. Make sure all fires are DEAD OUT before leaving them.
2. Do not smoke while traveling in fields and woods.
3. Smoke in cleared areas only.
4. Make sure matches and smokes are "dead out" before discarding.

You can help prevent hunter caused forest fires.

Report Wild Fires:

Forks 374-6223
Quinault - 288-2477

of the state-owned old-growth timber in the drainage had been sold (not necessarily logged).

The roads in the upper drainage basin are in steep terrain; side slopes often exceed 100%. Sidecast deposition of waste material during road construction had been the general practice until 1970. Landslides of varying size, caused by failure (slumping) of the sidecast from DNR roads and from those owned by private companies are quite numerous in the Clearwater River drainage system. Naturally-occurring landslides are also quite numerous in this watershed, pointing out the natural instability in this area. A comparison of natural and man-caused landslide occurrence in Stequaleho Creek by Fiksdal (1973) is given as a supplement to this report.

DESCRIPTION OF THE STUDY AREAS

The Clearwater River

The Clearwater River is one of the major tributaries of the Queets River Basin, with a watershed of approximately 150 sq miles and a mainstem of 35 linear miles. It enters the Queets River from the north about 7 miles from its mouth (Fig. 5). Between the years 1932 and 1950, flows near its mouth ranged from 62 cfs in late summer to 30,400 cfs in winter (USGS, 1955).[1] The river meanders in its lower reaches and is very steep and precipitous in its headwaters.

In order to make comparisons in the Clearwater River between sites above and below the mouth of Stequaleho Creek the point of introduced silt load by the documented landslides, we chose seven sampling locations, four above the creek (C-1, C-2, C-3 and SO-1) and three below (C-4, C-5, and C-6). Station C-3 cannot be thought of as a true control because it is influenced by man-caused sedimentation from the Solleks River. These study sections average approximately 500 ft in length (Fig. 5).

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[1]The State of Washington in cooperation with the United States Geological Survey. 1955. Monthly and yearly summaries of hydrographic data. Water Supply Bull. No. 6. page 58.

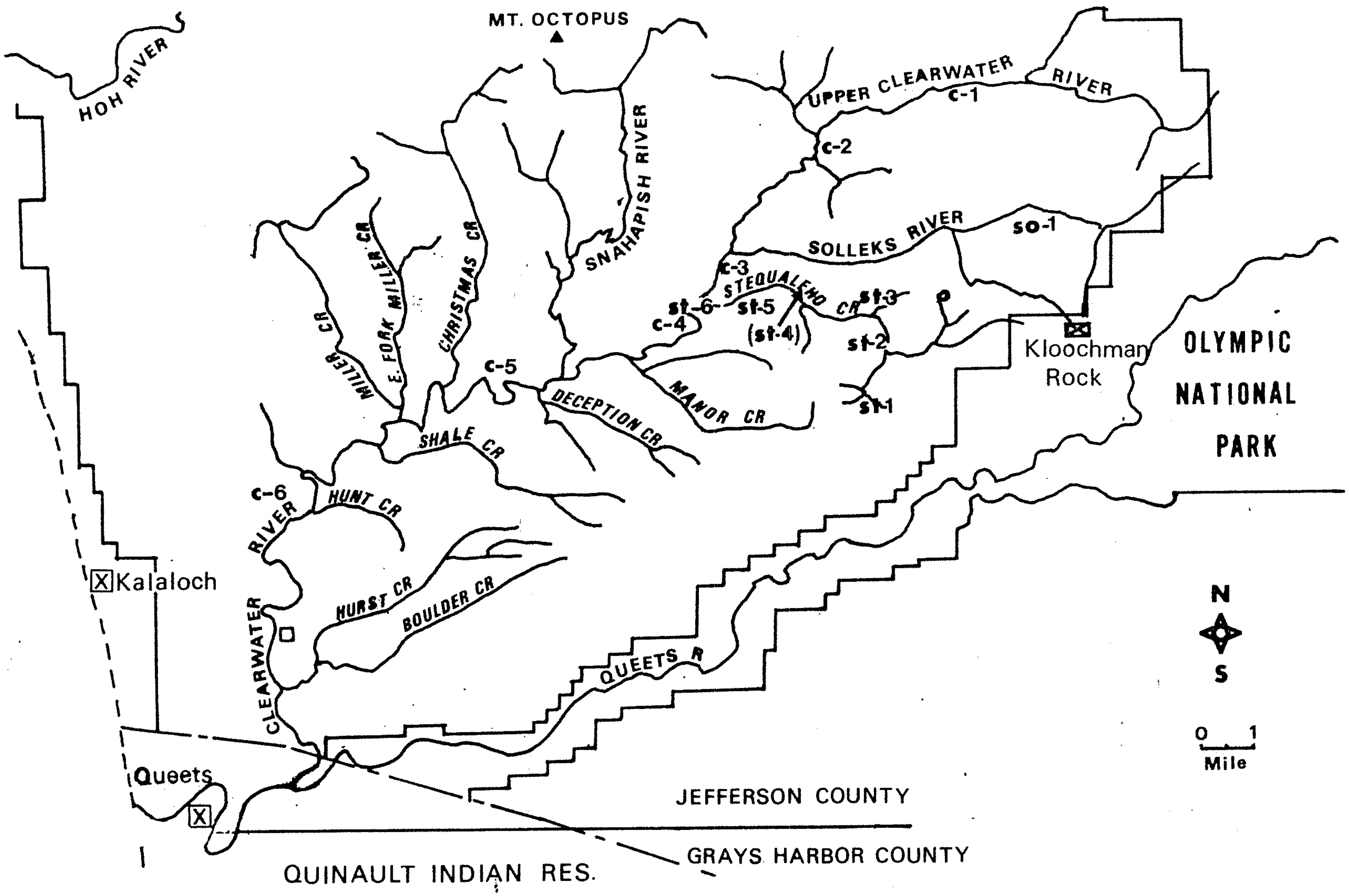


Fig. 5. General locations of experimental sampling sites in the Clearwater River, the Solleks River, and Stequaleho Creek.

Stequaleho Creek

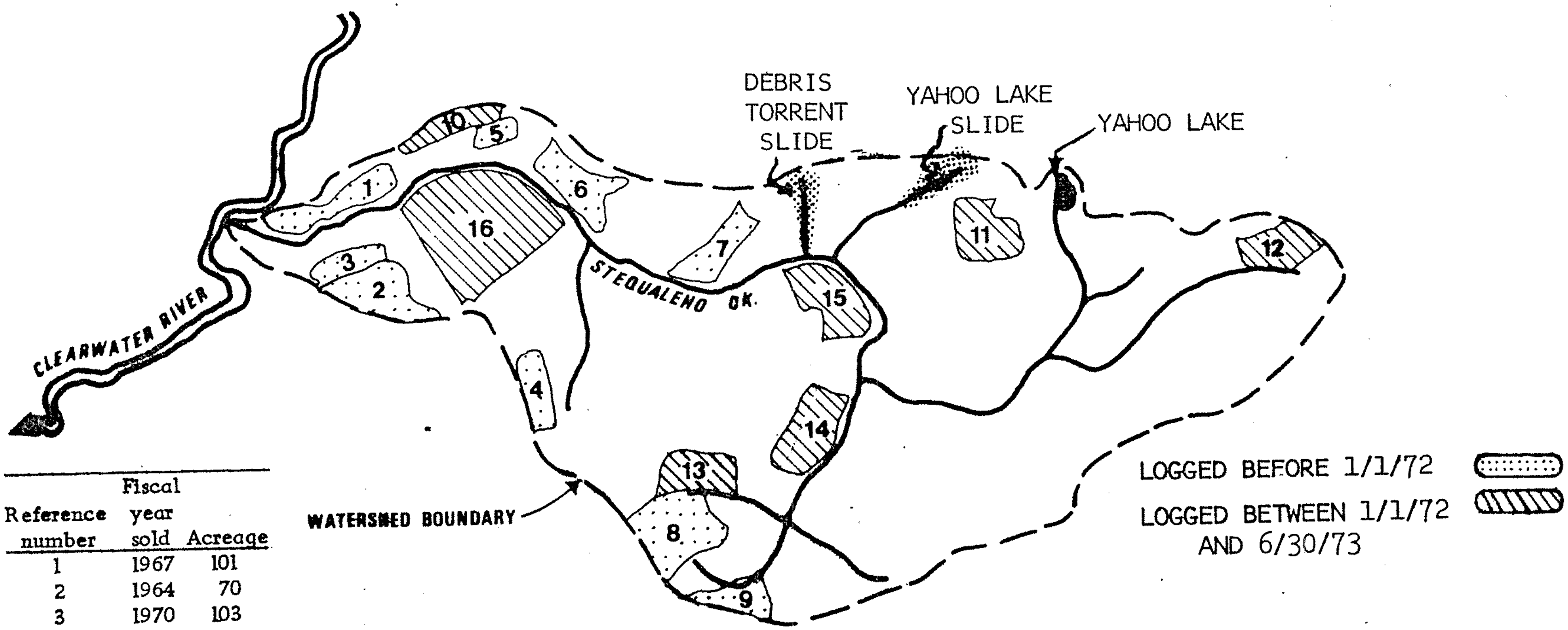
Stequaleho Creek is a major tributary of the Clearwater River, originating in the Olympic National Park and emptying into the Clearwater 24 miles from its mouth (Fig. 5). A high waterfall 2.1 linear miles above the mouth limits the available spawning ground for migratory fish. The remainder of the creek is utilized by resident cutthroat trout populations.

During 1972 and 1973 air temperatures near the mouth of Stequaleho Creek ranged from 86 F (August 1972) to 19 F (December 1972). The water temperatures ranged from 76 F (July 1972) to 32 F (December 1972). During the warmest months of 1972 (June, July, August, and September) the average air temperature was 58.6 F and the average water temperature was 57.1 F (Appendix Table 3). Annual rainfall in the Clearwater River basin averages between 140 and 180 inches. The months of heaviest rainfall are November, December, January, February, and March.

Between the months of March and December 1972 stream discharge was recorded for Stequaleho Creek at the mouth. The low flow discharge was approximately 8.8 cfs in mid-September; and the absolute maximum was found to be greater than 2,300 cfs in December. The mean daily discharges for these months are given in Appendix Table 4.

As of June 1973, the watershed has 16 logged clearcut units, which cover 19% of its area (Fig. 6). The units have an average size of 76 acres and a size range of 30-200 acres. There are 14 miles of roads in the watershed, comprising approximately 3% of the total watershed area (Fig. 7). The commercially harvested timber species are Western hemlock (*Tsuga heterophylla*), White fir (*Abies amabilis*), Sitka spruce (*Picea sitchensis*), Western red cedar (*Thuja plicata*), and Douglas fir (*Pseudotsuga menziesii*).

The various perennial tributaries of Stequaleho Creek were lettered A through D and six study sites (St-1, St-2, St-3, St-4, St-5, and St-6) were established above and below the landslides. Some of these sampling sites (St-1, St-2, and St-3) were further subdivided and so designated St-1_a, St-1_b, etc. (Fig. 7). Stations St-1, St-2, and St-3_a are unaffected



Reference number	Fiscal year sold	Acreage
1	1967	101
2	1964	70
3	1970	103
4	1964	49
5	1967	31
6	1967	91
7	1968	60
8	1964	75
9	1967	60
10	1969	61
11	1968	61
12	1968	30
13	1970	60
14	1970	60
15	1970	83
16	1972	197

Fig. 6. Sales in Stequaleho drainage basin logged before and after January 1, 1972. Indicated are landslide areas under study, this figure does not include all natural or man-caused landslides. Location of all natural landslides can be found in Allen J. Fiksdal report at the end of this paper.

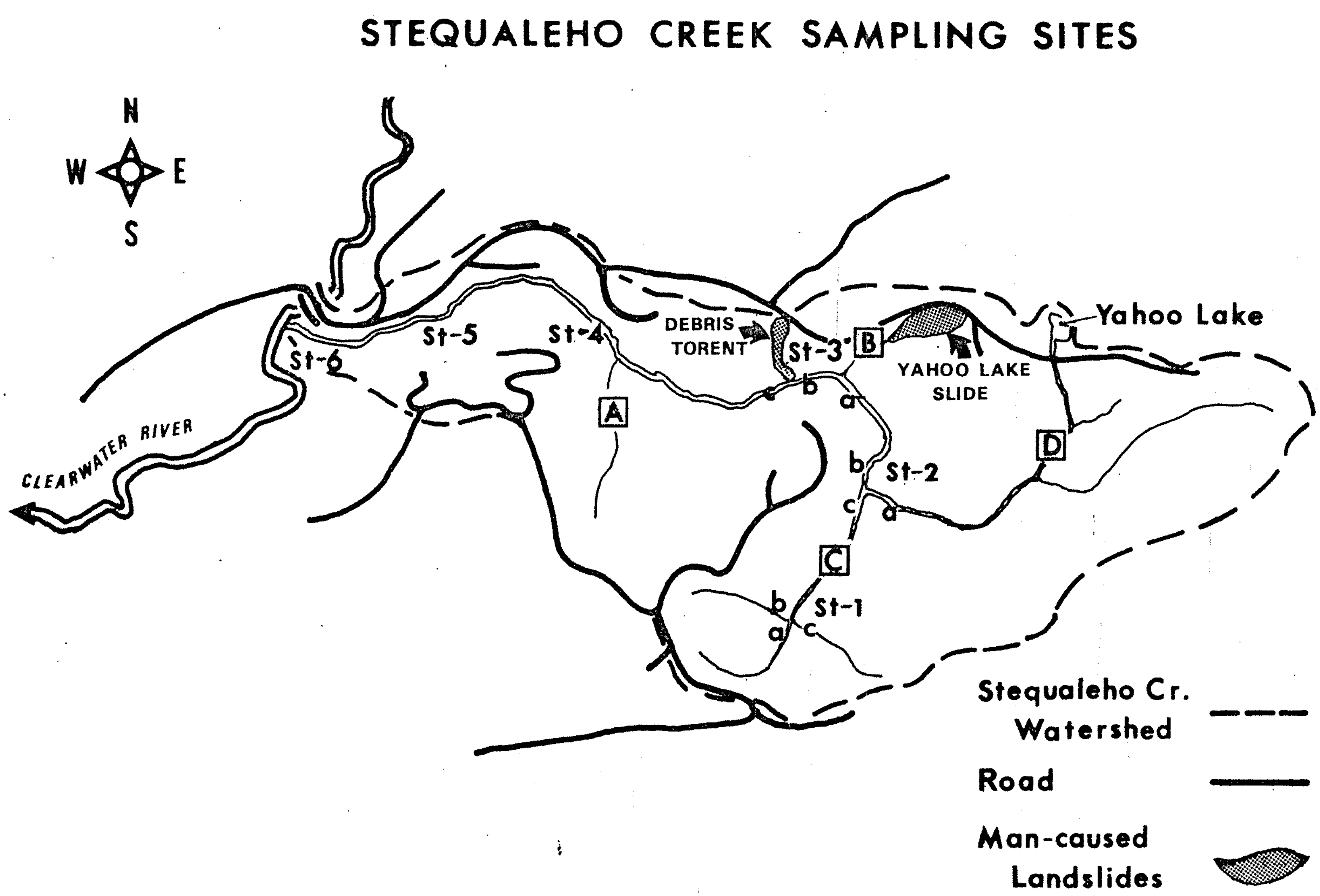


Fig. 7. Specific sampling sites, logging roads, and man-caused landslides in the Stequaleho Creek drainage basin. Depicted landslides are not drawn to scale.

by the slides and St-4, St-5, and St-6 are affected. Station St-3_b is affected only by the Yahoo Lake slide, as it is located between the two landslides. These study stations have an average length of approximately 300 ft and usually include three good salmonid spawning riffles.

Tributary A (463 acres) enters Stequaleho Creek 2.5 miles above the mouth (Fig. 7). Stequaleho Creek has an average streambed gradient of 2.5% from the mouth to Tributary A. Tributary A is 1.3 miles long, with an average streambed gradient of 17%. It is populated with resident cutthroat trout and sculpins.

Tributary B (336 acres) enters Stequaleho Creek 4.2 miles above the mouth (Fig. 7). Stequaleho Creek has an average streambed gradient of 1.6% from Tributary A to Tributary B. Tributary B is 0.8 miles long and has an average streambed gradient of 17%. The Yahoo Lake landslide is in the headwaters of this tributary (Plates 3 and 4).

The Debris Torrent landslide, which was a part of the initial slide of 1971, is located in a small feeder stream approximately 500 ft downstream of the mouth of Tributary B (Plates 1 and 2).

The Yahoo Lake and Debris Torrent landslides occurred along DNR's FRC-3130 road and these slides put a combined volume of sediment and debris of approximately 20,000 $yards^3$ into Stequaleho Creek. (*See* Fiksdal's 1973 supplemental report to this paper.)

Tributary C (1,158 acres) enters Stequaleho Creek approximately 5.3 miles above the mouth (Fig. 7). Stequaleho Creek has an average streambed gradient of 3.6% from Tributary B to Tributary C. Tributary C is 1.6 miles long and has an average streambed gradient of 4%. From 50 to 100 resident cutthroat trout spawned in this stream during the springs of 1972 and 1973. The east and west forks of this tributary are the site of an intensive thesis study on the effects of debris removal on the carrying capacity of these small coastal cutthroat trout streams (by Lawrence Lestelle). The watershed area of the west fork (St-1_b) is 260 acres and that of the east fork (St-1_c), 182 acres.

Tributary D (400 acres) enters Stequaleho Creek approximately 6.4 miles above the mouth (Fig. 7). Stequaleho Creek has an average streambed gradient of 1.9% from Tributary C to Tributary D. During the spring of 1972, a considerable number of resident cutthroat trout spawned in this stretch of Stequaleho Creek. Tributary D is 1.1 miles long and has an average streambed gradient of 13%. A feeder stream of this tributary drains Yahoo Lake (water surface elevation - 2,350 ft).

The mainstem of Stequaleho Creek above Tributary D is 1.7 miles long and has an average streambed gradient of 10.8% (Fig. 7). The upper end of the Stequaleho Creek watershed is located in the Olympic National Park on Queets Ridge at an elevation of 2,600 ft.

MATERIALS AND METHODS

Composition of Spawning Gravel

Sample Collection

Samples of salmonid spawning gravel were collected in Stequaleho Creek and the Solleks River, as well as the main stem of the Clearwater River, by a technique similar to the one described by McNeil and Ahnell (1964) (Fig. 8 and Plates 7 and 8). The stainless steel tube was worked manually to a depth of 8-10 inches, and the contents were transferred by hand to the basin. Some of the very fine sediments that became suspended as a result of agitation during sampling were trapped by insertion of the plunger. This plunger constituted the main difference between our sampler and that used by McNeil and Ahnell (1964).

Sorting and Measuring of Samples

Gravel samples were separated into size classes by washing and shaking them through five standard Tyler sieves having the following square mesh openings: 77 mm (3.0 inch), 26.9 mm (1.06 inch), 3.36 mm (0.132 inch), 0.841 mm (0.033 inch), and 0.124 mm (0.005 inch). Silt passing the 0.124-mm screen was collected in a plastic graduated cylinder, allowed to settle for 1 hr, and then measured volumetrically. The volume of solids retained by

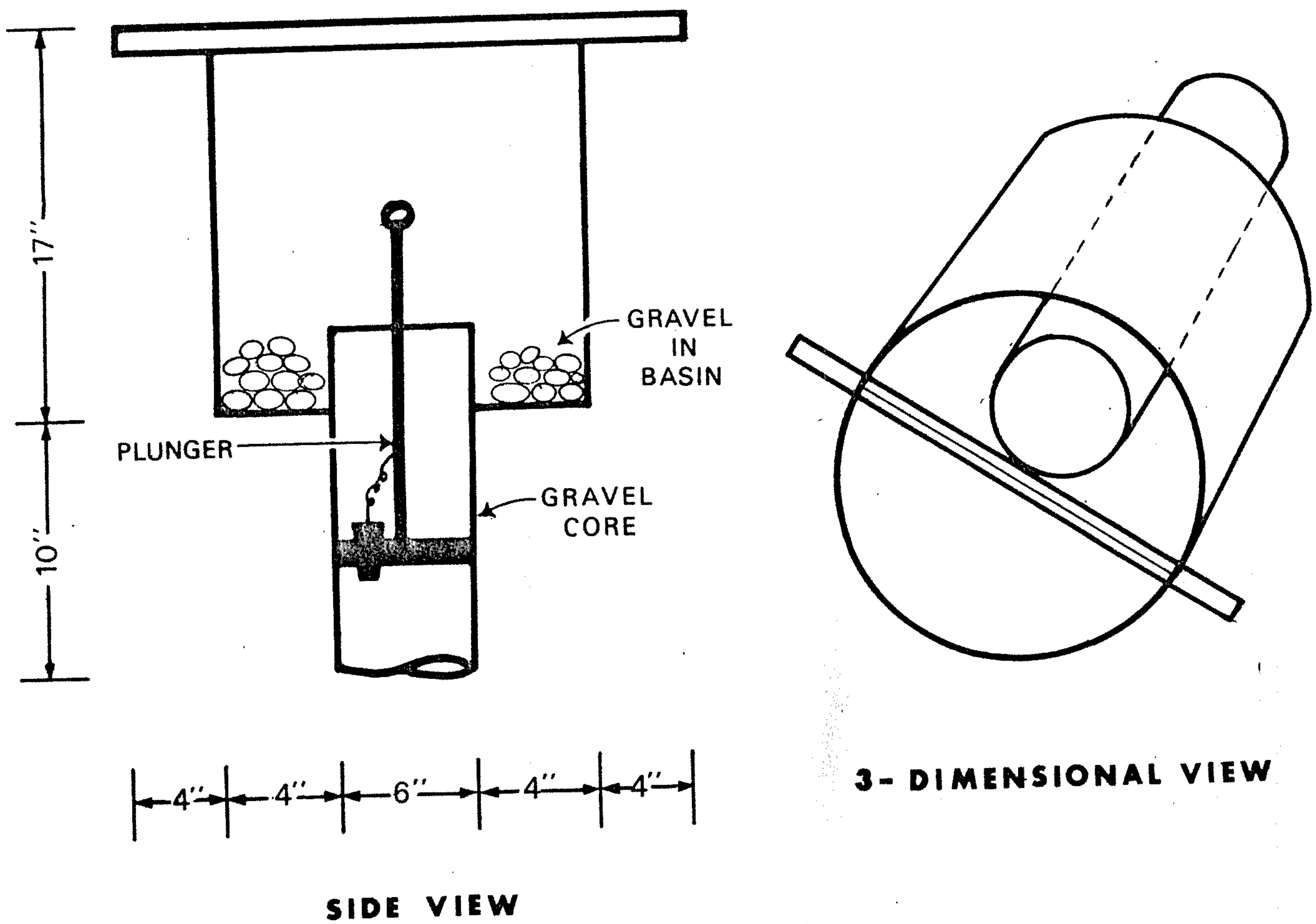


Fig. 8. The gravel sampler used in this study.

each of the five Tyler sieves was then measured volumetrically in a displacement cylinder, and the percentage of the total sample passing each sieve was determined.

Sampling Problems Associated with this Gravel Sampler

The sampling problems encountered in this experiment generally fall into three categories:

(1) Choice of site: salmonids do not choose their spawning sites randomly; they seek out gravel beds with specific physical characteristics that will maximize the survival of their eggs. Such characteristics as water temperature, cover, supra-gravel velocities, water depth at spawning, intragravel water seepage, and gravel composition have been suggested as some of the many considerations a salmonid makes before spawning (Foerster, 1968; Burner, 1951; Schroder, 1973; Hunter, 1973). Therefore, the spawning gravel sampling sites were not ramdom, but in chosen locations where salmonids were believed to spawn. Later observations of coho and chinook salmon and steelhead and cutthroat trout spawning showed the sampling sites to correspond with spawning sites.

(2) Digging the sample: a major problem was the obtaining of a uniform sampling depth of 8-10 inches. As the substrate is composed of many large boulders and cobbles, it was impossible to obtain uniformity. This also caused some selectivity by the person sampling. This apparent bias is compensated for by a similar selectivity by the female salmon.

When digging the sediment out of the core and placing it in the basin care must be taken not to cause a suction action with the arm and hand. If this suction occurs one could cause an artifact in the sample by drawing fine silt in from outside the sample core. There has been a freeze core technique recently developed by the U.S. Forest Service (Walkotten, 1973) that removes a nearly undisturbed, stratified sample containing stream gravel, intergravel water, and organic material and allows sampling in rocky streambeds.

(3) Transporting the sample: The sheer weight of the sample (often greater than 30 pounds) presented a problem.

Intragravel Sedimentation

Intragravel sedimentation was monitored through the use of devices described by Bird (1970) (Plate 9). They were placed in groups of two at three locations upstream and three locations downstream from the landslides. The sediment monitors were composed of a perforated (1/2-inch holes) inner stainless steel cylinder, with sides and bottom enclosed in an identically perforated, composition rubber cylinder. The inner cylinder was filled with marbles. The size of the opening was controlled by rotation of the inner cylinder to a position where the inner and outer perforations were in or out of alignment.

The monitors were buried approximately 2 inches in the gravel (from the gravel surface to the top of the monitor) in a standard-sized pit 10 inches deep that was dug with the gravel sampler. At the time of burial, the sampler perforations were placed in alignment.

At the time of recovery, the contents of the sediment monitor were washed into a heavy-duty plastic bag and weighed to a constant dry weight. The sediment was dried in an oven for approximately 24 hr at a constant temperature of 105 F.

Intragravel Egg Survival Experiments

These experiments were designed to supply information on the effects of gravel siltation on survival of salmonids from eyed-egg stage to hatch (cutthroat trout) or to yolk absorption (steelhead trout and coho salmon). It must be remembered that this set of experiments provides information relating only to the effects of silt on survival during a brief period of the total intragravel life, but it is felt this is the most important stage since oxygen levels are most critical during the hatching period. The boxes used in burial of these eggs were designed to protect the eggs from gravel bed instability and therefore measured only the effects of silt in the gravel.

Cutthroat Trout

An experiment was conducted to test the effects of intragravel siltation on the survival, to hatching, of eyed cutthroat trout eggs. A total of 54 individual boxes of 100 eggs each was planted in Stequaleho Creek, 27 boxes above the landslide influence, and 27 boxes below. Approximately 500 eggs were kept at the Washington State Department of Game trout hatchery on the Cowlitz River as a control.

The boxes were standard pint-sized freezer containers 3 inches high, perforated on all sides with 5/64-inch holes (120 holes/side) (Plate 10) and buried in the streambed. Bottomless 5-gal cans were dug into the streambed, and then gravel inside these containers was removed to a depth of 6 inches. Some of the material removed was then placed into the egg boxes, and the trout eggs were distributed throughout the material. Then the cover was fastened securely to the box with a wrap of twine, and the box was buried approximately 2-3 inches below the gravel surface.

The burial locations were all at possible cutthroat trout spawning sites. There was no preparation (gravel cleaning) of the site before egg box burial. Colored plastic tubing was used to mark the egg box sites. Burial took place on the last day of March 1972 and recovery in the second week of May 1972.

Steelhead Trout

An experiment was conducted designed to test the effects of intragravel siltation on the survival to yolk absorption of eyed steelhead trout eggs. A total of 18 individual boxes of 200 eggs each was planted in Stequaleho Creek, 9 boxes in landslide-affected areas and 9 in -unaffected areas. Approximately 1,000 eggs were kept at the Washington State Department of Game trout hatchery on the Cowlitz River for control over inherited mortality.

The egg boxes were identical in construction to those used in the experiment with cutthroat trout and were buried with the gravel sampler. The boxes were filled with small 1/2-inch diameter marbles instead of filling them with sediment removed from the burial site. Likewise, there was no attempt to clean the gravel before planting the boxes. Burial took place in the first week of February 1973 and recovery in the last week of April 1973.

Coho Salmon

An experiment was attempted to test the effects of intragravel siltation on the survival to yolk absorption of eyed coho salmon eggs. A total of 60 individual boxes of 100 eggs was planted in Stequaleho Creek, 36 boxes in landslide-affected areas and 24 in -unaffected areas. Approximately 7,000 eggs were retained at the Washington State Department of Fisheries George Adams Hatchery on Hood Canal. We also kept 1,500 eggs in two small tributaries of Stequaleho Creek to have a check on mortality from transportation from the hatchery to Stequaleho Creek.

The egg boxes were of the same construction and were buried in the same manner as the steelhead eggs. An attempt was made to clean the gravel at half of the sites, much as a salmon might. Burial took place in the first week of January and recovery in the last week of April 1973. Unfortunately, almost all of the egg boxes in this experiment were lost during a storm in January.

Streambed Stability

Cross-sectional surveys were conducted in the manner described by Cederholm (1972) to provide baseline documentation of the amount of streambed gravel movement in lower Stequaleho Creek. Unfortunately, no information was gathered in any other tributaries during this initial year of study. Twenty cross-sectional measurement stations (25 ft apart) were established at each of three study stations (St-4, St-5, and St-6) in the anadromous zone (Fig. 9). Net annual streambed changes could be measured at these stations; the surveys were carried out in June 1972 and in August 1973.

At each station relative cross-sectional elevations of the streambed were obtained by means of a transit-level and rod (Plate 11). Distance was taken from benchmarks located on the embankments on the right side of the stream (looking downstream); these benchmarks were small cedar pegs driven into the ground with numbers designating their positions along the stream. Volumes of gravel deposited or eroded from a given cross section were calculated by superimposition of the survey measurements for the two

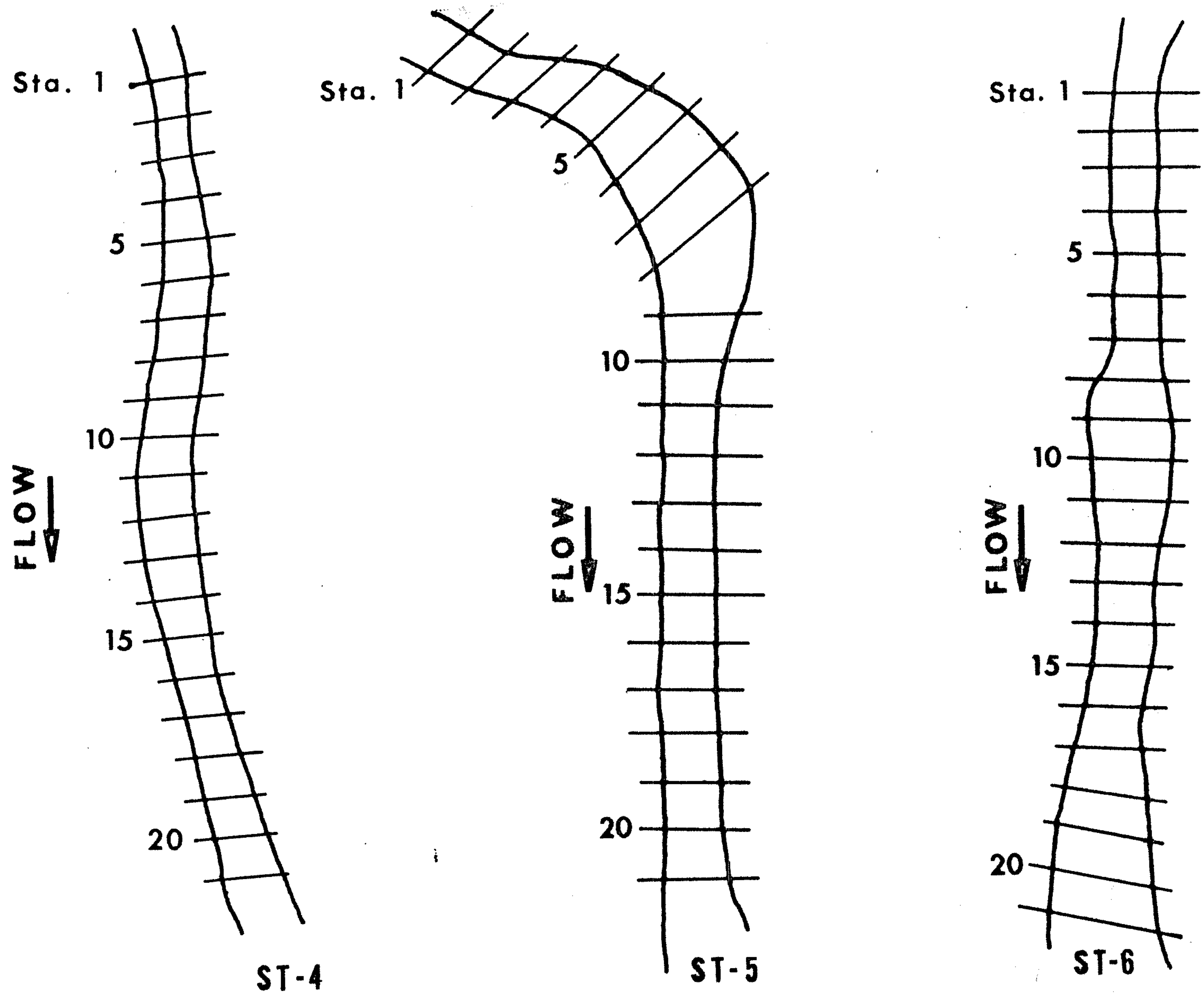


Fig 9. Cross-sectional streambed measurement stations in lower Stequaleho Creek.

measurement periods on the same graph (Fig. 10). The area between the plotted lines belonging to each of three categories, (1) erosion of embankments, (2) streambed degradation, and (3) streambed aggradation, was calculated and its volume found by multiplying by 25 ft, the distance between cross sections. Sediment-composing streambed aggradation within the study section was given a positive value and streambed degradation and streambank erosion were given negative values. Then, the algebraic sum of the values was used to arrive at the net change in a study section.

Suspended Sediment

Sample Collection

Suspended sediment samples were collected from streams by the DH-48 handheld depth-integrating sampler (Plate 12) by a technique similar to one described by Guy and Norman (1970). The sampler, weighing 4-1/2 lb, including the container, samples from the surface to within 3-1/2 inches of the streambed. A streamlined aluminum casting 13 inches long partially encloses the sample container, a round, pint-size glass milk bottle. The container is sealed against a gasket in the head cavity of the sampler by a hand-operated, spring-tensioned, pull-rod assembly at the tail of the sampler.

The sample is collected through the 1/4-inch intake nozzle and is discharged into the bottle. The displaced air from the bottle is ejected downstream through the air exhaust alongside the head of the sampler. A standard stream-gauging wading rod is threaded into the top of the sampler body as a handle.

An automatic water sampler (Plate 13) was also used to intermittently monitor a stream. The ISCO Model 1391 Sample Collector is a portable device designed to collect up to 28 separate samples of a predetermined volume (70 to 490 ml) from a liquid source at intervals from 0.5 to 6 hr. This instrument can be calibrated with the DH-48 depth-integrated handheld sediment sampler. Power sources can be either a 110-v AC or 12-v DC external battery or an optional rechargeable 4-amp-hour nickel-cadmium battery. This battery will furnish sufficient power to collect 100 samples of 0.5 liter each. Occasionally samples were taken by dipping a bottle into the water to "elbow depth."

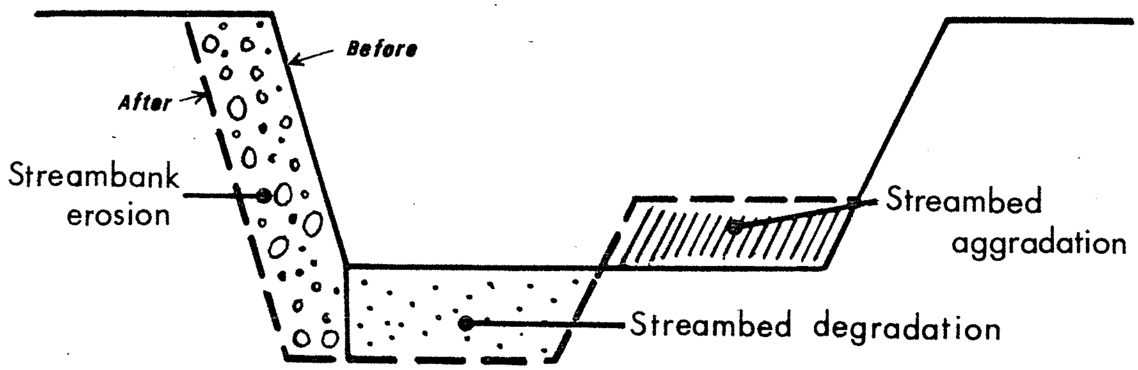


Fig. 10. Example of graphing of the results of the cross-sectional surveys.

Laboratory Analysis

The samples were analyzed for dry weight and expressed as weight per volume. Processing was done in a Gooch crucible fitted with a glass-fiber filter paper and adapted to an aspirator system for vacuum filtration (Plate 14). The filter paper was weighed while dry and before filtration began. After filtration of the whole sample, the paper was again transferred to an oven for drying. The sample was dried for approximately 24 hr at 105 F, then weighed to the nearest milligram. The weight of the filter paper was subtracted from the sample weight, volume correction was then made, and the weight of the sample was expressed in milligrams/liter (ppm).

Juvenile Fish Populations

Fish Capture, Marking, and Recovery

Populations were estimated by the Petersen method, based on the release and recapture of marked fish. Block seines were placed at both ends of the sections to prevent emigration and immigration of fish (Plates 15 and 16). Fish traps were used to measure any emigration from the two forks of C-tributary throughout the summer (Plate 16). The fish were marked with a small clip of the dorsal lobe of the caudal fin.

Two types of backpack shockers were used to capture the fish--the BP-1C variable-voltage pulsator made by Coffelt Electronics Company of Denver, Colorado, and the Type V Electrofisher made by Smith-Root, Inc. of Vancouver, Washington (Plate 17). Average capture efficiency was 39% of the total population during the initial capture. This efficiency was applied to sampling in the upper Clearwater River. Information on length, weight, and scales was recorded for most fish so that numbers, biomass, and age could be estimated for the different size groups.

Extent of Salmonid Habitat

Water surface area was measured in all study sections of Stequaleho Creek at the time of shocking, July through October. Average widths and lengths of study sections were taken and the areas of exposed boulders and logs were subtracted to arrive at net water surface area.

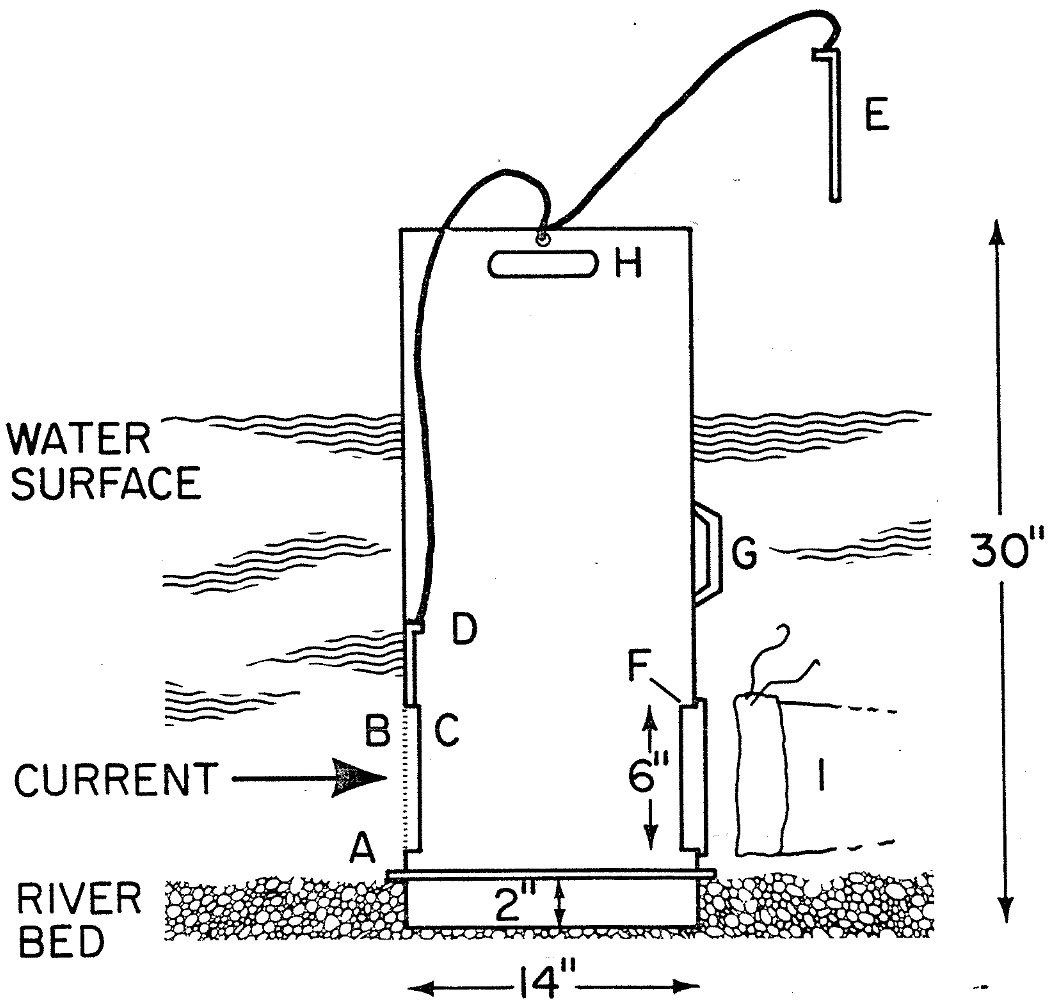
Spawning gravel area was estimated during foot surveys along Stequaleho Creek. The square footage of all patches of gravel suitable for spawning of salmon and trout was approximated. Spawning gravel of salmon or steelhead trout was defined as any depositions of gravel smaller than 6 inches in diameter in water averaging less than 1.5 ft deep. This usually included small scattered deposits of spawnable gravel as the majority of the substrate was of the larger cobble size (Plate 19).

Relative Abundance of Benthic Invertebrates

Of the 15 gravel sampling stations, 10 were selected for study of benthic organisms. The number of stations was limited due to the quantity of time involved in taking and working up bottom samples. Benthic invertebrate sampling stations in Stequaleho Creek unaffected by man-caused slides were St-2_a, St-2_c, and St-3_a; and those affected were St-3_b, St-4, and St-6 (Fig. 7). The stations sampled in the Clearwater River unaffected by the Stequaleho slides were C-2 and C-3, and those affected were C-4 and C-5 (Fig. 5).

The sampler used in this study was Neill's cylinder (Neill, 1938) (Fig. 11 and Plate 20). This device samples 1.1 ft^2 (1,000 cm^2) of substrate. It is simultaneously pushed and rotated into the stream bottom to a depth of 2 inches where a projecting flange stops its progress. Sampling depth was increased to 4.5 inches by thoroughly stirring up and digging the gravel with a metal probe. Organisms trapped by the cylinder are washed into a trailing net by flush water passing through the two openings in the device. The trailing net has 25 meshes per inch, or apertures of slightly less than 1 mm (the manufacturer's standard pore size for the Surber sampler is 1.02 mm). To determine the efficiency of the trailing net, we took 12 samples with another net with a pore size of 247 microns tied behind it.

All samples collected with the larger-meshed net were picked in the field and preserved in 70% alcohol. At a later date they were classified in the laboratory. Because of limitations of time, classification was carried out



A Flange
B Screen over front opening
C Track for sliding door
D Sliding door with attached cord (in track)
E Rear sliding door (hung outside cylinder for flushing)
F Rear opening with flange
G Carrying handle
H Handle for rotating cylinder
I Trailing net
(adapted from Neill, 1938)

Fig. 11. Neill's cylinder.

only to family. It is also important to note that thorough classification keys of insect larvae to species are lacking for this region of the country at this time. Samples collected with the smaller-meshed net were preserved in the field and later picked and classified in the laboratory.

All sampling stations were located on riffles. Most sampling sites had water velocities of 1.0 to 1.5 ft/sec, but occasionally 2.0 ft/sec. Sampling sites were chosen randomly as long as the substrate was able to be sampled (Plate 19).

Two sets of samples were collected in the summer of 1972. The first set was collected between June 12 and 24, and the second from July 27 to August 6. A total of six samples (five in one case) was collected at each station in Stequaleho Creek during each of the two sampling periods and nine samples (eight in three cases) in the Clearwater River.

The data were analyzed by the use of a one-way analysis of variance with a Scheffe's comparison (McCaughran, personal communication). However, normality is a basic assumption of this analysis and since it is known that the bottom fauna is not distributed in a normal fashion (Allen, 1959), a square root transformation of the data was made. For the analysis, St-2_a, St-2_c, and St-3_a were considered as one treatment; St-3_b was considered a second treatment (since this station was affected only by one of the slides); and St-4 and St-6 were considered as a third treatment. For the Clearwater River, C-2 and C-3 were considered as one treatment and C-4 and C-5 as a second treatment.

RESULTS

Composition of the Spawning Gravel

During the summer of 1972, streambed gravel samples were collected from 15 sampling locations in the Clearwater River, Stequaleho Creek, and the Solleks River. A total of 151 samples was collected, or an average of 10 samples per site. The mean percentages of the size classes of gravel for each sampling site are listed in Table 3 and the basic statistics are in Appendix Table 1. The relationships among the gravel sampling sites for 3.36 and 0.841 mm size categories are shown in Fig. 12.

Groups of samples from gravel beds unaffected by the landslides were combined to serve as the control samples and were compared with combined groups of samples from sections of streambed downstream of the landslide in Stequaleho Creek and the lower Clearwater River (Table 4). Their relationship is graphed in Fig. 13.

Statistical tests were performed on the combined groups of samples using a t-test with a Behrens-Fisher distribution. Since sample sizes were unequal, Cochran's approximation of the significance level of t' was used, (Snedecor and Cochran, 1967). The following tests were performed:

Control versus experimental area (anadromous zone of Stequaleho Creek:

Percentage of gravel <3.36 mm

H_o: control = experimental area of Stequaleho Creek

computed $t' = 4.12$

$t'_{0.05} = 2.03$

since $4.12 > 2.03$ reject H_o

Percentage of gravel <0.841 mm

H_o: control = experimental area of Stequaleho Creek

computed $t' = 5.04$

$t'_{0.05} = 2.03$

since $5.04 > 2.03$ reject H_o

Control versus lower Clearwater River:

Percentage of gravel <3.36 mm

H_o: control = lower Clearwater River

computed $t' = 5.45$

$t'_{0.05} = 2.03$

since $5.45 > 2.03$ reject H_o

Table 3. The mean percentages of gravel classes smaller than each sieve size category in samples taken at fifteen locations in the Clearwater River basin, 1972

No.	Location	N	Streambed slope near sampling site (%)	Percentages <77 mm <3.0 inches	<26.9 mm <1.06 inches	<3.36 mm <.132 inches	<0.841 mm <0.0331 inches	<0.124 mm <.0049 inches
1.	ST-2a	8	2.9	92.5	48.7	14.6	7.2	2.7
2.	ST-2_b	8	1.4	100.0	49.3	15.9	7.1	1.9
3.	ST-2_c	7	2.1	95.6	59.0	22.5	8.8	2.8
4.	ST-3_a	8	4.2	100.0	64.6	21.9	7.3	2.5
5.	ST-3_b	8	3.2	98.0	61.7	16.5	6.7	1.9
6.	ST-4	9	2.5	92.9	66.0	25.0	11.0	2.4
7.	ST-5	11	1.7	96.1	62.5	25.5	11.4	2.8
8.	ST-6	12	1.7	96.7	64.5	28.7	10.5	2.7
9.	SO-1	15	3.1	91.1	54.9	20.9	8.2	3.1
10	Cl-1	8	1.4	94.5	66.8	22.2	7.6	2.5
11.	Cl-2	12*	1.0	-	-	-	-	-
12	Cl-3	10	0.8	94.4	60.4	30.6	9.3	2.1
13	Cl-4	10	0.4	97.4	70.4	35.5	9.5	2.6
14.	Cl-5	17	0.2	93.2	47.2	19.6	8.4	2.6
15.	Cl-6	8	0.2	100.0	78.8	31.9	10.5	1.8
		Σ151						

*These samples were washed away during the July storm.

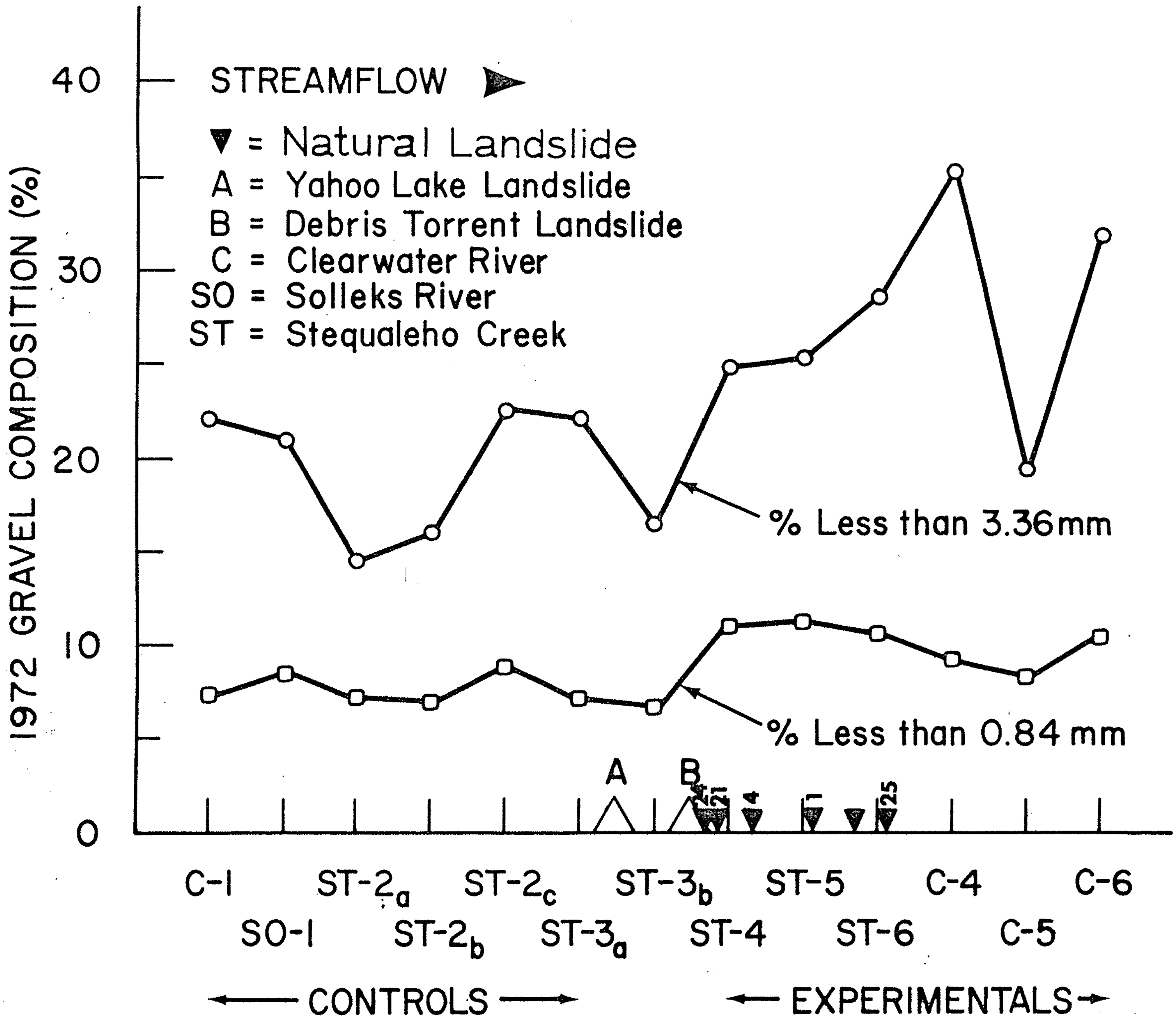


Fig. 12. Mean gravel composition data for 1972 - Clearwater River watershed.

Table 4. Mean percentages of gravel classes in combined control gravel samples and combined experimental samples from the Clearwater River basin, 1972

	<77 mm 3.0 inch	<26.9 mm 1.06 inch	<3.36 mm .132 inch	<0.841 mm .033 inch	<0.124 mm .0049 inch
A. Control					
(St-2$_a$, St-2$_b$, St-2$_c$, St-3$_a$, C-1, SO-1)					
Mean	94.84	56.57	19.66	7.78	2.65
Variance	77.93	143.68	35.12	4.72	0.85
St. Dev.	8.83	11.99	5.93	2.17	0.92
SE MN	1.22	1.66	0.83	0.30	0.13
95 Con	2.46	3.34	1.65	0.61	0.26
Mean - 95 Con	92.38	53.23	18.01	7.18	2.39
Mean + 95 Con	97.30	59.91	21.31	8.39	2.91
N=52					
B. Stequaleho Creek (Anadromous Zone)					
Experimental (St-4, St-5, St-6)					
Mean	95.42	64.26	26.58	10.91	2.65
Variance	107.94	144.67	69.57	9.61	0.76
St. Dev.	10.39	12.03	8.34	3.10	0.87
SE MN	1.84	2.13	1.47	0.55	0.15
95 Con	3.73	4.32	2.99	1.11	0.31
Mean - 95 Con	91.69	59.94	23.58	9.80	2.33
Mean + 95 Con	99.15	68.58	29.57	12.03	2.96
N = 32					
C. Clearwater River (Below Stequaleho Creek)					
Experimental (C-4, C-5, C-6)					
Mean	95.97	61.05	26.96	9.21	2.41
Variance	67.60	276.20	102.92	7.80	0.65
St. Dev.	8.22	16.62	10.15	2.79	0.80
SE MN	1.39	2.81	1.72	0.47	0.14
95 Con	2.82	5.70	3.48	0.96	0.28
Mean - 95 Con	93.15	55.35	23.47	8.25	2.13
Mean + 95 Con	98.79	66.75	30.44	10.17	2.68
N = 35					

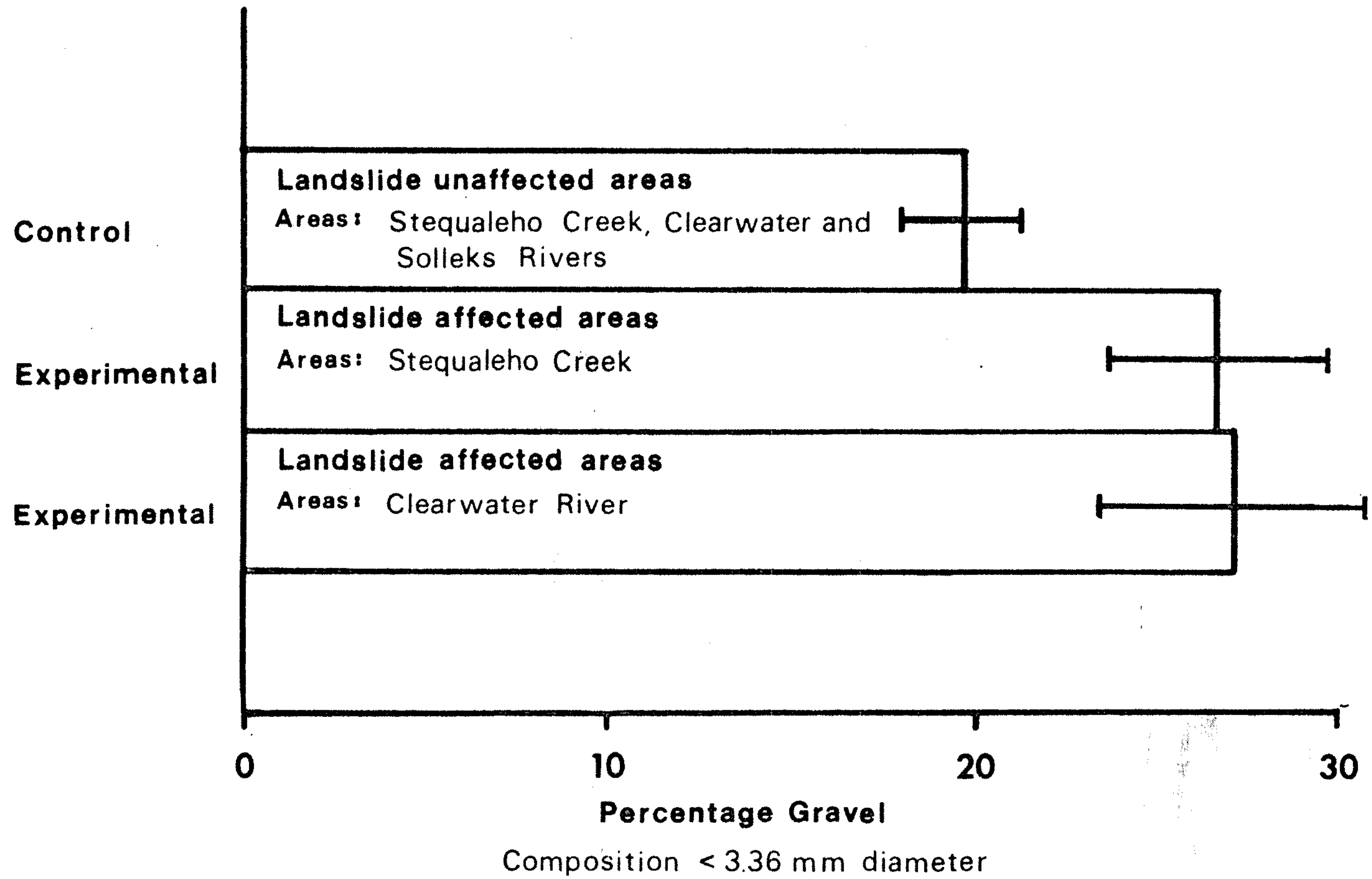


Fig. 13. Means and 95% confidence intervals of gravel less than 3.36 mm in diameter in combined control and combined experimental samples.

Percentage of gravel <0.841 mm

H_o: control = lower Clearwater River

computed t' = 2.56

$t'_{0.05} = 2.02$

since 2.56 > 2.02 reject H_o

Results of the analysis show that spawning areas affected by the man-caused landslide of May 1971 have a higher content of fine sediment than those unaffected. The spawning gravel in the anadromous zone of Stequaleho Creek has statistically higher amounts of material less than 3.36 mm and 0.841 mm in size than the spawning gravel in the control sites. The spawning gravel in the affected (lower) parts of the Clearwater River also had statistically higher amounts of material smaller than 3.36 mm and 0.841 mm, than the spawning gravel in the control sites.

Intragravel Sediment Monitors

Two sediment monitors were placed at each of three locations in landslide-affected areas of Stequaleho Creek ($St\text{-}3_b$, St-4, and St-6) and two were placed in each of three locations above the landslide influence ($St\text{-}1_a$, $St\text{-}2_a$, and $St\text{-}3_a$). The plan was to retrieve these samples once every 2 months; but during the second period we lost 10 of the samplers from high streamflow. The results of this experiment for the period October through December are shown in Table 5. It appears that accumulated sediment was noticeably higher ($\overline{x}$ = 248 g) in the monitors placed in the area affected by the man-caused landslides than in the unaffected sites ($\overline{x}$ = 90 g).

Table 5. Accumulated amounts of fines in the intragravel sediment monitors from October through December 1972

Sample number	Experimental			Control		
	$St\text{-}3_b$	St-4	St-6	$St\text{-}1_a$	$St\text{-}2_a$	$St\text{-}3_a$
1	139 g	346	--[1]	119	74	42
2	--[1]	313	193	180	19	100
Mean		248			90	

[1]These samples were lost during retrieval.

Intragravel Egg Box Experiments

Cutthroat Trout

During the winter and early spring of 1972, 54 boxes of 100 eyed cutthroat trout eggs were planted and recovered in landslide-affected and -unaffected areas of Stequaleho Creek to test the effect of sedimentation on the intragravel survival to hatching of cutthroat trout. This experiment had complications due to the inability to account for all 100 eggs in each box at recovery time. There are three pieces of evidence that may explain this discrepancy: (1) decomposition of the eggs made it hard to distinguish the individual dead eggs. This explanation is probably the most realistic because a similar problem was encountered by Kral (1967) at the Satsop Springs incubation channel. If this explanation is accepted, unaccounted-for eggs were probably dead eggs; (2) the missing eggs could also have been eaten by stoneflies of the genus *Alloperla* which were found in the egg boxes at recovery. Nicola (1966) found that stoneflies were scavengers on dead eggs, but not predators on live eggs. If this explanation were accepted, again the missing eggs would be dead; (3) it may have been possible that some of the smaller alevins escaped through the 5/64-inch holes in the egg boxes. In this case, the missing eggs would have survived. This may have occurred, because some alevins were found halfway through the holes of the boxes at the time of recovery, but we doubt if it could account for all of the missing eggs. Since either of these explanations could have occurred the data are presented in two ways: (a) the missing eggs were dead, and (b) the missing eggs were alive.

Either way it appears as if the cutthroat trout survival from eyed egg to hatch was the same in the landslide-affected (78.3% or 90.3%) and -unaffected areas (76.0% or 88.3%) (Table 6).

Table 6. Percentage survival to hatching of planted eyed cutthroat trout eggs in landslide-affected (experimental) and -unaffected (control) areas of Stequaleho Creek, 1972

		Experimental						Control					
		St-6		St-4		$St\text{-}3_b$		St-3[1]		$St\text{-}2_a$		$St\text{-}2_c$	
Site No.	Buried egg No.	A	B	A	B	A	B	A	B	A	B	A	B
1	100	84	94	83	84	63	94	83	89	77	88	76	86
2	100	80	94	86	98	84	97	82	91	79	97	87	97
3	100	82	95	81	92	85	92	86	97	83	96	76	87
4	100	79	87	88	95	85	95	79	93	79	87	79	90
5	100	87	93	84	91	84	99	87	97	38	62	84	86
6	100	89	98	85	98	80	99	78	95	65	87	88	91
7	100	77	83	59	88	48	76	79	87	76	87	77	94
8	100	87	93	74	84	96	97	85	96	73	87	89	92
9	100	87	99	93	96	6	24	16	41	64	89	90	98
$\overline{X}$	100	84	93	81	92	70	86	75	87	70	87	83	91

Experimental: $\overline{X}A = 78.3$, $\overline{X}B = 90.3$; Combined $\overline{X} = 84.3$

Control: $\overline{X}A = 76.0$, $\overline{X}B = 88.3$; Combined $\overline{X} = 82.1$

A = missing are dead
B = missing escaped

[1]St-3 boxes were planted in "A" tributary.

Steelhead Trout

During the winter and early spring of 1973, 18 boxes of 200 eyed steelhead trout eggs each were planted and recovered in landslide-affected and -unaffected areas of Stequaleho Creek to test the effect of sedimentation of spawning gravels on the intragravel survival to yolk absorption.

Station St-6 experienced an extremely high mortality of eggs. This high mortality was not consistent with experimental stations St-4 and St-5, which had high survivals. One explanation of the unusually high mortality at St-6 was that a low water period in March may have killed some of the eggs due to poor water circulation to the boxes. Another explanation would be that high silt levels in these boxes may have killed these eggs.

Due to the possibility that the egg boxes at St-6 may have been dry during a low water period in March, the results are presented in two ways. Table 7a includes the St-6 boxes and Table 7b does not. A shifting stream channel at station $St\text{-}2_a$ left three control egg boxes high and dry, and therefore no data are presented, except that there was 100% mortality in each box. At station St-5, one experimental box was accidently dropped and many of the alevins were lost, but the survival in this box appeared to be high.

If the St-6 samples are included, then there was a 16% greater survival in the control boxes than in the experimental. If the St-6 samples are not included, then there was a 7% greater survival in the experimental boxes than in the controls. Again, this is survival from eyed egg stage to yolk absorption, and it is survival of eggs in a protective plastic box which would eliminate the gravel shift factor (crushing of eggs).

Coho Salmon

During the winter and early spring of 1973, 60 boxes of 100 eyed coho salmon eggs each were planted in landslide-affected and -unaffected areas of Stequaleho Creek to test the effects of intragravel sediment on survival to yolk absorption. High flows in January 1973 washed out or buried beyond recovery 55 of the 60 boxes; therefore, the data from this experiment were not used. However, evidence of gravelbed instability in both the experimental and control areas was apparent from the loss of most boxes in both areas.

Streambed Stability

During 1972 and 1973 changes in the streambed cross section were measured throughout three 500-ft stations of Stequaleho Creek (St-4, St-5, and St-6) to serve as an index to the relative stability of the streambed.

As one progresses downstream in the anadromous area of Stequaleho Creek there is an increase in gravel deposition as well as an increase in streambank

Table 7a. Percentage survival to yolk absorption of eyed steelhead trout eggs planted in landslide-affected (experimental) and -unaffected (control) areas of Stequaleho Creek, 1973 (including St-6)

	Experimental						Control					
	St-4		St-5		St-6		$St\text{-}2_a$ [1]		$St\text{-}2_a$		$St\text{-}2_c$	
Box number	% Survival	Weight silt (g)	% Survival	Weight silt (g)	% Survival	Weight silt (g)	% Survival	Weight silt (g)	% Survival	Weight silt (g)	% Survival	Weight silt (g)
1	77	18	80	21	0.5	37	--	--	82	14	97	37
2	76	26	89	9	1.0	44	--	--	62	5	53	21
3	92	22	-- [2]	--	42.0	49	--	--	96	4	68	37
$\bar{X}$												
Overall	60.0% survival, 26.7 grams silt						76.0% survival, 19.0 grams silt					

[1]Lost all eggs due to stream drying up.
[2]Dropped the egg box and lost many eggs. The survival appeared to be high.

Table 7b. Percentage survival to yolk absorption of eyed steelhead trout eggs planted in landslide-affected (experimental) and -unaffected (control) areas of Stequaleho Creek, 1973 (not including St-6)

	Experimental						Control					
	St-4		St-5		St-6		$St\text{-}2_a$ [1]		$St\text{-}2_a$		$St\text{-}2_c$	
Box number	% Survival	Weight silt (g)	% Survival	Weight silt (g)	% Survival	Weight silt (g)	% Survival	Weight silt (g)	% Survival	Weight silt (g)	% Survival	Weight silt (g)
1	77	18	80	21	--	--	--	--	82	14	97	37
2	76	26	89	9	--	--	--	--	62	5	53	21
3	92	22	-- [2]	--	--	--	--	--	96	4	68	37
$\bar{X}$												
Overall	83.0% survival, 18 grams silt						76.0% survival, 19 grams silt					

[1]Discarded this sample because of shifting streambed left it high and dry.
[2]Dropped the egg box and lost many eggs. The survival appeared to be high.

erosion. Streambed degradation (scour) seems to remain about the same in each section, but appears to be slightly higher in St-5.

There is a net downstream movement of streambed gravels, with a loss of 23 yd^3 from station St-4, a loss of 432 yd^3 from station St-5, and a gain of 478 yd^3 at station St-6 (Fig. 14). The loss from stations St-4 and St-5 almost equals the gain at station St-6 (Appendix Table 2).

Lower Stequaleho Creek is unstable in the streambed and embankments, but because comparisons with other streams were not made, the relative stability of Stequaleho Creek cannot be determined (Fig. 14).

Concentrations of Suspended Sediment

During February and March of 1972, a series of 14 tributaries of the Clearwater River and the Hoh River were sampled at nine different times for determination of general concentration of suspended sediment (Fig. 15). The greatest interval of time separating the first and last samples taken on any particular occasion was 2.5 hr.

During the summer of 1972, Stequaleho Creek was clear almost all of the time, except during the storm in July. Occasionally, the creek would turn turbid for no apparent reason. The source was later discovered to be sloughing of loose material from the Yahoo and Debris Torrent slide areas (Plate 18).

Concentrations of suspended sediment ranged widely among the various tributaries of the Clearwater River. They were highest during periods of heavy rainfall and relatively heavy in those tributaries with great mineral soil exposure (i.e., logging roads and associated erosion). During February and March 1972, Stequaleho Creek, Kunnamahst Creek, and Deception Creek had the highest concentrations of suspended sediment of the tributaries sampled, and it was found that these were mainly associated with failure of logging road sidecast. Those streams sampled having minimum amounts of recent soil disturbance, had low concentrations of suspended sediment (Table 8).

During November and December 1972 we sampled Stequaleho Creek and two unlogged tributaries of the Clearwater River (Upper Solleks River and Kloochman Creek). In almost every case, concentrations of suspended sediment

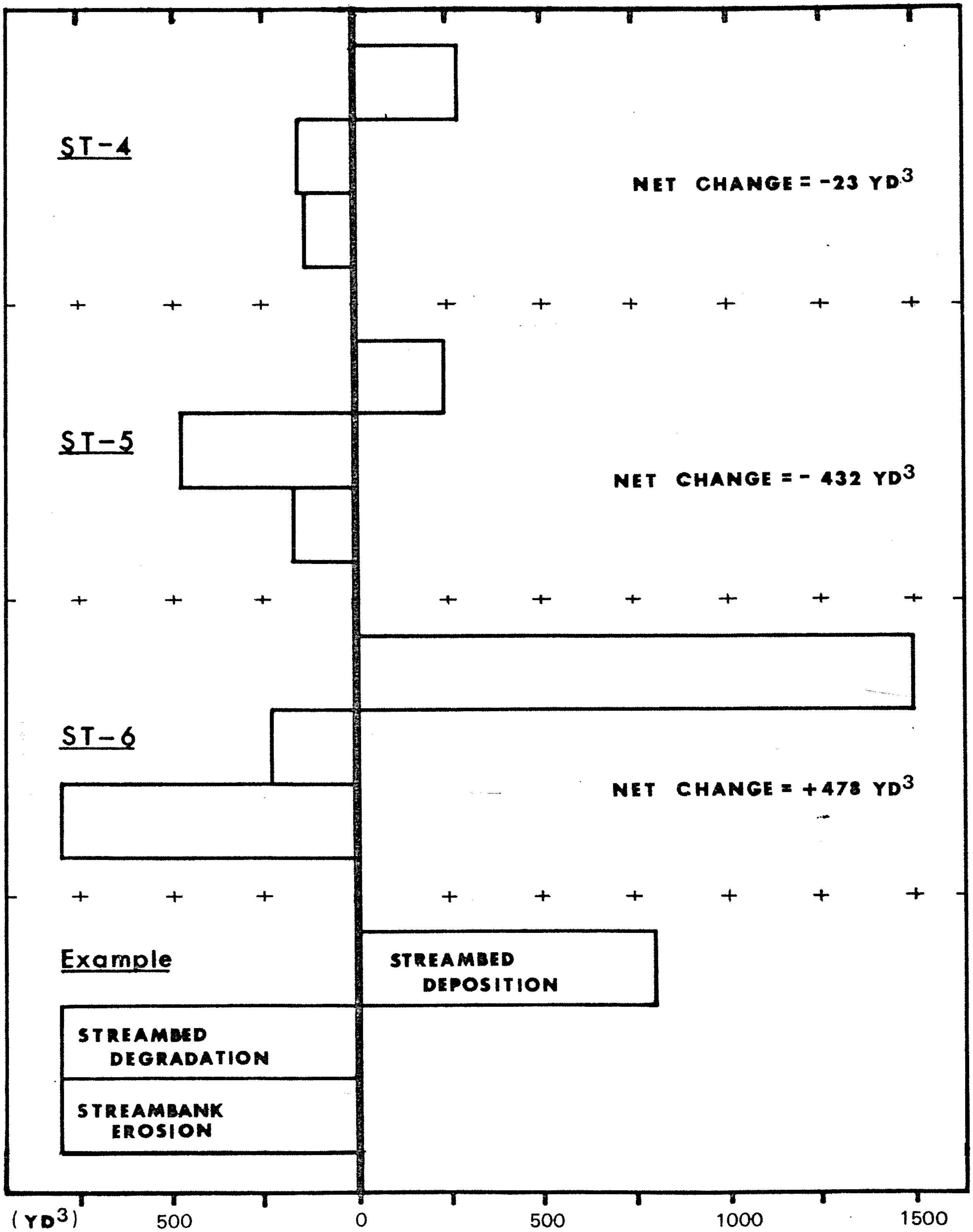


Fig. 14. Streambed and embankment changes at stations St-4, St-5, and St-6 of Stequaleho Creek, 1972-73.

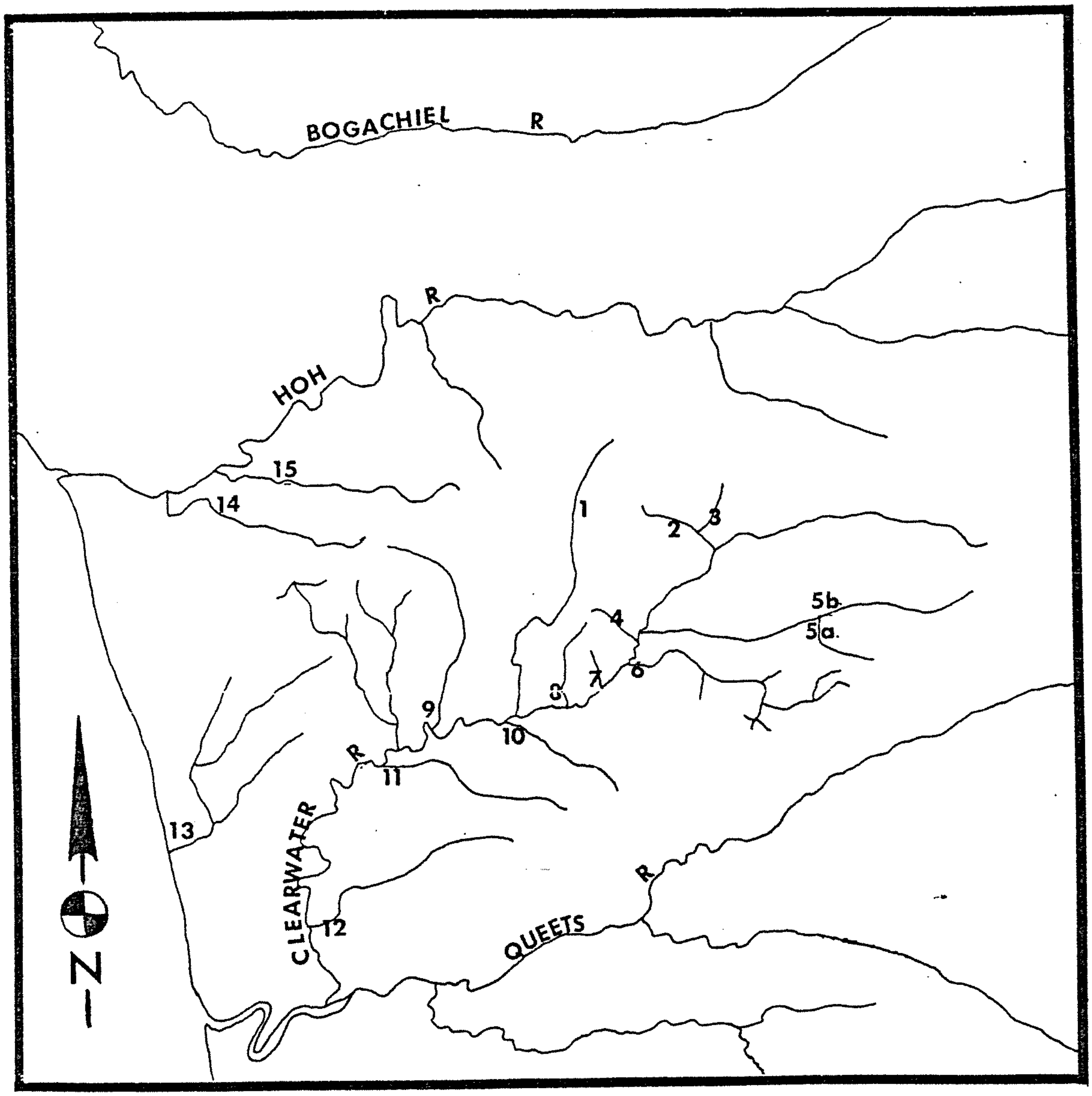


Fig. 15. Stations from which suspended sediment was sampled in the Clearwater River and Hoh River, 1972.

1. Snahapish River
2. Kunnamakst Creek
3. Kunnamakst East Fork
4. Nancy Creek
5a. Kloochman Creek
5b. Solleks River above Kloochman Creek
6. Stequaleho Creek
7. Unnamed Creek
8. Bull Creek
9. Christmas Creek
10. Deception Creek
11. Shale Creek
12. Hurst Creek
13. Kalaloch Creek
14. Braden Creek
15. Nolan Creek

Table 8. Concentrations of suspended sediment in Stequaleho Creek and 13 nearby streams, 1972.

Location	Total drainage area (mile^2)	Approx. area clearcut (%)	Approx. miles of logging road	Concentrations of suspended sediment (mg/l)								
				2/13	2/15	2/15	2/16	2/23	2/26	2/27	2/28	3/5
Upper Snahapish River	5.1	36	9.7	18	32	87	1	0	0	22	66	224
Kunnamakst Creek	2.2	15	2.7	9	14	37	100	0	0	*4,379	*279	*2,089
Kunnamakst East Fork	0.8	8	0.6	11	15	112	87	0	0	179	53	250
Nancy Creek	0.3	5	0.0							0	0	2
Unnamed Creek	0.2	0	0.0		9	39	22	0	0	14	12	66
Stequaleho Creek	9.5	12	14.0	50	93	361	416	0	0	941	246	2,778
Bull Creek	2.0	29	5.3	6	14	60	10	0	0	41	6	87
Christmas Creek	9.2	15	10.6	24	50	131	36	0	0	167	80	592
Deception Creek			4.5					2,766**	1,683**			188
Shale Creek	5.7	18	6.2	3	28	48	9	0	0	0	9	195
Hurst Creek	8.3	33	12.1	3	54	61	35	0	0	-	-	134
Kalaloch Creek	16.7	30	14.9	9	86	96	33	0	0	-	-	278
Braden Creek	2.0	15	5.4	3	9	25	18	0	0	-	-	61
Nolan Creek	8.7	30	12.3	19	40	58	49	0	0	-	-	486

*Originated in sidecast failure from a logging road.
**Caused by landslide in Prairie Creek during winter road building.

were several times greater in Stequaleho Creek than in the other two areas (Table 9).

During a storm on May 24, 1973 an aerial survey of the Clearwater River was made to detect major sediment-contributing tributaries. Four were found: (1) Miller Creek, (2) Christmas Creek, (3) Snahapish River, and (4) Stequaleho Creek. Each of these tributaries had been and was then being heavily logged. The more turbid of the tributaries had extensive soil exposure in landslide areas caused by logging road construction. The upper Clearwater River above logging road construction was clear (Table 10).

Fishery Habitat and Resources, Stequaleho Creek

Anadromous Zone

Habitat. A waterfall formed by a natural rockslide, 2.1 miles upstream from the mouth of Stequaleho Creek, marks the limit of upstream migration. The mean streambed slope in the anadromous zone is 2.3%. The low flow in 1972 of 8.8 cfs occurred during the second week of September. At that time the total water surface area was 29,363 yd^2. Rapids form the greater part of this stretch of stream, making up 19,488 yd^2 of surface area; whereas pools cover only 9,875 yd^2 (Table 11).

Our surveys show a total of 1,240 yd^2 of spawning gravel available in the anadromous zone, mostly occurring in the upstream half. For example, between St-4 and St-5 we found 29.1 yd^2 per 100 linear ft as compared to 4.9 yd^2 per 100 linear ft near the mouth (Table 12). The stream bottom in the rapids is principally composed of cobbles and boulders with interspersed deposits of spawning gravel (Plate 19).

Fish Resources. The standing crop of fish in the anadromous zone (St-4, St-5, and St-6) was derived from two indices, the relative density (number of fish per unit of water surface area) and the relative biomass (weight of fish per unit of water surface area) supported during low flow.

During low flow in 1972 the average standing crop of trout was 0.277 fish/yd^2 (10.8 lb/acre), and the average standing crop of coho salmon was 0.043 fish/yd^2 (2.7 lb/acre). The standing crop, expressed as biomass, of

Table 9. Concentrations of suspended sediment mg/l in Stequaleho Creek and two relatively natural streams, 1972

Date	Stream gauge height	Stequaleho Creek[1]	Solleks River[2]	Kloochman Creek[3]
11/1	0.5	21	9	5
11/3	1.50	187	60	63
11/4	1.86	57	8	5
11/4	1.53	47	-	-
11/6	1.35	15	7	0
11/6	1.35	15	0	0
11/6	1.45	9	2	5
11/6	1.50	26	5	4
11/6	1.55	27/30	2	2
12/16	1.34	98	5	8
12/16	1.52	98	11	72
12/16	2.50	182	56	37
12/17	1.70	33	89	14
12/17	1.85	53	10	11
12/17	3.20	1,074/1,026	410	273
12/19	2.34	365	-	-
12/20	1.68	56	5	5

[1]Approximately 14 miles of road in watershed.

[2]Approximately 0.1 mile of road in watershed.

[3]0 miles of road in watershed.

Table 10. Locations and conditions of sediment sources in the Clearwater River from aerial survey, 9:30 - 10:30 A.M., May 24, 1973

Location	Clear	Semi-turbid	Turbid	Very turbid	Muddy
Bogachiel River Park Boundary				X	
Queets River at mouth				X	
Clearwater River at mouth					X
Queets River above Clearwater River			X		
Hurst Creek at mouth	X				
Clearwater River above Hurst Creek					X
Hunt Creek at mouth	X				
Clearwater River above Hunt Creek					X
Shale Creek at mouth		X			
Clearwater River above Shale Creek					X
Miller Creek at mouth*					X
Clearwater River above Miller Creek					X
Christmas Creek at mouth*					X
Clearwater River above Christmas Creek					X
Deception Creek at mouth	X				
Clearwater River above Deception Creek					X
Snahapish River at mouth *					X
Clearwater River above Snahapish River				X	
Stequaleho Creek at mouth *				X	
B tributary (Muddy tributary)					X
Above B tributary		X			
Clearwater River above Stequaleho Creek			X		
Solleks River at mouth		X			
Clearwater River above Solleks River			X		
Kunnamakst Creek at mouth	X				
Clearwater River above Kunnamakst Creek			X		
Wilson Creek at mouth	X				
Clearwater River above Wilson Creek		X			
Ding-a-ling at mouth		X			
Clearwater River above Ding-a-ling Creek	X				

* Major sediment sources

Table 11. Areas of total water surface, pools, and rapids of study stations in the anadromous zone of Stequaleho Creek 1972

Location	Survey date	Stream discharge (cfs)	Length (ft)	Net water surface area yd^2 (acres) Pools	Rapids	Total
St-4	9/13	12	466	468 (0.10)	833 (0.18)	1,351 (0.28)
St-5	9/11	12	452	473 (0.10)	562 (0.12)	1,035 (0.22)
St-6	9/14	12	474	619 (0.13	1,060 (0.22)	1,679 (0.35)
Mean			464	520 (0.11)	835 (0.17)	1,355 (0.28)
Total anadromous zone		12	11,090	9,875	19,488	29,363

Table 12. Actual and relative amounts of spawning gravel found throughout the anadromous zone of Stequaleho Creek, 1972.

	Length of section (miles)	Total spawning gravel area	Relative spawning gravel area (yd^2/lineal 100 ft)
Anadromous block to St-4	.47	49	2.0
St-4	.09	69	14.5
St-4 to St-5	.23	353	29.1
St-5	.09	52	10.9
St-5 to St-6	.89	573	12.2
St-6	.09	64	13.5
St-6 to mouth	.31	80	4.9
Total	2.17	1,240	

total teleosts was 72.0 lb/acre (Tables 13 and 14) of which approximately 80% was made up of dace and sculpins.

An estimate was made of the total trout and coho salmon populations in the anadromous zone of Stequaleho Creek. It was found that there were 7,020 age-0 trout, 1,177 age-1 trout and older, and 1,188 coho salmon juveniles (Table 15).

A comparison was made between the anadromous zone of Stequaleho Creek and the upper Clearwater River. There were 0.24 age-0 trout/yd^2 in Stequaleho Creek, compared to 0.41 age-0 trout/yd^2 in the Clearwater River, and 0.04 age-1 and older trout/yd^2 in Stequaleho Creek, compared to 0.07 age-1 and older trout/yd^2 in the Clearwater River. There were 0.04 coho salmon/yd^2 in Stequaleho Creek, compared to 0.15 coho salmon/yd^2 in the Clearwater River (Table 16). The data collected in the Clearwater River are not detailed enough to be tested statistically at this time.

Resident Zone

A major portion of the Clearwater River headwaters supports resident cutthroat trout populations. These fish are quite small (largest found 9 inches) during their residence in the steeper feeder streams, and usually are not of catchable size. The value of these small tributaries must not be underestimated, however, for they may provide recruitment to the resident and anadromous populations in lower Stequaleho Creek (Royal, 1972).

As part of the general surveys of the fish resources of Stequaleho Creek some of the characteristics of these cutthroat populations were looked at. The work centered on C-tributary, a major branch of Stequaleho Creek (Fig. 5). This stream has an average streambed slope of 4% and a summer low flow discharge of approximately 1.5 cfs. Cutthroat spawning takes place between March and June, peaking in early May. Gravid females were observed as small as 4 inches actively spawning. The fecundity of eight females in late March 1973 ranged from 63 to 276 eggs. These fish were from 113 mm to 193 mm in length. Three redds, ranging in size from 2.5 ft^2 to 9.8 ft^2, were found to have actual egg depositions of 46 and 167 eggs, respectively.

Table 13. Estimated population densities, mean fork lengths, and absolute numbers of juvenile salmonids in study stations--St-4, St-5, and St-6--of Stequaleho Creek, September 1972

Station	Survey date	Steelhead and coastal cutthroat*						Coho salmon		
		Age 0			Age 1 and older					
		Number/ yd^2	Average fork length (mm)	Number	Number/ yd^2	Average fork length (mm)	Number	Number/ yd^2	Average fork length (mm)	Number
St - 4	9/13									
Pool		.143	58	67	.026	132	12	.179	82	84
Riffle		.274	57	242	.052	101	46	.009	81	8
Overall		.229	57	309	.043	108	58	.068	81	92
St - 5	9/11									
Pool		.135	58	64	.017	79	8	.076	81	36
Riffle		.265	61	149	.078	105	44	.007	80	4
Overall		.206	60	213	.050	102	52	.039	81	40
St - 6	9/14									
Pool		.268	63	166	.003	102	2	.021	79	13
Riffle		.277	61	294	.045	96	48	.025	80	26
Overall		.274	61	460	.030	96	50	.023	80	39
Average	11,13,14									
Pool		.182			.015			.092		
Riffle		.272			.058			.014		
Overall		.236			.041			.043		

*Includes resident cutthroat .

Table 14. Estimated relative biomass of teleosts in the anadromous zone of Stequaleho Creek, September 1972

	Survey date	Stream discharge (cfs)	Trout lbs/acre	Coho lbs/acre	Total salmonids lbs/acre	Total non-salmonids lbs/acre	Total teleosts lbs/acre
St-4	9/13	12	10.7	4.3	15.0	42.8	57.8
St-5	9/11	12	12.8	2.4	15.2	79.3	94.5
St-6	9/14	12	8.9	1.3	10.2	53.5	63.7
	Mean	12	10.8	2.7	13.5	58.5	72.0

Table 15. Total population of juvenile salmonids in the area available to anadromous fishes of Stequaleho Creek, September 1972

	Stream discharge (cfs)	Total water surface area (yd^2)	Trout[1] Age 0	Trout[1] Age 1 & older	Coho salmon
Pool		9,875	2,365	395	915
Rapid		19,488	4,655	782	273
Total	12	29,363	7,020	1,177	1,188

[1]Cutthroat and steelhead trout combined.

Table 16. Densities of trout and coho salmon in Stequaleho Creek compared with those in the upper Clearwater River, 1972

	Survey date	Stream discharge (cfs)	Steelhead and cutthroat trout: Age 0		Age 1 & older		Coho salmon	
			No/yd^2 =	Length (mm)	No/yd^2 =	Length (mm)	No/yd^2 =	Length (mm)
Stequaleho Creek	9/11-14	12	0.24	59	0.04	102	0.04	81
Clearwater River*	9/18	18	0.41	57	0.07	104	0.15	68

*Preliminary data; cannot be tested statistically at this time.

Resident cutthroat trout eggs and alevins incubate through early summer and emerge from the gravel sometime in early July, showing up in the October catches as 25-50 mm fry.

The population size of a very small fork of C-tributary, referred to as the "East Fork of C-tributary" ($St\text{-}1_c$) was determined. East Fork has been used as the control stream by Lawrence Lestelle in his thesis research, concerned with the effects of log jam removal on the carrying capacity of a small coastal cutthroat trout stream. This tributary has a low flow discharge of 0.2 cfs and an average streambed slope of 6%. The fish population size varies, depending on the time of year. In July 1972 there were approximately 158 age-1 and older trout in the 1,600 ft of habitable stream. By October 1972 there were 277 trout of which 130 were age-0 recruits from the previous spring spawn. There was an over-summer mortality of approximately 11 age-1 and older fish. The following March we found 183 trout and thus estimated an over-winter mortality of approximately 94 fish. It is believed that by July 1973 the population will again approximate the size found during the previous July (Table 17). The population densities and relative biomasses of trout and sculpins found in East Fork during 1972-73 are shown in Table 18.

Table 17. Means and 95% confidence intervals for the total populations of juvenile salmonids in East Fork "C," a headwater tributary of Stequaleho Creek, July, October, and March 1972-73.

1972-73 month	Total water surface area (yd^2)	Trout		Total combined
		Age 0	Age 1 & older	
July	1,099	0	158 (99-217)	158 (99-217)
October	1,099	130	147 (103-191)	277 (213-341)
March	1,099+	0	183 (110-255)	183 (110-255)

Table 18. Estimated relative biomass of teleosts in East Fork "C," a headwater tributary of Stequaleho Creek, July, October, and March 1972-73.

Survey date	Trout lb/acre	Sculpin lb/acre	Total lb/acre
July 1972	11.7	23.8	35.5
October 1972	13.0	15.3	28.8
March 1973	15.3	17.3	32.6

Comparison of Numbers of Benthic Invertebrates

Stequaleho Creek

The mean numbers of benthic organisms per 1.1 ft^2 for the stations are given in Tables 19 and 20. They were highest at the three unaffected stations during both sampling periods (Fig. 16a); the mean for the three stations combined was 158.5 organisms per 1.1 ft^2 during the first sampling period and 124.9 during the second. The means for the two stations below the Debris Torrent Slide were significantly lower than those for the stations unaffected by the landslides; they were 40.9 and 31.6 organisms per 1.1 ft^2 for the two sampling periods, respectively. Thus, approximately one-fourth as many organisms per sample were taken during both sampling dates in the two affected stations as in the three unaffected stations. Station St-3$_b$, located between the Yahoo Lake slide and the Debris Torrent slide, had averages of 76.4 and 86.2 organisms per 1.1 ft^2 for the two sampling dates, respectively.

Table 19. Average numbers of benthos per 1.1 ft^2 in Stequaleho Creek and the Clearwater River from June 12 to 24, 1972 (by family)

Order and family	Stequaleho Creek above C-tributary St - 2a	C-tributary St - 2c	Stequaleho Creek above B-tributary St - 3a	Stequaleho Creek below B-tributary St - 3b	St - 4	St - 6	C-2	C-3	C-4	C-5
Number of samples	6	6	6	6	6	6	9	9	8	9
ACARINA	1.7	2.3	0.5	0.5	0.2	0	2.4	1.0	0.5	0
COLEOPTERA										
Dryophidae	3.3	0.3	13.7	4.5	1.5	1.8	21.1	7.8	4.8	0.3
Dytiscidae	1.0	0.5	0	0.2	0.5	0	0	0.2	0	0
Elmidae adults	5.0	2.2	11.8	7.3	0.8	1.8	5.4	5.9	4.2	2.7
Elmidae larvae	13.2	5.7	12.5	1.3	0.8	1.0	4.2	3.4	8.6	0.7
Total	22.5	8.7	38.0	13.3	3.8	4.6	30.7	17.3	17.6	3.7
DIPTERA										
Ceratopogonidae	0.3	0.3	0.5	0	0.2	0.2	0.4	0	0.1	0
Chironomidae	18.3	31.0	6.2	5.8	2.5	2.2	7.9	3.1	2.5	13.4
Empidae	0.2	0.3	0	0.3	0	0	0	0	0	0
Psychodidae	0	0	0	0	0	0	0	0	0	0
Rhagionidae	0.3	0	0	0	0.5	0	0.7	1.2	0.5	0.4
Simulidae	0	0	0	0.3	0	0	0.1	0	0	0.1
Tabanidae	0	0	0	0	2.2	0	0	0	0.4	0
Tipulidae	2.5	4.3	2.3	2.3	0.7	0.5	3.6	1.7	0.9	0.4
Total	21.6	35.9	9.0	8.7	6.1	2.9	12.7	6.0	4.4	14.3

Table 19. Average numbers of benthos per 1.1 ft^2 in Stequaleho Creek and the Clearwater River from June 12 to 24, 1972 (by family) - continued

Order and family	Stequaleho Creek above C-tributary St - 2a	C-tributary St - 2c	Stequaleho Creek above B-tributary St - 3a	Stequaleho Creek below B-tributary St - 3b	St - 4	St - 6	C-2	C-3	C-4	C-5
Number of samples	6	6	6	6	6	6	9	9	8	9
EPHEMEROPTERA										
Baetidae	8.5	16.8	27.2	6.5	5.8	4.8	9.8	5.0	8.9	8.1
Ephemerella	17.7	35.5	31.2	15.5	11.2	4.0	12.4	4.8	6.6	8.8
Heptagenidae	29.0	14.8	21.2	18.7	6.0	3.3	32.0	3.4	7.9	9.7
Leptophlebiidae	5.5	0.2	2.2	0.7	0	0	0	0.1	0	0.1
Siphlonuridae	17.0	7.0	3.0	1.2	6.2	3.3	2.0	0.9	1.0	1.1
Total	77.7	74.3	84.8	42.6	29.2	15.4	56.2	14.2	24.4	27.8
OLIGOCHAETA	1.0	0	0.2	0.2	0.3	0.3	1.4	0	2.0	0
PLECOPTERA										
Chloroperlidae	10.2	10.2	11.3	5.8	0.7	1.5	1.9	0.6	0.6	1.0
Nemouridae	0	0	0	0	0	0	0	0	0	0
Peltoperlidae	0	0	0	0.2	0	0	0	0	0	0
Perlidae	12.7	3.5	11.0	3.3	1.5	1.2	3.7	6.0	3.9	1.0
Perlodidae	0.2	1.7	0.2	0.7	0.7	0.2	0.2	0	0.1	0
Pteronarcidae	0	0	0	0	0	0	0.1	0.2	0.2	0.1
Total	23.1	15.4	22.5	10.0	2.9	2.9	5.9	6.8	4.8	2.1

Table 19. Average numbers of benthos per 1.1 ft^2 in Stequaleho Creek and the Clearwater River from June 12 to 24, 1972 (by family) - continued

Order and family	Stequaleho Creek above C-tributary St - 2a	C-tributary St - 2c	Stequaleho Creek above B-tributary St-3a	Stequaleho Creek below B-tributary St - 3b	St - 4	St - 6	C-2	C-3	C-4	C-5
Number of samples	6	6	6	6	6	6	9	9	8	9
TRICHOPTERA										
Glossosomatidae	0.3	0	0.5	1.2	0	0	0	3.4	5.5	0.1
Hydropsychidae	0	0	0.5	0.3	0.3	0	1.	7.1	12.8	7.2
Leptostomatidae	0.2	0	0.7	0	0.3	0	0.3	0.4	0.5	1.3
Limniphilidae	7.2	1.2	2.7	1.5	1.3	7.8	4.6	7.0	4.1	7.9
Rhyacophilidae	3.0	5.5	4.8	2.3	0.7	0.3	4.0	2.6	3.1	3.0
Total	10.7	6.7	9.2	5.3	2.6	8.1	9.9	20.5	26.0	19.5
HIRUDINEA	0	0.2	0.3	0	0.2	0	0.2	0	0.1	0
OTHER (Pupa)	1.2	6.3	1.8	0.7	1.7	0.7	0.4	0.7	1.6	1.0
GRAND TOTAL	159.5	149.8	166.3	81.5	46.8	35.0	120.0	66.7	81.5	68.5

Table 20. Average numbers of benthos per 1.1 ft^2 in Stequaleho Creek and Clearwater River from July 27 to August 6, 1972 (by family)

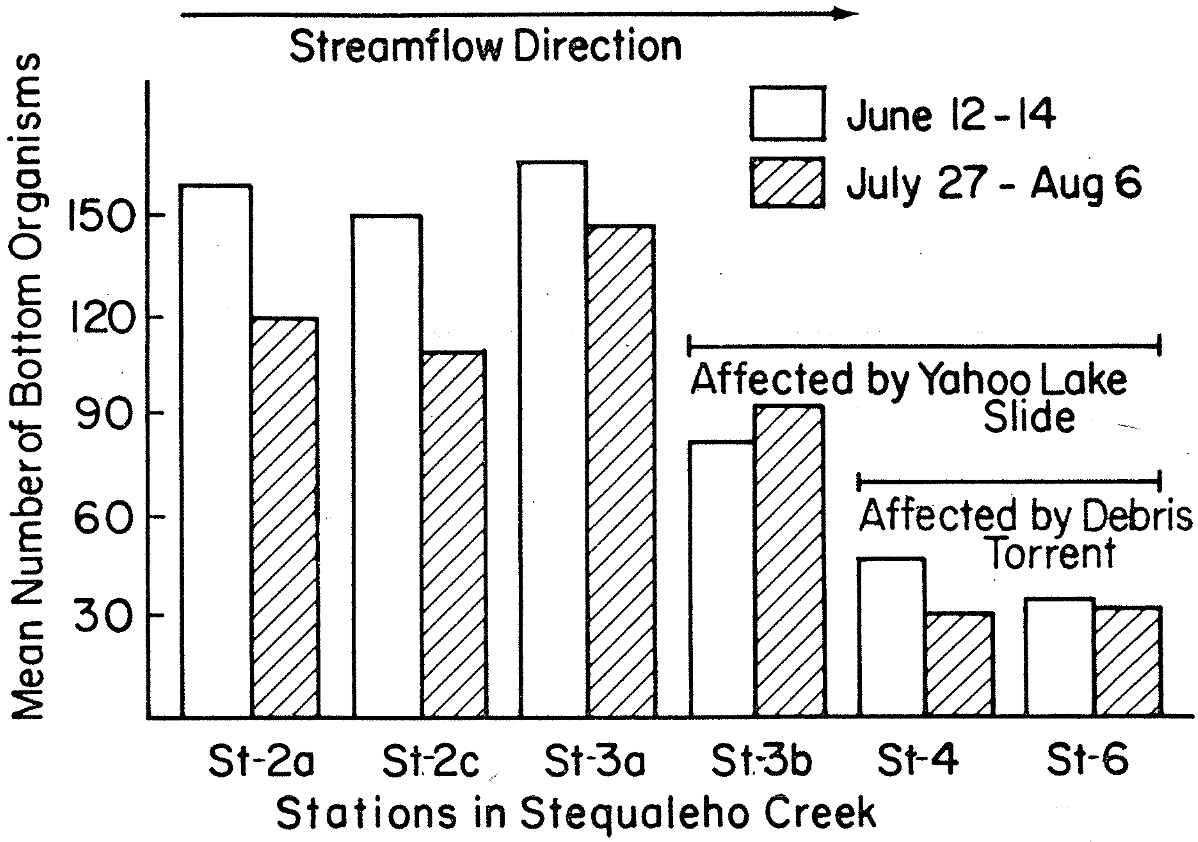
Order and family	Stequaleho Creek above C-tributary St - 2a	C-tributary St - 2c	Stequaleho Creek above B-tributary St - 3a	Stequaleho Creek below B-tributary St - 3b	St - 4	St - 6	C-2	C-3	C-4	C-5
Number of samples	6	5	6	6	6	6	8	8	9	9
ACARINA	9.3	1.6	0.7	0.2	0	0	0.1	0.1	0	0.2
COLEOPTERA										
Dryophidae	4.8	0	1.8	3.7	2.6	0.7	9.2	5.8	11.1	1.3
Dytiscidae	2.8	0.4	0	0.8	0.7	0	0	0.2	0.2	0
Elmidae adults	17.8	17.0	54.8	18.2	2.5	1.0	3.5	6.6	6.1	3.9
Elmidae larvae	13.3	4.8	9.0	6.3	1.3	1.3	4.5	6.2	6.7	3.1
Total	38.8	22.2	65.6	28.7	7.2	3.0	17.2	18.9	24.1	8.3
DIPTERA										
Ceratopogonidae	1.2	0	0.5	0.2	0	0	0.4	0	0	0
Chironomidae	6.2	32.4	3.3	5.5	0.16	1.7	1.6	0.8	1.4	24.7
Empidae	0.33	0	0	0.33	0.16	0	0	0	0	0.1
Psychodidae	0	0	0	0	0	0	0.1	0	0	0
Rhagionidae	0.33	0.4	0	0.2	0.33	0.33	1.2	0.6	0.7	0.1
Simulidae	0.16	0.2	0	0.33	0	0	0.2	0	0.3	11.3
Tabanidae	0	0	0	0	0	0	0.1	0.1	0.1	0
Tipulidae	2.3	0.2	1.2	3.2	0	0.2	0.7	0.6	0.2	0.4
Total	10.5	33.6	5.0	9.3	0.7	2.2	4.5	2.1	2.8	36.6

Table 20. Average numbers of benthos per 1.1 ft^2 in Stequaleho Creek and Clearwater River from July 27 to August 6, 1972 (by family) - continued

Order and family	Stequaleho Creek above C-tributary St - 2a	C-tributary St - 2c	Stequaleho Creek above B-tributary St - 3a	Stequaleho Creek below B-tributary St - 3b	St - 4	St - 6	C-2	C-3	C-4	C-5
Number of samples	6	5	6	6	6	6	8	8	9	9
EPHEMEROPTERA										
Baetidae	19.5	15.0	25.7	25.2	9.3	11.5	49.6	28.2	32.0	26.4
Ephemerelle	2.8	2.6	8.3	5.2	0.66	6.2	4.6	1.9	4.0	3.1
Heptagenidae	14.7	12.0	25.0	11.2	6.6	2.7	5.8	2.2	2.8	5.2
Leptophlebiidae	2.2	1.8	0	0.2	0.7	0.5	0	0	0.2	7.4
Siphlonuridae	6.5	11.0	7.8	3.5	1.5	2.2	0	0.4	0.1	0.4
Total	45.7	42.4	67.0	45.1	18.8	23.0	60.0	29.2	39.1	42.7
OLIGOCHAETA	0.33	0	0.5	0	0	0	0.1	1.9	0.7	0
PLECOPTERA										
Chloroperlidae	2.8	0.8	1.0	1.2	0	0	2.2	1.4	1.4	3.3
Nemouridae	0.33	0	0	0	0	0	0	0	0	0
Peltoperlidae	0	0.2	0	0	0	0	0	0	0	0
Perlidae	6.7	1.6	2.5	3.8	1.5	1.0	3.1	2.2	2.0	1.2
Perlodidae	0.8	0.6	0	0	0.2	0	0.2	0	0	0
Pteronarcidae	0	0	0	0	0	0	0	0.1	0.7	0
Total	10.7	3.6	3.5	5.0	1.7	1.0	5.6	3.7	4.1	4.5

Table 20. Average numbers of benthos per 1.1 ft^2 in Stequaleho Creek and Clearwater River from July 27 to August 6, 1972 (by family) - continued

Order and family	Stequaleho Creek above C-tributary St - 2a	C-tributary St - 2c	Stequaleho Creek above B-tributary St - 3a	Stequaleho Creek below B-tributary St - 3b	St - 4	St - 6	C-2	C-3	C-4	C-5
Number of samples	6	5	6	6	6	6	8	8	9	9
TRICHOPTERA										
Glossosomatidae	0.3	0.2	0.5	0.3	0	0	0	0	0.3	0
Hydropsychidae	0	0	0	0.2	0.8	0.3	0.1	0.1	1.0	0.9
Leptostomatidae	0	0.2	0	0.3	0	0.2	0	0	0	0
Limniphilidae	1.0	0.4	1.8	1.2	0.3	2.2	1.4	0.8	0.7	0.8
Rhyacophilidae	1.3	0.6	1.5	1.5	0.8	0.7	1.5	0.5	1.3	0.3
Total	2.7	1.4	3.8	3.1	2.0	3.2	3.0	1.4	3.3	2.0
HIRUDINEA	0.3	0	0	0	0	0	0.1	0	0	0
OTHER (Pupa)	0.5	4.0	0.8	0.7	0.3	0	0.4	0.4	0.2	0.7
GRAND TOTAL	118.9	108.8	146.9	92.0	30.7	32.4	91.0	57.7	74.3	95.0



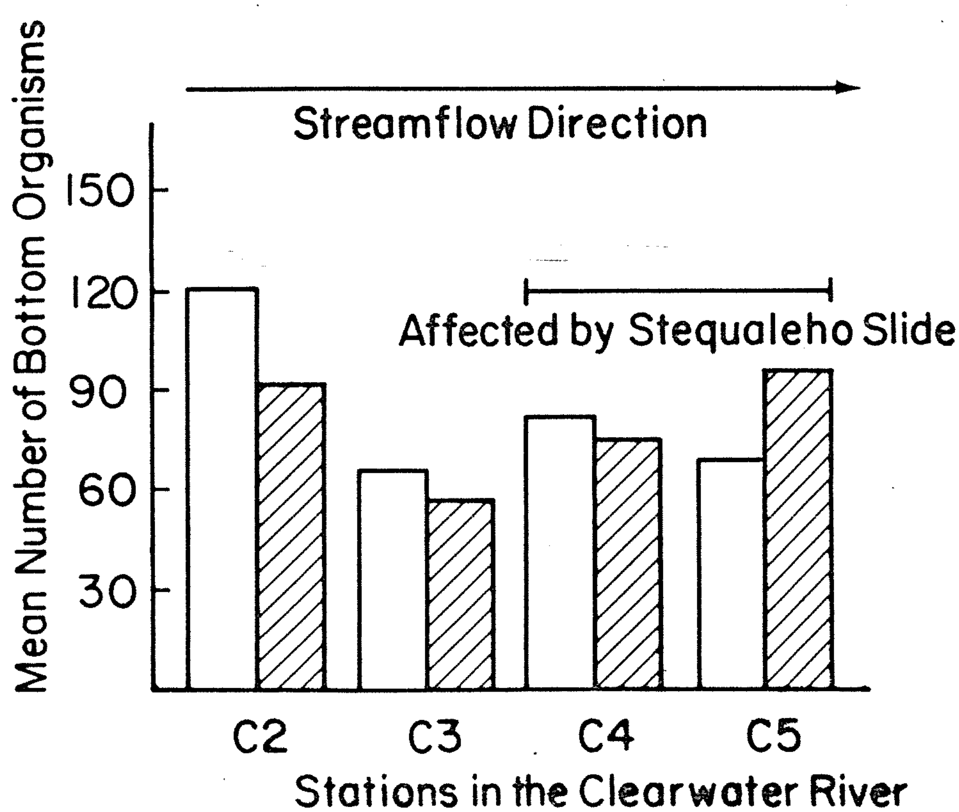


Fig. 16. a) Mean numbers of bottom organisms per 1.1 ft^2 in landslide-affected and -unaffected areas of Stequaleho Creek, 1972.

b) Mean numbers of bottom organisms per 1.1 ft^2 in the Clearwater River above and below the mouth of Stequaleho Creek, 1972.

A statistically significant difference at the 1% level was found between the unaffected and affected stations for both sampling periods. A significant difference at the 1% level was found also between the unaffected stations and St-3_b during the first sampling period but not for the second sampling period at the 1% and 5% levels. No significant difference at either level was found between St-3_b and the two affected stations during the first sampling period, but a significant difference at the 1% level was found during the second sampling period (Table 21).

Large differences in total organisms between stations occurred as a result of marked reduction in all taxa. There appeared to be no preference among the groups for the conditions existing at the three affected stations.

Clearwater River

The mean numbers of benthic organisms per 1.1 ft^2 for the stations classified to family are given in Tables 19 and 20. No obvious difference in total number of organisms per 1.1 ft^2 existed between the two affected stations and the two unaffected stations (Fig 16b) during either sampling period.

Statistical analysis showed no significant difference at the 5% level between the two treatments for both sampling periods (Table 21).

The station farthest upstream (C-2) had more total organisms per sample than the other three stations except for the higher value recorded at C-5 during the second sampling period. It is important to note that the increase at C-5 in total numbers from one sampling period to the next was caused by an increase in Chironomidae (13.4-24.7) and Simuliidae (0.1-11.3) larvae. The station with the fewest total organisms per sample consistently was C-3, located downstream from the mouth of the Solleks River.

In Stequaleho Creek and the Clearwater River there occurred a reduction in mean number of total organisms from the first sampling period to the next. The average reduction for all stations was 10.1%. This reduction was partially the result of insect emergence but also may have been influenced by a sudden increase in flow during an unusual summer storm on July 12.

Table 21. Results of application of Scheffe's multiple comparison on the abundance of insects in landslide-affected and -unaffected areas of Stequaleho Creek and Clearwater River

Treatment compared		Significance of difference	
1	2	June 12-14	July 27 - August 6
St-2_a, 2_c, 3_a	St-4, 6	Yes (1% level)	Yes (1% level)
St-2_a, 2_c, 3_a	St-3_b	Yes (1% level)	No (5% level)
St-3_b	St-4, 6	No (5% level)	Yes (1% level)
C2, 3	C4, 5	No (5% level)	*

*No significant difference among the four stations by ANOVA.

Relationship of Gravel Composition to Benthos

Since it is known that increased sedimentation can have adverse effects on the benthic fauna, correlations were attempted between mean numbers of total benthic organisms per 1.1 ft^2 per station and mean percent of gravel less than 3.36 mm, 0.841 mm, and 0.1 mm in diameter per station. Table 3 summarizes the gravel composition data used here. Those at station St-3_b were not used because gravel samples were collected upstream of the benthic sampling sites. Correlation coefficients were calculated for both sampling periods independently.

Little or no relationships were found between mean numbers of total benthic organisms and percentages of gravel less than 3.36 mm and 0.1 mm. Strong inverse correlation was found for mean percentage of gravel less than 0.841 mm (Fig. 17). For both sampling periods the r values were -0.85 and -0.95, respectively.

Since Chironomidae and Simuliidae may not be adversely affected by a high percentage of fines in the gravel, separate correlations were made after subtraction of the figures for these groups. Chironomidae are known to inhabit heavily organic sedimented areas and Simuliidae attach themselves to the top of stones and thus may not be affected by high percentages of fines in the gravel. The r values for these two additional correlations were -0.85 and -0.90 for both sampling periods, respectively. This procedure then did not improve the correlation.

Comparison of 1-mm- and .25-mm-Mesh Nets

The efficiency of the 1-mm-mesh net was tested by attaching a .25-mm-mesh net behind it and taking a series of samples. Large numbers of small organisms were found to be passing through the larger-meshed net (Fig. 18) (Appendix Table 5). This net caught only an average of 18% of the combined catch of the two nets (range 7.8 to 36%), distributed by major groups as follows: Ephemeroptera (23.7%), Plecoptera (7.7%), Tricoptera (62%), Chironomidae (9.6%), Elimidae larvae (27%), Oligochaeta (4.7%) and Acari (1.9%). One reason for the low percentage of catch by the 1-mm-mesh net was the time of year during

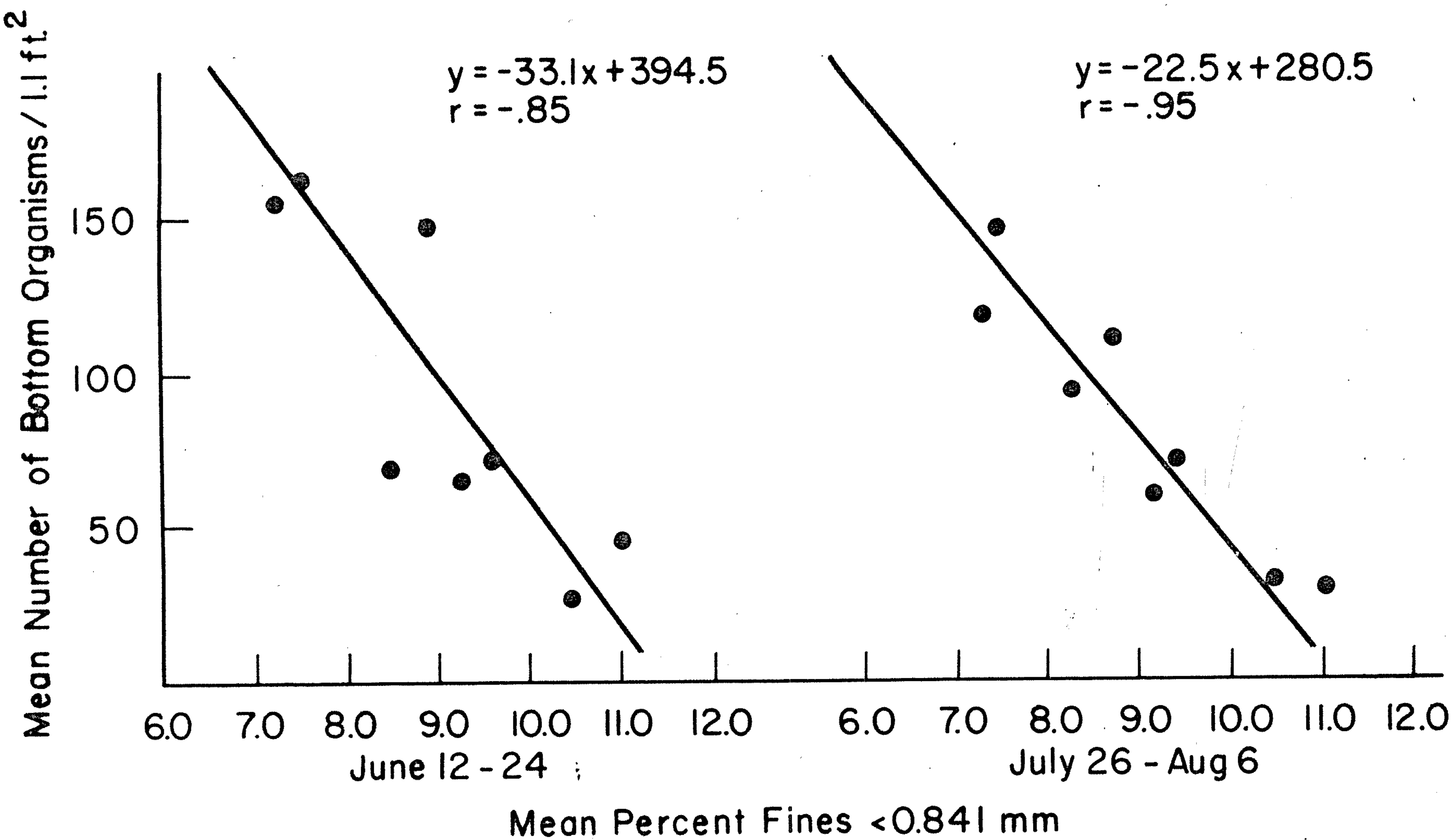


Fig. 17. Mean numbers of bottom organisms correlated with mean percentages of fines less than 0.841 mm in diameter.

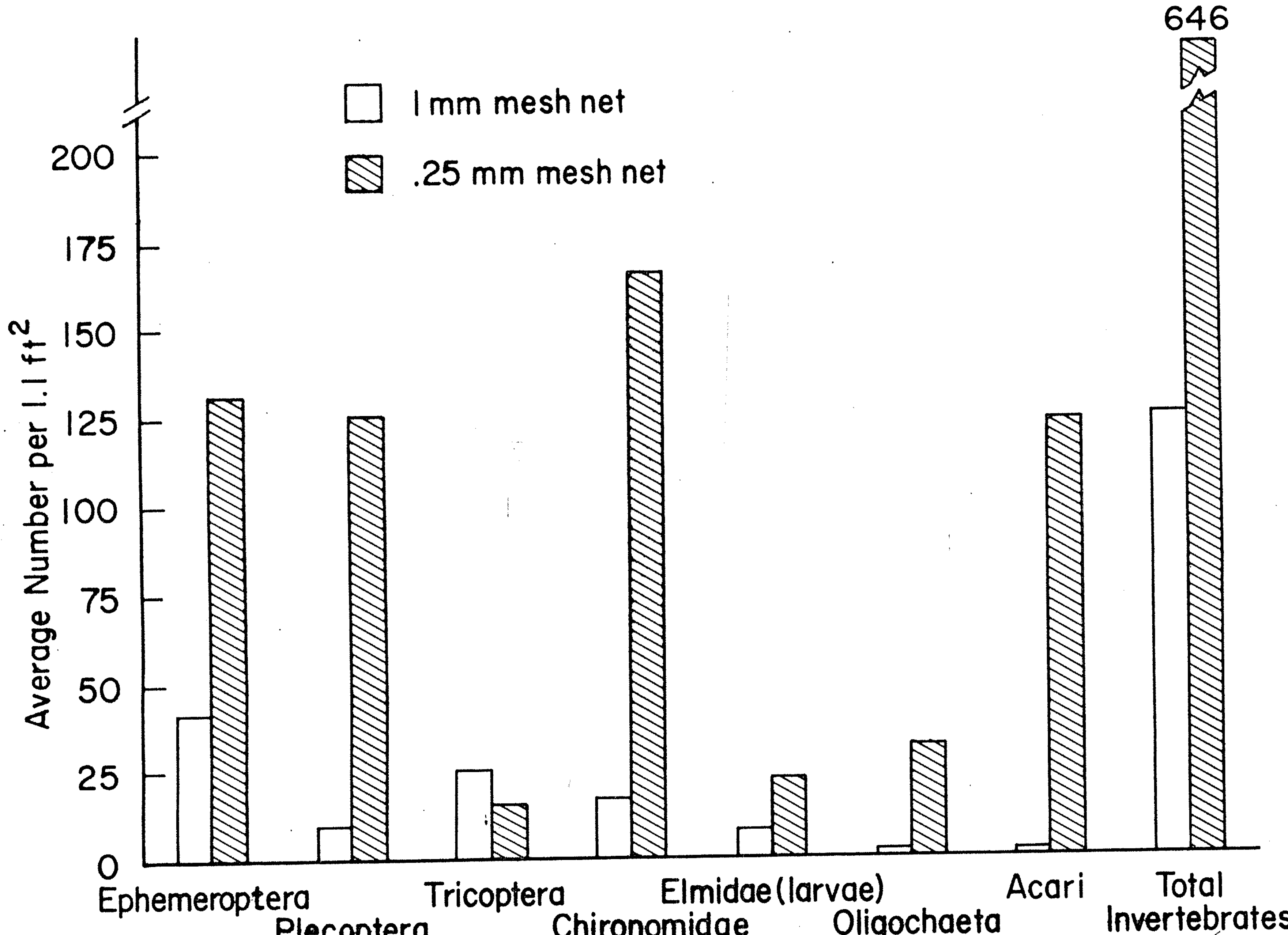


Fig. 18. Comparison of aquatic organisms captured in a 1-mm- and 0.25-mm-mesh net (Appendix Table ~~8~~ 5).

which sampling was conducted. During late summer the young of the year of many species hatch and can be caught with a very-fine-meshed net, similar to the one employed (Malick, personal communication). Thus, the high percentage of certain groups of insects passed by the 1-mm-mesh net cannot be assumed to be the same year class as those retained. This is not true for all groups, though, since the selectivity of a net depends largely on the shape of the insect. But generally speaking, the different selectivity of the two nets for two different age classes indicates that even though the large mesh net misses a high percentage of insects it can still be used to make approximate comparisons of the year class ready to emerge.

The principal reason for conducting this test was to establish a possible correlation between the number of Chironomidae caught by the large-mesh net and the small-mesh net. A different selectivity for different year classes of Chironomidae is probably not as defined as with other species due to: (1) very small young of the year which probably even pass through the small-mesh net, and (2) life histories of Chironomidae which are undetermined since many have two or more generations per year. Chironomidae have been shown to increase in number with an increase in organic sediment (Nuttall, 1972), but their response to inorganic sediment has not been clearly defined. A fair correlation was obtained between the two nets with an r value of .77. The equation for the correlation line was $Y = 5.09X + 76.53$, where Y equals the number of organisms that would be retained by a 0.25-mm-mesh net and X equals the actual number of organisms retained by the 1-mm-mesh net. The results indicated that fair comparisons of Chironomidae can be made between stations by sampling with the 1-mm-mesh net as a tool.

DISCUSSION

Gravel Composition

The greatest deficiency with our spawning gravel composition experiment has been the lack of knowledge of streambed gravel composition in lower Stequaleho Creek and the Clearwater River before the landslide occurred. It was assumed that streambed composition of the control area (landslide-unaffected) was the same as the experimental area (landslide-affected) before the landslide occurred. This assumption cannot be substantiated because natural streambeds have characteristically different gravel compositions, depending on the location, the gradient and the length. For example, the Mississippi River Commission in 1935 (Leopold et al., 1964) clearly demonstrates that from the headwaters to the mouth of the Mississippi River, there is a drastic increase in the average percentage of sand-sized material in the streambed. According to Leopold et al. (1964) and also Leliavsky (1966), in the steeper gradient "V"-notched headwater areas, there is far more energy available to move sediments than there is in the broad flat-gradient downstream areas. Since, for a given energy level, sediment movement is facilitated more easily for smaller-sized particles, the headwater streambeds would necessarily have, on the average, smaller amounts of fine material and just the opposite in the downstream areas.

This rule deals with averages over an entire watershed and is subject to exceptions, depending on local energy levels in the stream course. For example, the gravel bed just immediately upstream of a log jam is usually very high in percentages of fine material, and log jams may be found throughout a stream course. Also, high levels of fine sediment are found immediately downstream of sediment sources such as tributaries, or even landslides, depending on where they happen to occur on a stream course (Shapley and Bishop, 1965; Hertzog, 1953). During 1972, our control gravel samples were mainly from upstream areas, while our experimental samples were from areas considerably lower in the stream course. At this time we can only report that we found a significantly greater amount of fines (less than

3.36 mm and 0.841 mm diam) in the experimental areas when compared to the controls, but until we are able to gain additional information on the natural gradation of fine material in gravel beds throughout Stequaleho Creek and the Clearwater River, conclusions should be carefully qualified.

The possible influence of natural landslides (Fiksdal, 1973) occurring below the Yahoo Lake and Debris Torrent landslides in Stequaleho Creek on sampling sites St-4, St-5, and St-6 is, of course, real. The possible influence of landslides numbers 24 and 21 (Fig. 12) are difficult to assess as we do not have sampling sites directly upstream and downstream of them, but landslides numbers 4 and 1 can be discussed. Landslide number 4 (1,400 yd^3) (Fig. 12) occurred downstream of St-4 and upstream of St-5. The percentage of 3.36-mm fines increased from 25.0 to 25.5% and the percentage of 0.841-mm fines increased from 11.0 to 11.4%. Landslide number 1 (40,000 yd^3), which we believe to be the most active, occurred downstream of St-5 and upstream of St-6, and the percentage of 3.36-mm fines increased from 25.5 to 28.7% and the percentage of 0.841-mm fines decreased from 11.4 to 10.5%. Landslide number 25 (Fig. 12) occurred below St-6 and is therefore beyond influence on our Stequaleho Creek sampling sites. However, this slide may have influenced station C-4 in the Clearwater River.

There is evidence in the literature that there is a natural gradation of fine material in gravel beds of streams as one goes from the steeper gradients (headwaters) to the flatter gradients (near the mouth). Since our control samples are mainly taken in upstream areas and our experimental samples in the lower parts of streams, this could account for the differences we are finding. This needs to be investigated further before one could say that all those amounts of fines in the lower streams were caused by the Yahoo Lake and Debris Torrent landslides.

Samples taken at stations C-5 and C-6 may be influenced by other tributaries and therefore, the effects of the Stequaleho landslides on the mainstem Clearwater River are not distinguishable at this time.

The fact remains that those levels found during 1972 did not have a single location averaging greater than 11.5% (less than 0.841 mm), and 36% (less than 3.36 mm) fines. These findings are evidence that a tremendous amount of flushing has taken place in the landslide affected areas of Stequaleho Creek and the Clearwater River. If these compositions are compared with the Alsea watershed studies (Hall and Lantz, 1969; Koski, 1966), one would conclude that there is no longer a problem. However, conclusions must be reserved until we determine what effect these increases over unaffected levels have on Clearwater River salmonids.

Egg Box Experimentation

Our egg plant experiments were an attempt to detect the effects of deposited silt smaller than 5/64 inch diameter on trout and salmon intragravel survival. The results of these experiments have limited application to the real environment mainly because of the protective environment created by the containers. However, there is a certain amount of information that can be derived from these experiments. The tremendous flushing that has taken place in Stequaleho Creek has definitely reduced the amount of fines being deposited in the spawning gravels as evidenced by the high average survival of cutthroat eggs and generally good survival of steelhead eggs. The next step is to look at actual survival from egg deposition to emergence for all salmonid species in varying gravel compositions.

Gravel Stability

This experiment is incomplete at this time because we were able to measure only the gravel stability in the affected area of Stequaleho Creek. The next step will be to compare Stequaleho to other unaffected streams. However, during the winter of 1972-73, we did measure streambed scour, deposition, and streambank erosion in lower Stequaleho Creek. We found this streambed to be progressively unstable in a downstream direction. Whether this instability is a result of the man-caused landslides or just natural is hard to say at this time.

Our observations in the lower parts of other large tributaries (Solleks River, Upper Clearwater River, and Shale Creek) would lead us to conclude that Stequaleho Creek was more unstable, but we have no quantitative data at this time. The fact that almost all of the coho egg boxes planted in the control area as well as the experimental area were lost due to scour or deposition indicates general instability throughout the watershed.

Suspended Sediment

The suspended sediment concentrations found in Stequaleho Creek and the other tributaries cannot be used to express total sediment loads for these streams. Due to the amount of sampling variation involved in taking suspended sediment samples with the techniques used in this study (Guy and Norman, 1970) we recommend the data be used carefully. The concentrations found in the various locations only represent a very few points in time. We do, however, feel that the relative differences between the streams can be derived from this data. The question of comparing suspended sediment concentrations of various tributaries of the Clearwater River on a relatively quantitative basis needs to be investigated further.

Juvenile Fish Populations

During the summer of 1972, the major work on populations of juvenile anadromous fishes was carried out in lower Stequaleho Creek. The anadromous zone of Stequaleho Creek was divided into three study stations St-4, St-5, and St-6. There was one station established in the Upper Clearwater River (C-1). The population densities were developed, for the three Stequaleho stations, on repeated mark-release and recapture efforts, while those in the Clearwater River were based on one capture. It was found that the coho salmon and trout densities were low in Stequaleho Creek when compared to the Upper Clearwater River, but these comparisons are not testable statistically at this time.

A considerable amount of information was acquired about the resident cutthroat trout populations of the resident zone of Stequaleho Creek; but this information will be used mainly in future activities.

Some Problems of Insect Distribution Associated with Benthic Invertebrate Studies

Much discussion and criticism has been directed at quantitative studies in which an attempt is made to draw conclusions about the effect of some disturbance on the benthic fauna of streams. Quantitative comparisons of benthic organisms between two different stretches of stream can yield inaccurate or misleading results because of the extreme complexity of their distribution. According to Hynes (1970) there are several groups of factors determining distribution: (1) life history patterns, i.e., differing times of emergence of insects; (2) physical factors, i.e., current speed, temperature, and substrate; and (3) behavioral response, i.e., attraction of certain groups of insects to accumulations of detritus. Therefore, it is improper to assume that organisms are randomly distributed throughout the stream bottom.

Since the effect of siltation alone upon the benthic fauna was being sought, this nonrandom distribution created a problem of sampling. Therefore, precautions were taken to select sampling sites that had similar physical characteristics. This method of selective rather than random sampling is supported by Cordone and Kelley (1961). However, since Neill's cylinder is limited in use to particular substrate types, the location of workable gravel also played an important role in determining the sampling site. This factor could have influenced the results.

The complexity of benthic distribution also makes the analysis of the data very difficult. Other workers (Hildebrand, 1971; Cordone and Pennoyer, 1960; and Tebo, 1955) have carried out similar comparative benthic studies and have employed the F-test, which requires a normal distribution. Since this is not the case for benthic organisms, we were at first skeptical of employing this test, but on the advice of McCaughran (personal communication) a transformation was performed on the data making the test more acceptable.

Effects of Sediment on Benthic Invertebrates

A significant difference in mean number of total organisms was found between the three unaffected and the two affected stations (by both slides) in Stequaleho Creek. Gravel less than 0.841 mm and 3.36 mm was significantly higher at the two insect sampling stations downstream of the slides. If we assumed that benthic fauna and gravel composition were alike in the two separate treatments before the spring of 1971, then the sediment source continued to have an adverse effect on the benthic fauna in lower Stequaleho Creek during the summer of 1972. More than one full year after the slides benthic invertebrate abundance at the two affected stations in Stequaleho Creek were still approximately 76% less than would normally occur.

No significant difference in mean number of total organisms existed between treatments for the Clearwater River during both sampling periods. There may be two reasons. First, the slides in Stequaleho Creek had no effect on the benthos in the lower Clearwater River. Second, the effect of Stequaleho Creek slides was masked by sedimentation above the mouth of the creek, possibly from the Solleks River. The fact that a low number of organisms was found at station C-3 (as compared to C-2), just downstream from the mouth of the Solleks River, may indicate validity for the second line of reasoning.

In attempting to understand the effect of inorganic sediment on the benthic fauna of Stequaleho Creek and possibly the Clearwater River, it is important to consider the correlations presented in the Results (Fig. 17). These relationships may reflect a decrease in available living space for benthic invertebrates with an increasing percentage of fines less than 0.841 mm. Hynes (1961) states that the shelter of crevices in the gravel (living space actually inhabitable) is a first requirement to invertebrates in rapidly flowing water. He also states that as an animal grows it needs a larger crevice and therefore it is continually leaving small crevices for larger ones. The nonselective reduction in numbers of organisms (by groups) that occurred in lower Stequaleho Creek may reflect a decrease in intragravel living space, caused by clogging of the gravel interstices by the sediments. McNeil and Ahnell (1964) demonstrated how the coefficient of permeability of stream bottoms sharply decreases with small increases in fines less than 0.833 mm in diameter (*see Fig. 2*). The change in intragravel living space with increasing fine sediment may be similar to that of the coefficient of permeability. It is of interest to note that the range of gravel percentages in which the sharp reduction in the coefficient of permeability occurs is comparable to the range of gravel percentages observed in this study.

Aside from a reduction in living space due to increasing fines, there may also occur a reduction in food for detrital feeding organisms. Scott and Rushforth (1959) stated that increasing amounts of sand particles will reduce not only the amount of available living space but also the probability that organic matter will lodge among stones and provide food. The importance of detrital matter within the gravel was shown by Egglishaw (1964) when he correlated the abundance of certain insects to the amount of detritus. He showed that plant detritus within the gravel acts as an attractant to certain insects. This factor may influence the low numbers of organisms found in the stations with high amounts of inorganic fines.

The decrease in numbers of organisms shown in Stequaleho Creek does not necessarily constitute the final effect of siltation. A drastic change in the environment of the benthic fauna will cause an initial reduction in the fauna that inhabits the area. However, if the environment does not recover to predisturbance levels, a fauna of different composition than before the landslides may eventually reach a population size that equals or even surpasses the previous one. Further study is needed in this regard for Stequaleho Creek. How a change in benthic fauna composition would affect the fish fauna is unclear at this time.

It is important to recognize that this correlation was only established for organisms retained by a 1-mm-mesh net. It must not be assumed that the same relationship exists for the total number of organisms inhabiting the stream bottom. Larger individuals may be more sensitive to a reduced living space than smaller individuals. It has previously been established that the 1-mm-mesh net misses a large number of the smaller organisms, but the catches of the two nets combined did not provide a good correlation. Further study is needed to establish the possible relationship between these smaller organisms and siltation. However, since the catches of Chironomidae did show a fair correlation between the two sampling nets, the study did not demonstrate a preference in this group for inorganic silted areas.

Recovery Rate of Benthic Invertebrates

On July 27, 1971 Deschamps sampled lower Stequaleho Creek and the Clearwater River just upstream from the mouth of Stequaleho Creek for benthic organisms. He used a one-square-foot Surber sampler and collected 10 samples from each of the two areas. Stequaleho Creek yielded an average of 9.8 organisms per ft^2 and the Clearwater River 84.8 organisms per ft^2. Although our methods of sampling were not identical to those of Deschamps, they were similar enough for us to make some comparisons. Both samplers were equipped with nearly identical mesh nets. The Surber sampler sampled a 1-ft^2 area to an approximate depth of 2-3 inches, whereas Neill's cylinder sampled a 1.1-ft^2 area to a depth of 4.5 inches. We sampled at nearly the same time of year that Deschamps did.

The data demonstrate that populations of benthic fauna in Stequaleho Creek were showing some signs of recovery after one full year (Table 22). It must be noted that station C-3 is approximately one-half mile upstream from Deschamps' sampling site, and this difference could have influenced the number of organisms present. This station is influenced directly by sediment originating in the Solleks River just upstream.

Faster recovery rates have been observed in other streams affected by siltation. Reports published by the Oregon State Game Commission et al. (1955) and Wilson (1957) showed that one year after extensive siltation of over 15-20 miles of the Powder River, Oregon, had greatly reduced the bottom fauna, there was a remarkable recovery. Reese (1959) reported that after the bottom fauna of Little Bear Creek, Washington, had been reduced by 97 percent after a dredging operation, there was complete recovery in 11 months.

The slow recovery rate in Stequaleho Creek may reflect the large magnitude of the initial disturbance. It gives an indication of how long-lasting the effect of several large man-caused slides may be in an area of unstable slopes and very high rainfall. It can be argued that freshets from the heavy rainfall serve to clean the streambed but they also serve to keep these large earth scars continual sources of sediment.

SUMMARY

1) In 1960, the DNR began their intensive timber management program in the Clearwater River system. They presently manage approximately 79% of the drainage basin and the principal harvest technique is clearcutting.

2) In May of 1971, heavy rainstorms caused two massive sidecast failures on the DNR's FR-C-3130 road near Yahoo Lake. These two landslides (Yahoo Lake and Debris Torrent slides) caused extensive siltation to occur in Stequaleho Creek and the lower Clearwater River.

3) Surveys during the summer of 1971 by the Washington State Department of Fisheries showed heavy siltation throughout Stequaleho Creek, which

Table 22. Comparison of Deschamps' data (1971) with those from the work we carried out in early summer, 1972

Area	July 1971 (Surber sampler) insects/1.0 ft^2	July 1972 (Neill's cylinder) insects/1.1 ft^2
Lower Stequaleho Creek	9.8	32.8[1]
Clearwater River upstream of Stequaleho Creek	84.8	66.7[2]

[1]Station St-6.

[2]Station C-3.

they thought could reduce the future survival to emergence and carrying capacity of salmonids in this stream.

4) The Fisheries Research Institute began an investigation in January 1972 to document the short-term effects of the landslides on the spawning and rearing capacities of Stequaleho Creek and the Clearwater River.

5) In June 1972, one year after the initial landslides, siltation levels of the spawning gravel of lower Stequaleho Creek were found to be significantly higher (5% level) than the natural levels (unaffected by the landslides) for both the 3.36-mm and the 0.841-mm fines. Further study is needed to determine the natural gradiation of silt in spawning gravels from the headwaters to the mouths of these streams.

6) An experiment to determine survival to hatching of cutthroat trout indicated no difference in this regard between landslide-affected and -unaffected areas. Questionable results in the steelhead trout experiment do not allow conclusions to be drawn at this time.

7) It was found that as one progresses downstream in the landslide-affected parts of Stequaleho Creek, there is an increase in gravel deposition, streambed scour, and streambank erosion. These evidences of instability could be either man-caused or natural.

8) Based on a limited number of samples Stequaleho Creek had higher concentrations of suspended sediment during winter flows of 1972-73 when compared to other logged and unlogged tributaries of the Clearwater and Hoh Rivers. The small tributary (B-tributary) draining the Yahoo Lake landslide had visually short periods of high suspended sediment concentrations during the summer of 1972.

9) Rapids form the greater part of the water surface area in areas accessible to anadromous fish in Stequaleho Creek, covering 19,488 yd^2, whereas the pools have a combined surface area of only 9,885 yd^2. There are 1,240 yd^2 of spawning gravel in the anadromous zone of Stequaleho Creek.

10) During September 1972 there were 0.236 age-0 trout per yd^2, 0.041 age-1 and older trout per yd^2, and 0.043 coho salmon per yd^2 in the anadromous zone of Stequaleho Creek. The biomass of trout (age 0 + age 1 and older) amounted to 10.8 lb/acre, and 2.7 lb/acre of coho salmon in the anadromous

zone of Stequaleho Creek. Including other incidental fish species (dace and sculpins), the total biomass of teleosts amounted to 72 lb/acre in this zone.

11) In September 1972 there were approximately 7,020 age-0 trout, 1,177 age-1 and older trout, and 1,188 juvenile coho salmon in the anadromous zone of Stequaleho Creek.

12) We found 0.41 age-0 trout per yd^2, 0.07 age-1 and older trout per yd^2, and 0.15 coho per yd^2 in the upper Clearwater River.

13) In October 1972 we found approximately 0.12 age-0 trout per yd^2 and 0.13 age-1 and older trout per yd^2 in a small headwater tributary of Stequaleho Creek (resident cutthroat only).

14) In October 1972 we found a total biomass of 13.0 lb/acre of trout in this same headwater tributary of Stequaleho Creek. The overall biomass of teleosts including sculpins was found to be 28 lb/acre.

15) One full year after man-caused slides had reduced the bottom fauna of Stequaleho Creek there was still a significant difference (1% level) in total numbers of organisms between stations below the slides and those above. No significant difference (1% or 5% levels) existed for the same period of time for stations in the Clearwater River above and below the mouth of Stequaleho Creek.

16) When all stations were considered together, strong correlation (June, $r = -0.85$; July and August, $r = -0.95$) was found between mean numbers of total insects per 1,000 cm^2 (1.1 ft^2) per station and percentage of gravel less than 0.841 mm in diameter. A reduction in the available living space is suggested by this relationship between benthic organisms and gravel size composition.

CONTINUING RESEARCH ON THE FISHERY RESOURCES OF THE CLEARWATER RIVER

The major emphasis of this project was to document the effects of siltation from landslides due to logging on the fishery resources of Stequaleho Creek. We also devoted much of our time to developing background data on both the biological and physical characteristics of this stream to aid the management agencies. During the next two years four M.S. projects will be conducted in connection with the Clearwater River fishery resources, as follows:

1) Mr. Lawrence C. Lestelle. "The effects of log jam removal on the carrying capacity of a small coastal cutthroat trout stream." The study is being carried out with resident cutthroat trout in two small headwater tributaries of Stequaleho Creek. It will provide information to aid the fishery and forestry agencies concerned in management of the many small tributaries of the Clearwater River. It is now in progress and will be finished in June of 1974.

2) Mr. Brian Edie. "The production of the juvenile anadromous fishery resources of the Clearwater River system." The study will provide relative densities, biomasses, and standing crops of the salmonids and nonsalmonids in all of the major tributaries of the Clearwater River system. Information will be sought, too, on growth and population dynamics of the fish in these tributaries. This project has been underway for one summer now and should be completed by June 1975.

3) Mr. Jack Taggart. "Survival from egg deposition to emergence of coho salmon and steelhead and cutthroat trout in the Clearwater River system." The study will provide information that will help us to judge more precisely the impact of siltation from landslides on the intragravel survival of Clearwater River salmonids. It will also provide information on the magnitudes of the adult salmon and steelhead trout runs. It is just getting underway and is schedulted for completion in June 1975.

4) Mr. Douglas Martin. "The influence of organic and inorganic detritus on benthic macroinvertebrate populations of the Clearwater River." The project will provide insight into the influence of organic and inorganic siltation on the monthly abundance of benthic fishfood organisms. Comparisons will be made between natural conditions and conditions under various degrees of siltation from logging. The study is just getting underway and is scheduled to be completed in June 1975.

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PLATES

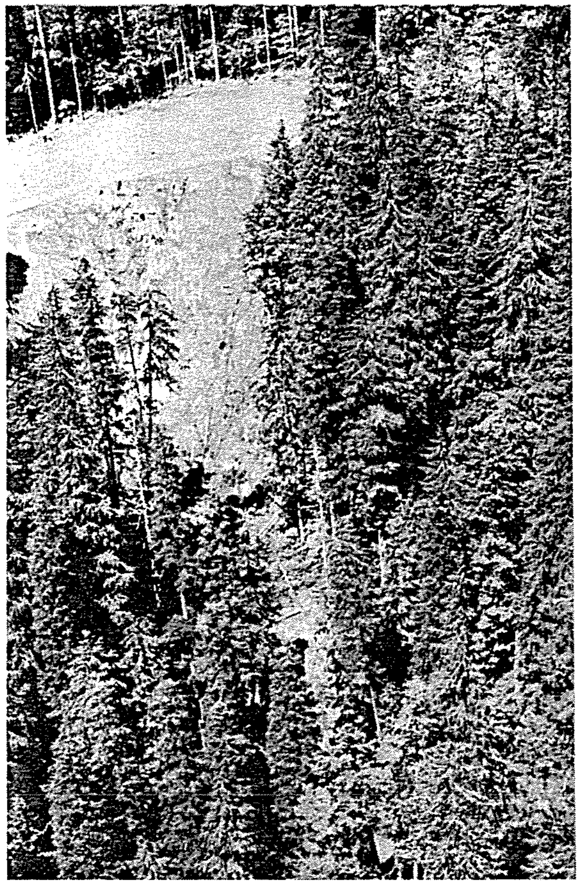


Plate 1. Aerial view of the debris torrent landslide in the Stequaleho Creek drainage basin.

Plate 2. Closeup of the debris torrent landslide.

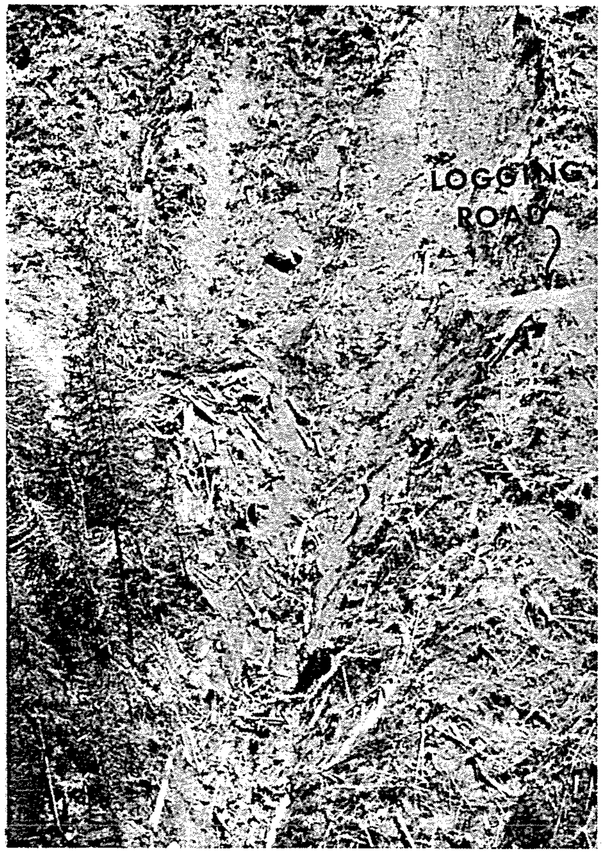


Plate 3. Aerial view of the Yahoo Lake landslide in the Stequaleho Creek drainage basin.

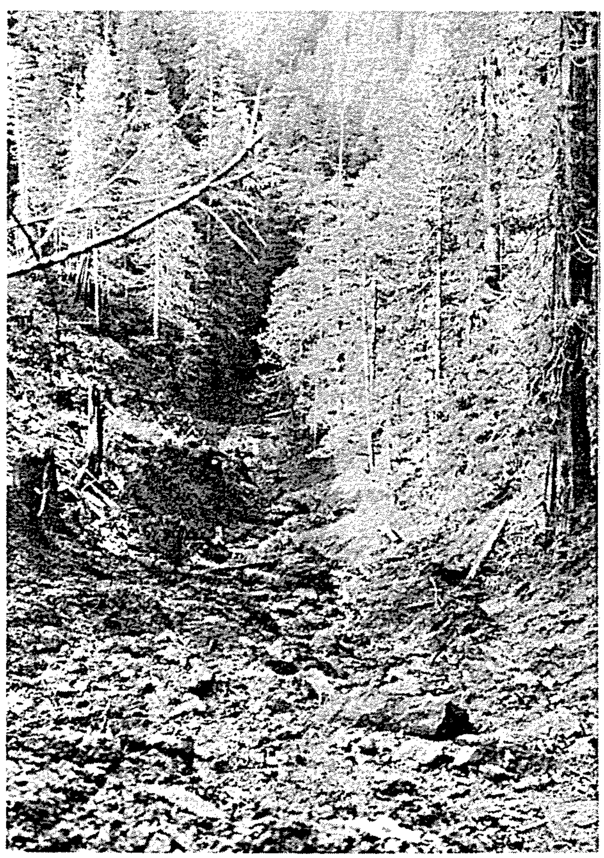


Plate 4. Closeup view of the landslide trace of the Yahoo Lake landslide.

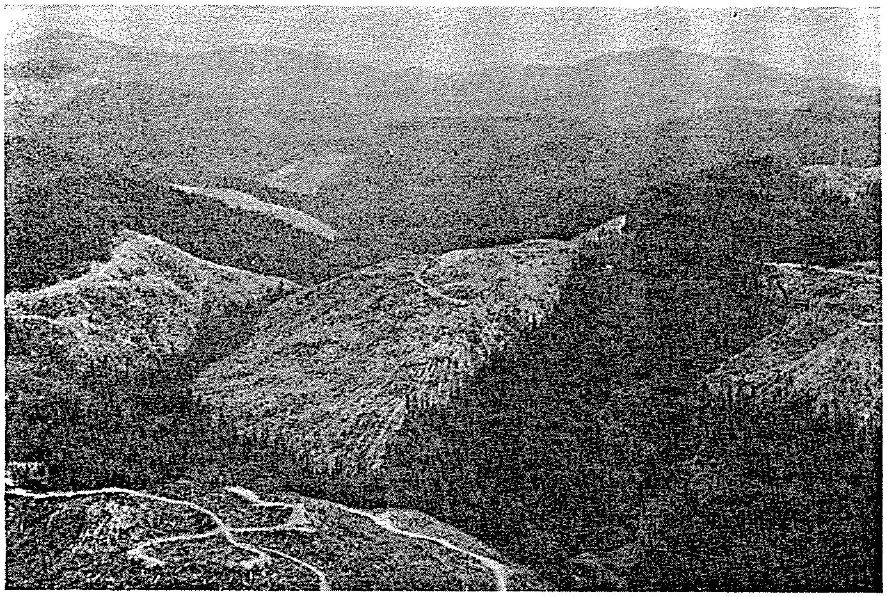


Plate 5. Pattern of clearcut units in the lower Stequaleho Creek drainage basin.

Plate 6. Clearcutting of a small headwater tributary of the Clearwater River.

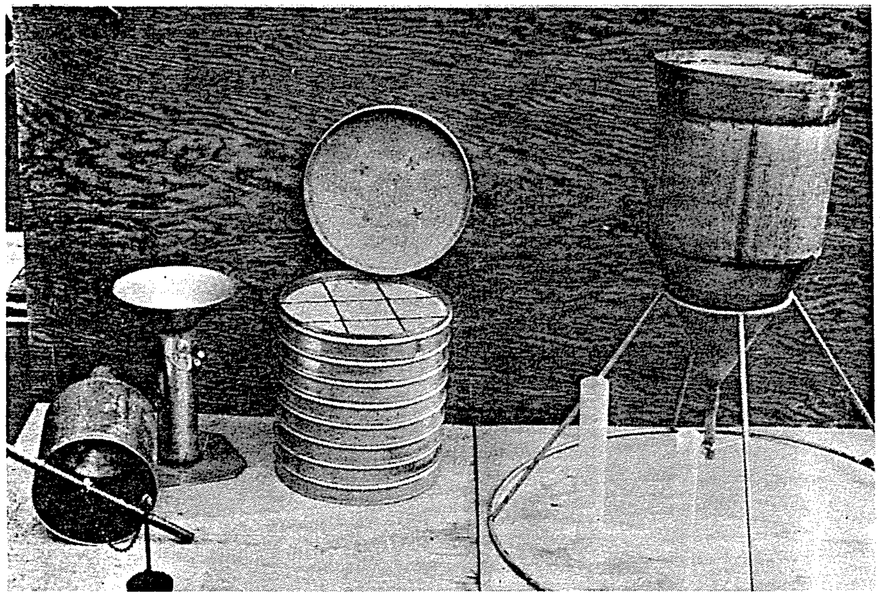


Plate 7. General view of the gravel sampling equipment and Tyler sieves.

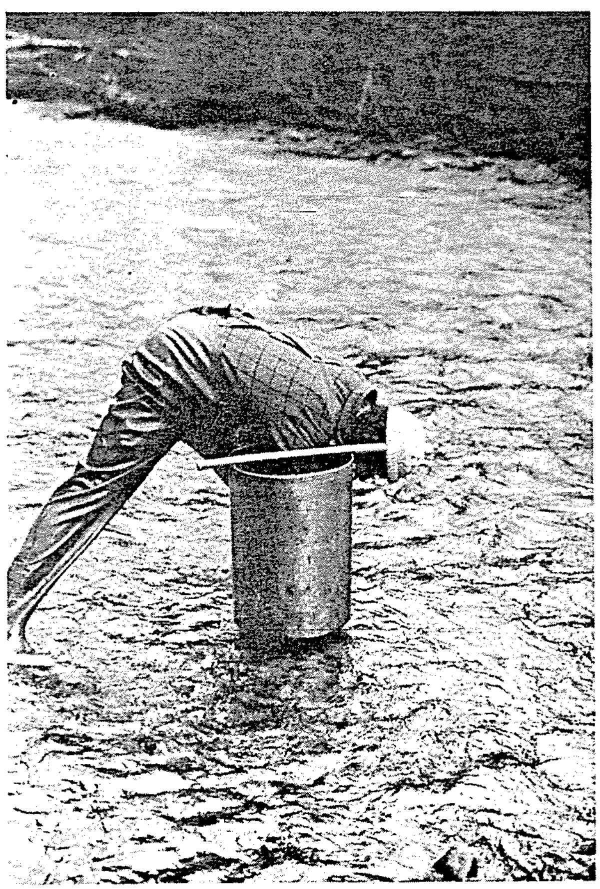


Plate 8. The gravel sampler in operation.

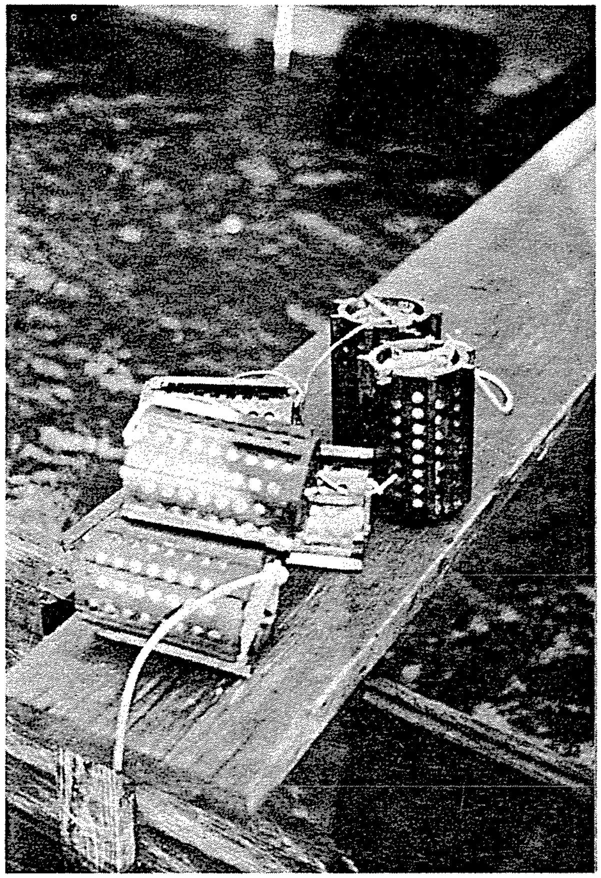


Plate 9. Intragravel sediment monitors used in this study.

Plate 10. Egg incubation boxes used in this study.

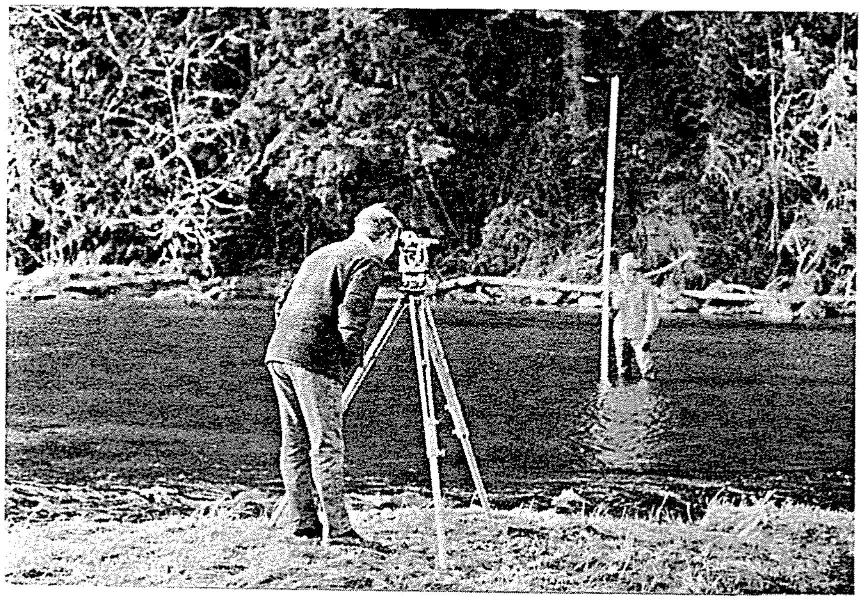


Plate 11. Survey technique used in making cross-sectional surveys.

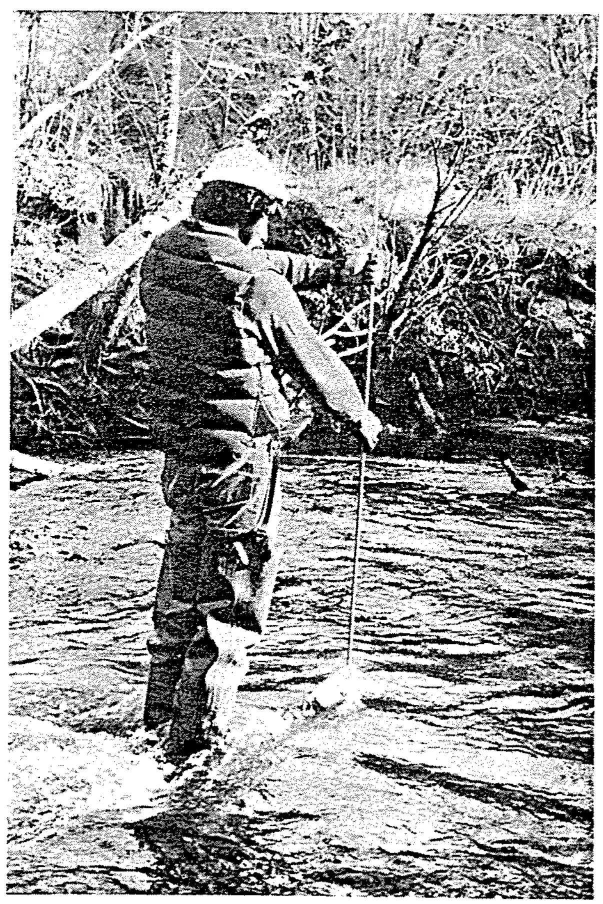


Plate 12. The DH-48 hand held depth integrating suspended sediment sampler.

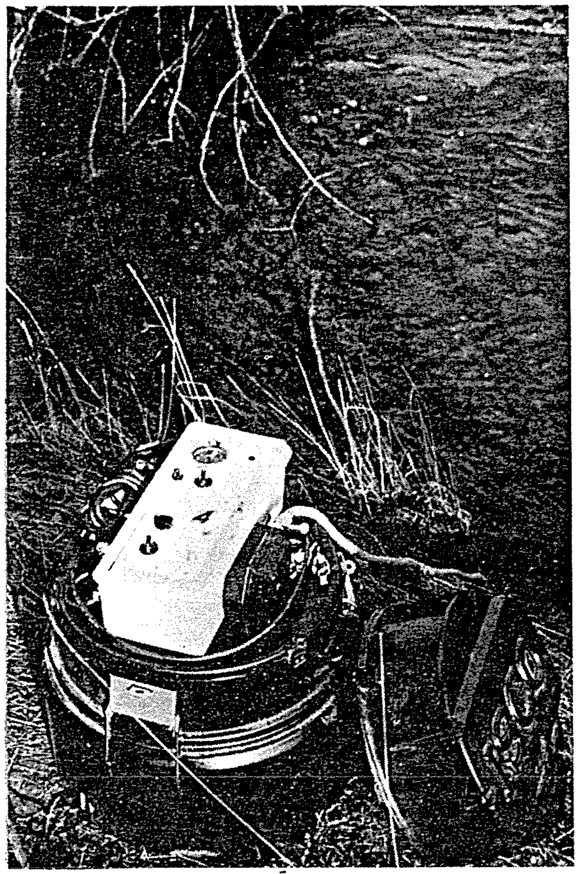


Plate 13. The I.S.C.O. model 1391 remote water sample collector.

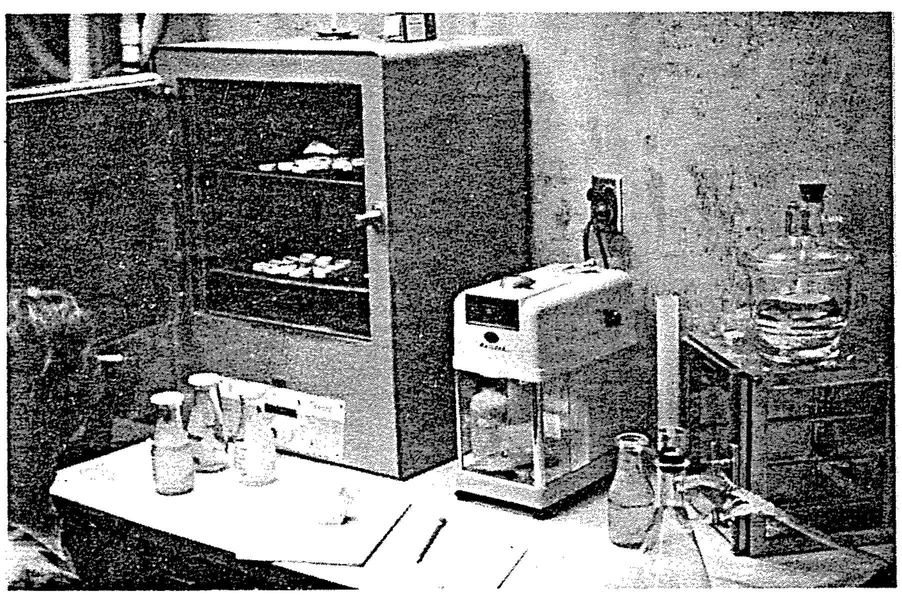


Plate 14. Laboratory equipment used to analyze the suspended sediment samples.

Plate 15. Block seines used during juvenile fish population estimates.

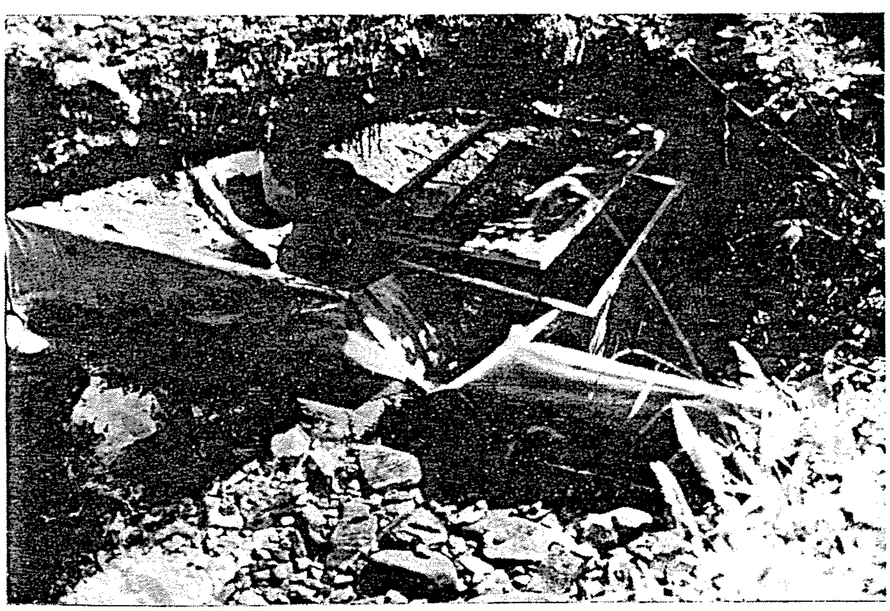


Plate 16. Fry trap used during juvenile fish population estimates.

Plate 17. Type V electrofisher made by Smith-Root Inc. of Vancouver, Washington.

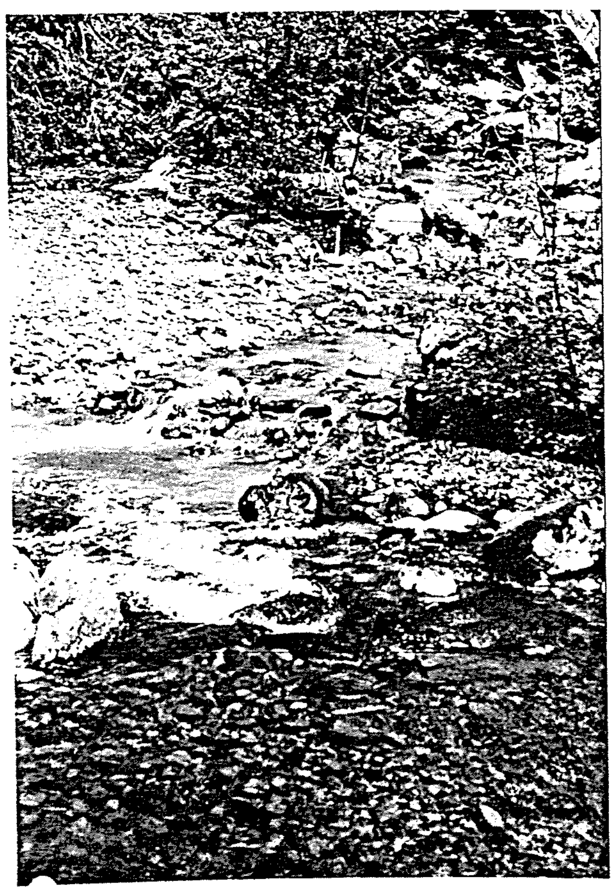


Plate 18. Turbid water coming out of B-tributary (the muddy tributary) during the summer of 1972.

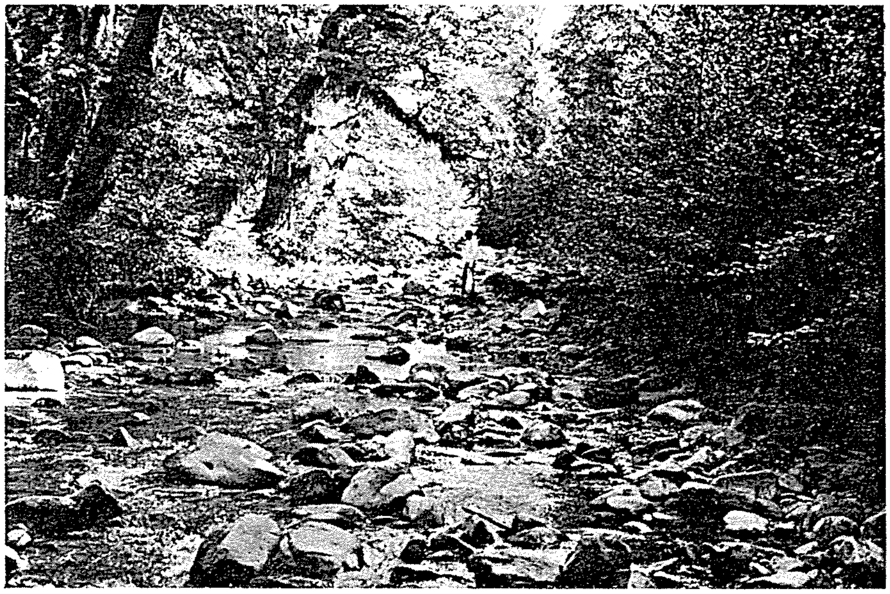


Plate 19. Typical Stequaleho Creek streambed type.

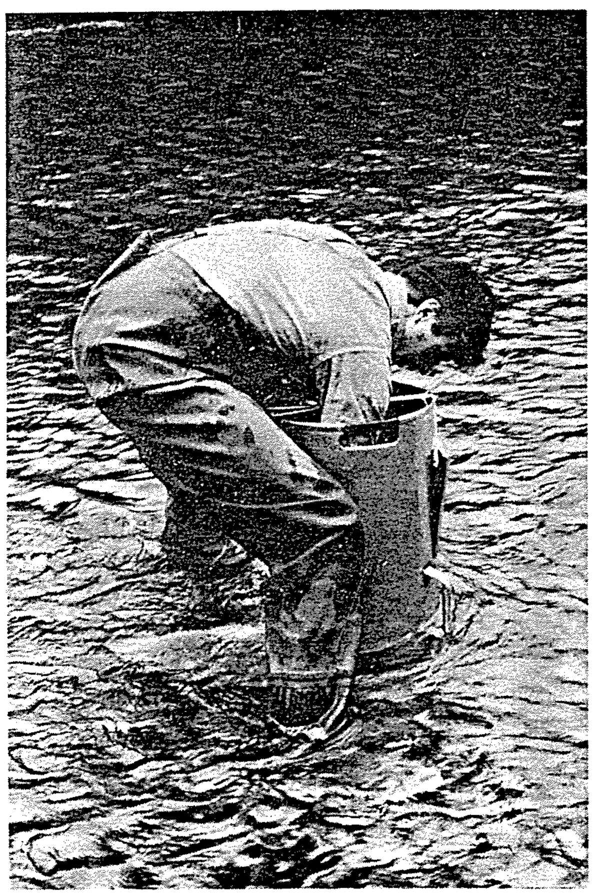


Plate 20. Neil's cylinder in operation.

APPENDICES

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972

Location: C-1

Sample number	Percentage of total volume 53.8	26.9	3.36	0.841	0.105	< 0.105
1	11.551	25.271	38.042	17.412	5.793	1.931
2	0.000	33.359	43.053	13.817	6.221	3.550
3	0.000	27.824	43.828	18.201	6.206	3.940
4	0.000	29.690	41.593	20.519	5.697	2.501
5	0.000	34.783	49.182	12.605	2.473	.957
6	32.887	19.299	35.644	7.404	3.230	1.536
7	0.000	43.506	37.857	12.500	3.571	2.565
8	0.000	7.734	67.421	14.119	7.990	2.736
Mean	5.555	27.683	44.578	14.572	5.148	2.465
S^2	138.306	115.872	103.212	16.701	3.484	.980
SD	11.760	10.764	10.159	4.087	1.866	.990
SE Mean	4.158	3.806	3.592	1.445	.660	.350
95% Con.	9.813	8.982	8.477	3.410	1.557	.826
Mean- 95% Con.	-4.258	18.702	36.101	11.162	3.590	1.639
Mean+ 95% Con.	15.367	36.665	53.054	17.982	6.705	3.290

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	94.445	66.762	22.184	7.612	2.465
S^2	138.306	167.435	35.586	6.986	.980
SD	11.760	12.940	5.965	2.643	.990
SE Mean	4.158	4.575	2.109	.934	.350
95% Con.	9.813	10.797	4.977	2.205	.826
Mean- 95% Con.	84.633	55.965	17.207	5.407	1.639
Mean+ 95% Con.	104.258	77.559	27.162	9.818	3.290

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: C-3

Sample number	Percentage of total volume					
	53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	38.277	28.991	25.150	5.544	2.037
2	11.280	38.456	21.290	20.233	6.345	2.397
3	0.000	35.371	30.563	24.451	7.761	1.854
4	0.000	30.342	34.884	23.110	8.830	2.834
5	0.000	38.161	30.479	21.635	7.963	1.762
6	16.231	32.937	22.724	18.211	7.284	2.613
7	21.968	26.831	26.802	16.382	6.310	1.708
8	6.940	35.506	28.321	20.084	6.660	2.489
9	0.000	34.070	37.216	19.516	7.504	1.694
10	0.000	29.879	36.147	24.822	7.229	1.922
Mean	5.642	33.983	29.742	21.359	7.143	2.131
S^2	67.015	15.834	28.496	8.894	.909	.173
SD	8.186	3.979	5.338	2.982	.953	.416
SE Mean	2.589	1.258	1.688	.943	.301	.132
95% Con.	5.851	2.844	3.815	2.131	.681	.298
Mean-95% Con.	-.209	31.139	25.927	19.228	6.462	1.833
Mean+95% Con.	11.492	36.827	33.557	23.491	7.824	2.429

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	94.358	60.375	30.633	9.274	2.131
S^2	67.015	57.724	10.963	1.243	.173
SD	8.186	7.598	3.311	1.115	.416
SE Mean	2.589	2.403	1.047	.353	.132
95% Con.	5.851	5.430	2.366	.797	.298
Mean-95% Con.	88.508	54.945	28.267	8.477	1.833
Mean+95% Con.	100.209	65.805	33.000	10.071	2.429

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: C-4

Sample number	Percentage of total volume					
	53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	42.410	30.201	17.791	6.104	3.494
2	0.000	35.755	34.690	20.288	6.700	2.567
3	0.000	30.096	33.345	28.215	6.019	2.326
4	0.000	19.000	46.089	26.083	5.841	2.988
5	0.000	22.446	37.755	29.141	7.925	2.732
6	0.000	16.209	39.093	33.352	8.736	2.610
7	13.957	17.544	33.386	25.399	8.170	1.545
8	12.000	19.807	36.000	23.117	6.538	2.538
9	0.000	26.055	31.582	31.705	7.846	2.813
10	0.000	40.654	26.525	24.938	5.553	2.330
Mean	2.596	26.997	34.867	26.003	6.943	2.594
S^2	30.157	94.819	28.904	23.465	1.270	.253
SD	5.492	9.737	5.376	4.844	1.127	.503
SE Mean	1.737	3.079	1.700	1.532	.356	.159
95% Con.	3.925	6.959	3.842	3.462	.805	.360
Mean- 95% Con.	-1.329	20.038	31.024	22.541	6.138	2.235
Mean+ 95% Con.	6.520	33.957	38.709	29.465	7.749	2.954

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	97.404	70.407	35.540	9.537	2.594
S^2	30.157	76.481	30.113	1.196	.253
SD	5.492	8.745	5.488	1.094	.503
SE Mean	1.737	2.766	1.735	.346	.159
95% Con.	3.925	6.250	3.922	.782	.360
Mean- 95% Con.	93.480	64.157	31.619	8.756	2.235
Mean+ 95% Con.	101.329	76.657	39.462	10.319	2.954

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: C-5

Sample number	Percentage of total volume 53.8	26.9	3.36	0.841	0.105	<0.105
1	13.295	41.297	25.273	13.102	3.179	3.854
2	0.000	38.140	27.064	20.820	10.841	3.135
3	30.683	28.366	20.163	11.240	7.765	1.785
4	0.000	58.105	24.040	7.880	6.234	3.741
5	0.000	54.122	22.573	12.288	8.320	2.696
6	11.567	57.444	16.882	41.420	5.744	4.220
7	0.000	42.565	30.563	17.986	6.091	2.795
8	0.000	32.352	50.130	12.300	3.727	1.491
9	0.000	59.971	23.558	10.459	4.545	1.466
10	0.000	54.490	24.175	13.277	6.101	1.957
11	0.000	39.829	33.704	14.304	10.407	1.756
12	0.000	54.512	24.422	12.304	5.891	2.871
13	0.000	53.891	32.700	8.330	2.740	2.338
14	21.885	39.846	28.883	6.068	1.780	1.537
15	25.489	43.241	21.393	5.508	2.321	2.048
16	12.126	44.947	31.892	5.255	2.627	3.153
17	0.000	39.256	32.405	14.170	11.386	2.784
Mean	6.767	46.022	27.636	11.143	5.865	2.566
S^2	109.320	91.782	57.084	20.766	9.299	0.752
SD	10.456	9.580	7.555	4.557	3.049	0.867
SE Mean	2.536	2.324	1.832	1.105	0.740	0.210
95% Con.	5.376	4.926	3.885	2.343	1.568	0.446
Mean- 95% Con.	1.391	41.096	23.752	8.800	4.297	2.120
Mean+ 95% Con.	12.143	50.948	31.521	13.486	7.433	3.012

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	93.233	47.211	19.574	8.431	2.566
S^2	109.320	114.665	49.114	10.611	0.752
SD	10.456	10.708	7.008	3.257	0.867
SE Mean	2.536	2.597	1.700	0.790	0.210
95% Con.	5.376	5.506	3.603	1.675	0.446
Mean- 95% Con.	87.857	41.705	15.971	6.756	2.120
Mean+ 95% Con.	98.609	52.717	23.178	10.106	3.012

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: C-6

Sample number	Percentage of total volume 53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	13.917	44.798	24.760	15.482	1.043
2	0.000	25.126	45.924	19.598	6.756	2.596
3	0.000	17.057	38.712	33.152	8.528	2.550
4	0.000	23.232	60.675	9.020	5.840	1.233
5	0.000	32.009	40.725	17.624	7.713	1.928
6	0.000	20.269	52.599	19.188	6.834	1.110
7	0.000	21.483	46.476	22.325	8.481	1.236
8	0.000	16.813	44.935	25.945	9.374	2.933
Mean	0.000	21.238	46.856	21.452	8.626	1.829
s^2	0.000	32.395	48.113	49.507	8.985	.597
SD	0.000	5.692	6.936	7.036	2.997	.773
SE Mean	0.000	2.012	2.452	2.488	1.060	.273
95% Con.	0.000	4.749	5.788	5.871	2.501	.645
Mean- 95% Con.	0.000	16.489	41.068	15.581	6.125	1.184
Mean+ 95% Con.	0.000	25.987	52.643	27.322	11.127	2.473

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	100.000	78.762	31.906	10.455	1.829
s^2	0.000	32.395	83.321	8.690	.597
SD	0.000	5.692	9.128	2.948	.773
SE Mean	0.000	2.012	3.227	1.042	.273
95% Con.	0.000	4.749	7.616	2.460	.645
Mean- 95% Con.	100.000	74.013	24.290	7.995	1.184
Mean+ 95% Con.	100.000	83.511	39.523	12.914	2.473

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: St-2-a

Sample number	Percentage of total volume 53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	39.041	42.877	10.913	4.247	2.922
2	20.263	39.685	24.945	6.803	6.035	2.268
3	22.430	25.131	31.193	13.475	5.621	2.149
4	0.000	30.018	44.807	14.092	6.936	4.147
5	0.000	51.386	36.442	5.762	3.745	2.665
6	0.000	51.401	38.310	3.984	3.371	2.933
7	0.000	64.508	30.311	1.917	1.969	1.295
8	17.621	48.886	24.185	1.830	4.574	2.904
Mean	7.539	43.757	34.134	7.347	4.562	2.660
S^2	109.928	164.006	59.973	24.257	2.548	.670
SD	10.485	12.806	7.744	4.925	1.596	.819
SE Mean	3.707	4.528	2.738	1.741	.564	.289
95% Con.	8.748	10.686	6.462	4.109	1.332	.683
Mean- 95% Con.	- 1.209	33.072	27.672	3.237	3.230	1.977
Mean+ 95% Con.	16.288	54.443	40.595	11.456	5.894	3.343

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	92.461	48.703	14.570	7.223	2.660
S^2	109.928	156.814	44.222	4.801	.670
SD	10.485	12.523	6.650	2.191	.819
SE Mean	3.707	4.427	2.351	.775	.289
95% Con.	8.748	10.449	5.549	1.828	.683
Mean- 95% Con.	83.712	38.255	9.021	5.395	1.977
Mean+ 95% Con.	101.209	59.152	20.118	9.051	3.343

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: St-2-b

Sample number	Percentage of total volume					
	53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	55.494	33.439	3.478	5.731	1.858
2	0.000	47.409	33.592	9.326	7.686	1.986
3	0.000	36.357	42.127	11.957	6.604	2.954
4	0.000	54.984	29.639	7.753	5.815	2.809
5	0.000	53.209	29.279	13.154	3.407	.951
6	0.000	59.459	27.793	8.468	3.108	1.171
7	0.000	49.828	36.337	6.499	5.465	1.871
8	0.000	48.742	36.302	9.487	3.872	1.597
Mean	0.000	50.685	33.439	8.765	5.211	1.900
s^2	0.000	49.357	23.475	9.211	2.605	.496
SD	0.000	7.025	4.845	3.035	1.614	.704
SE Mean	0.000	2.484	1.173	1.073	.571	.249
95% Con.	0.000	5.862	4.043	2.532	1.347	.588
Mean- 95% Con.	0.000	44.823	29.396	6.233	3.864	1.312
Mean+ 95% Con.	0.000	56.547	37.481	11.298	6.558	2.487

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	100.00	49.315	15.876	7.111	1.900
s^2	0.000	49.357	11.771	4.772	.496
SD	0.000	7.025	3.341	2.185	.704
SE Mean	0.000	2.484	1.213	.772	.249
95% Con.	0.000	5.862	2.863	1.823	.588
Mean- 95% Con.	100.00	43.453	13.013	5.288	1.312
Mean+ 95% Con.	100.00	55.177	18.739	8.934	2.487

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: St-2-c

Sample number	Percentage of total volume 53.8	26.9	3.36	0.841	0.105	<0.105
1	10.608	52.322	25.481	6.304	3.700	1.586
2	20.035	36.506	28.944	8.083	4.302	2.130
3	0.000	34.308	39.658	16.869	6.419	2.746
4	0.000	23.010	48.115	16.468	8.798	3.609
5	0.000	40.103	31.602	14.813	9.146	4.337
6	0.000	25.397	40.740	25.041	6.163	2.660
7	0.000	44.811	41.104	8.114	3.377	2.595
Mean	4.378	36.637	36.520	13.670	5.986	2.809
S^2	63.296	107.049	64.423	44.166	5.496	.834
SD	7.956	10.346	8.026	6.646	2.344	.913
SE Mean	3.007	3.911	3.034	2.512	.886	.345
95% Con.	7.367	9.581	7.433	6.154	2.171	.846
Mean- 95% Con.	-2.990	27.056	29.088	7.516	3.815	1.963
Mean+ 95% Con.	11.745	46.218	43.953	19.824	8.157	3.655

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	95.622	58.986	22.465	8.795	2.809
S^2	63.296	224.933	78.239	10.172	.834
SD	7.956	14.998	8.845	3.189	.913
SE Mean	3.007	5.669	3.343	1.205	.345
95% Con.	7.367	13.888	8.191	2.953	.846
Mean- 95% Con.	88.255	45.098	14.275	5.842	1.963
Mean+ 95% Con.	102.990	72.874	30.656	11.749	3.655

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: St-3-a

Sample number	Percentage of total volume					
	53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	28.622	49.750	13.990	5.318	2.320
2	0.000	47.623	31.936	12.280	5.204	2.958
3	0.000	27.123	50.246	16.526	3.719	2.386
4	0.000	38.820	39.342	14.372	5.379	2.088
5	0.000	30.054	47.397	16.807	4.556	1.187
6	0.000	40.217	37.793	13.253	4.766	3.972
Mean	0.000	35.410	42.744	14.538	4.824	2.485
S^2	0.000	65.465	55.984	3.236	.398	.863
SD	0.000	8.091	7.482	1.799	.631	.929
SE Mean	0.000	3.303	3.055	.734	.258	.379
95% Con.	0.000	8.489	7.850	1.887	.662	.975
Mean- 95% Con.	0.000	26.921	34.893	12.651	4.161	1.510
Mean+ 95% Con.	0.000	43.899	50.594	16.425	5.486	3.459

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	100.000	64.590	21.847	7.309	2.485
S^2	0.000	65.465	.631	1.361	.863
SD	0.000	8.091	.794	1.166	.929
SE Mean	0.000	3.303	.324	.476	.379
95% Con.	0.000	8.489	.833	1.224	.975
Mean- 95% Con.	100.000	56.101	21.013	6.085	1.510
Mean+ 95% Con.	100.000	73.079	22.680	8.532	3.459

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: St-3-b

Sample number	Percentage of total volume					
	53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	42.255	38.873	12.157	5.196	1.520
2	0.000	17.567	57.027	13.203	9.246	2.959
3	16.199	23.983	38.123	7.165	3.816	1.713
4	0.000	48.600	33.520	12.071	3.709	2.099
5	0.000	20.553	52.293	15.480	8.585	3.089
6	0.000	35.165	60.714	2.669	1.099	.353
7	0.000	40.946	43.718	9.091	4.435	1.811
8	0.000	52.008	37.245	6.660	2.361	1.727
Mean	2.025	36.260	45.189	9.812	4.806	1.909
S^2	32.804	152.328	103.271	17.530	8.027	.741
SD	5.727	12.342	10.162	4.187	2.833	.861
SE Mean	2.025	4.364	3.593	1.480	1.002	.304
95% Con.	4.779	10.298	8.479	3.494	2.364	.718
Mean- 95% Con.	-2.754	52.962	36.710	6.318	2.442	1.191
Mean+ 95% Con.	6.804	46.558	53.668	13.305	7.170	2.627

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	97.975	61.715	16.527	6.715	1.909
S^2	32.802	169.964	57.507	13.111	.741
SD	5.727	13.037	7.583	3.621	.861
SE Mean	2.025	4.609	2.681	1.280	.304
95% Con.	4.779	10.378	6.327	3.021	.718
Mean- 95% Con.	93.196	50.838	10.199	3.693	1.191
Mean+ 95% Con.	102.754	72.593	22.854	9.736	2.627

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: St-4

Sample number	Percentage of total volume					
	53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	29.431	39.805	15.935	11.122	3.707
2	0.000	28.548	39.294	16.483	12.308	3.367
3	0.000	6.722	63.073	17.372	10.345	2.488
4	39.715	16.233	29.244	8.055	5.204	1.549
5	24.108	14.143	41.819	11.053	7.485	1.393
6	0.000	43.333	36.944	12.639	5.903	1.181
7	0.000	38.636	32.072	14.711	11.413	3.168
8	0.000	24.279	50.387	15.517	7.565	2.252
9	0.000	40.650	36.518	14.533	5.894	2.405
Mean	7.091	26.886	41.017	14.033	8.582	2.390
s^2	213.235	162.067	104.347	8.781	7.438	0.811
SD	14.603	12.731	10.215	2.963	2.727	0.901
SE Mean	4.868	4.244	3.405	0.988	0.909	0.300
95% Con.	11.244	9.803	7.866	2.282	2.100	0.693
Mean- 95% Con.	-4.153	17.084	33.152	11.751	6.482	1.696
Mean+ 95% Con.	18.335	36.689	48.883	16.315	10.682	3.083

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	92.909	66.022	25.005	10.972	2.390
s^2	213.235	192.725	36.527	12.408	0.811
SD	14.603	13.883	6.044	3.523	0.901
SE Mean	4.868	4.628	2.015	1.174	0.300
95% Con.	11.244	10.690	4.654	2.712	0.693
Mean- 95% Con.	81.665	55.333	20.351	8.260	1.696
Mean+ 95% Con.	104.153	76.712	29.659	13.684	3.083

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: St-5

Sample number	Percentage of total volume 53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	36.359	31.298	15.842	12.899	3.603
2	0.000	30.689	36.845	15.458	12.540	4.469
3	0.000	48.784	28.407	9.981	9.341	3.487
4	0.000	23.609	54.048	13.116	6.920	2.307
5	23.998	25.481	37.861	7.532	3.405	1.723
6	0.000	34.305	40.721	12.354	8.749	3.871
7	0.000	35.794	33.786	19.551	9.096	1.772
8	0.000	37.307	37.267	16.464	6.813	2.149
9	0.000	32.877	38.896	16.023	9.880	2.325
10	0.000	28.221	39.262	19.732	9.899	2.886
11	19.287	35.597	28.386	9.937	4.696	2.096
Mean	3.935	33.548	36.980	14.181	8.567	2.790
S^2	77.759	46.486	50.491	15.697	8.638	0.866
SD	8.818	6.818	7.106	3.962	2.939	0.931
SE Mean	2.659	2.056	2.142	1.195	0.886	0.281
95% Con.	5.929	4.584	4.778	2.664	1.976	0.626
Mean- 95% Con.	-1.994	28.963	32.202	11.517	6.591	2.164
Mean+ 95% Con.	9.864	38.132	41.757	16.845	10.543	3.415

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	96.065	62.517	25.538	11.357	2.790
S^2	77.759	93.433	43.550	13.507	0.866
SD	8.818	9.666	6.599	3.675	0.931
SE Mean	2.659	2.914	1.990	1.108	0.281
95% Con.	5.929	6.499	4.437	2.471	0.626
Mean- 95% Con.	90.136	56.018	21.101	8.886	2.164
Mean+ 95% Con.	101.994	69.016	29.975	13.828	3.415

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: St-6

Sample number	Percentage of total volume					
	53.8	26.9	3.36	0.841	0.105	<0.105
1	0.000	41.437	25.902	25.124	5.379	2.159
2	0.000	27.037	37.061	25.240	8.147	2.516
3	0.000	13.356	32.962	39.255	11.045	3.382
4	0.000	27.930	47.340	11.305	9.933	3.491
5	0.000	37.839	37.708	10.674	10.586	3.193
6	0.000	26.820	51.832	11.759	7.372	2.216
7	0.000	43.626	26.006	19.314	6.946	4.108
8	0.000	19.575	39.443	31.891	6.452	2.639
9	11.501	23.998	35.810	19.397	5.906	3.388
10	0.000	40.522	40.426	9.574	7.640	1.838
11	27.896	31.844	25.714	7.065	6.234	1.247
12	0.000	52.195	29.775	8.304	7.473	2.254
Mean	3.283	32.182	35.831	18.242	7.759	2.703
S^2	71.012	124.765	70.003	106.629	3.428	.674
SD	8.427	11.170	8.367	10.326	1.851	.821
SE Mean	2.433	3.224	2.415	2.981	.534	.237
95% Con.	5.352	7.094	5.314	6.558	1.176	.521
Mean- 95% Con.	-2.069	25.088	30.518	11.684	6.584	2.181
Mean+ 95% Con.	8.635	39.275	41.145	24.800	8.935	3.224

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	96.717	64.535	28.704	10.462	2.703
S^2	71.012	176.952	121.854	5.350	.674
SD	8.427	13.302	11.039	2.313	.821
SE Mean	2.433	3.840	3.187	.668	.237
95% Con.	5.352	8.448	7.011	1.469	.521
Mean- 95% Con.	91.365	56.087	21.693	8.993	2.181
Mean+ 95% Con.	102.069	72.983	35.714	11.931	3.224

Appendix Table 1. Gravel composition statistics for samples taken at 15 locations in the Clearwater River basin, 1972 - continued

Location: SO-1

Sample number	Percentage of total volume					
	53.8	26.9	3.36	0.841	0.105	<0.105
1	14.462	25.106	36.329	17.702	5.399	1.003
2	0.000	38.842	35.344	14.234	7.398	4.182
3	15.823	28.193	39.357	9.076	4.538	3.012
4	8.767	37.669	29.929	15.800	5.138	2.697
5	16.685	29.292	32.963	15.495	5.376	3.189
6	0.000	52.002	29.137	13.479	3.425	1.957
7	12.795	48.335	10.026	21.399	4.190	3.255
8	0.000	52.106	26.729	14.769	3.432	2.964
9	0.000	49.317	26.958	16.166	4.189	3.370
10	20.235	18.779	43.521	9.108	4.601	3.756
11	26.586	18.989	38.583	7.226	5.465	3.242
12	24.280	40.242	9.438	2.134	2.907	4.757
13	17.664	35.422	29.863	6.500	5.794	4.757
14	0.000	36.720	43.030	9.768	6.952	3.529
15	0.000	31.198	47.769	12.314	5.620	3.099
Mean	8.868	36.277	33.985	12.632	5.110	3.128
s^2	87.657	123.692	85.233	17.382	1.255	0.755
SD	9.363	11.122	9.232	4.169	1.120	0.869
SE Mean	2.417	2.872	2.384	1.076	0.289	0.224
95% Con.	5.173	6.145	5.101	2.304	0.619	0.480
Mean- 95% Con.	3.695	30.132	28.884	10.328	4.491	2.648
Mean+ 95% Con.	14.041	42.422	39.087	14.935	5.729	3.608

Percent gravel composition smaller than each size catagory

	<53.8	<26.9	<3.36	<0.841	<0.105
Mean	9.132	54.855	20.870	8.238	3.128
s^2	87.657	85.379	14.208	2.772	0.755
SD	9.363	7.641	3.769	1.665	0.869
SE Mean	2.417	1.973	0.973	0.430	0.224
95% Con.	5.173	4.222	2.083	0.929	0.484
Mean- 95% Con.	85.959	50.633	18.787	7.318	2.648
Mean+ 95% Con.	96.305	59.077	22.952	9.158	3.608

Appendix Table 2. Cross-sectional survey statistics at station St-4

Station	Streambed deposition (yd^3)	Streambed degradation (yd^3)	Streambank erosion (yd^3)	Net change per station (yd^3)
1	35	0	0	+ 35
2	12	19	11	- 8
3	20	2	0	+ 18
4	11	10	11	0
5	-	-	-	-
6	14	49	11	- 46
7	12	17	19	- 24
8	63	0	10	+ 53
9	7	0	20	- 13
10	33	0	0	+ 33
11	25	9	0	+ 16
12	2	2	7	- 7
13	8	6	7	- 5
14	10	10	16	- 16
15	0	18	13	- 31
16	3	7	0	- 4
17	2	0	1	+ 1
18	9	15	0	- 6
19	6	10	15	- 19
20	-	-	-	-
21	-	-	-	-
Σ =	+272	-154	-141	- 23

Appendix Table 2. Cross-sectional survey statistics at station St-5 - continued

Station	Streambed deposition (yd^3)	Streambed degradation (yd^3)	Streambank erosion (yd^3)	Net change per station (yd^3)
1	22	3	0	+ 19
2	3	7	12	- 16
3	5	17	0	- 12
4	0	18	11	- 29
5	55	0	20	+ 35
6	32	9	29	- 6
7	39	2	0	+ 37
8	10	153	0	-143
9	16	27	16	- 27
10	0	33	34	- 67
11	9	4	5	0
12	3	33	2	- 32
13	6	16	3	- 13
14	7	23	12	- 28
15	1	30	3	- 32
16	9	10	0	- 1
17	-	-	-	-
18	8	13	0	- 5
19	0	41	13	- 54
20	1	41	18	- 58
21	-	-	-	-
Σ =	+226	-480	-178	-432

Appendix Table 2. Cross-sectional survey statistics at station St-6 - continued

Station	Streambed deposition (yd^3)	Streambed degradation (yd^3)	Streambank erosion (yd^3)	Net change per station (yd^3)
1	69	74	8	- 13
2	41	25	26	- 10
3	74	13	11	+ 50
4	54	8	32	+ 14
5	138	0	12	+126
6	107	8	15	+ 84
7	118	15	32	+ 71
8	102	3	65	+ 34
9	27	9	32	- 14
10	-	-	-	-
11	49	7	7	+ 35
12	44	66	19	- 41
13	-	-	-	-
14	92	0	97	- 5
15	108	0	159	- 51
16	111	0	72	+ 39
17	121	0	47	+ 74
18	-	-	-	-
19	-	-	-	-
20	108	0	113	- 5
21	152	4	58	+ 94
Σ =	+1,515	-232	-805	+478

Appendix Table 3. Average and instantaneous maximum and minimum monthly air and water temperatures taken at Weather Station A in the old-growth, buffer strip near the mouth of Stequaleho Creek, 1972-73

Month	Number of days recording	Air temperature				Water			
		High		Low		High		Low	
		$\overline{X}$	Instant extreme	$\overline{X}$	Instant extreme	$\overline{X}$	Instant extreme	$\overline{X}$	Instant extreme
Jan.	-	-	-	-	-	-	-	-	-
Feb.	8	43	48	36	32	41	42	40	39
Mar.	30	47	60	39	31	43	46	42	39
Apr.	23	47	66	34	30	42	46	40	37
May	31	62	88	47	35	53	62	48	45
June	30	63	73	49	42	60	69	51	45
July	28	75	84	54	49	65	76	53	48
Aug.	24	71	86	53	45	65	72	56	51
Sept.	27	60	80	44	37	56	65	51	40
Oct.	23	50	60	39	30	45	52	42	36
Nov.	23	48	58	41	33	46	51	45	34
Dec.	31	40	50	35	19	40	45	38	32
Jan.	25	37	45	31	20	37	42	37	31
Feb.	15	45	52	35	28	41	48	39	37
Mar.	19	52	67	36	31	42	43	39	36
Apr.	30	55	69	38	32	46	52	40	37
May	23	58	72	43	35	51	59	44	40
June	26	59	70	48	39	53	60	46	42

Appendix Table 4. Mean daily discharge of Stequaleho Creek at mouth, March through December, 1972

Day	March	April	May	June	July
1	295.5 cfs	92.0	77.1	17.9	9.5
2	253.6	70.5	72.4	18.0	9.3
3	207.6	57.6	69.3	18.0	9.0
4	194.3	197.4	65.8	18.0	9.0
5	1,106.6	308.5	60.2	18.0	10.2
6	435.7	261.2	53.8	18.0	10.6
7	239.5	179.3	49.0	17.5	10.6
8	173.2	152.3	42.4	17.0	14.8
9	294.3	133.9	38.2	17.0	69.6
10	417.6	125.0	35.0	17.0	31.9
11	424.8	117.2	32.8	17.0	123.3
12	408.5	140.9	31.0	17.0	520.8
13	390.1	121.6	30.4	16.8	178.2
14	267.6	142.8	28.9	16.1	99.8
15	206.8	159.3	42.1	14.2	74.5
16	160.5	128.3	40.7	13.1	58.0
17	137.4	101.5	35.5	12.3	48.4
18	201.4	86.4	47.0	11.8	41.3
19	202.8	78.6	34.0	11.4	37.0
20	157.8	120.7	32.9	11.5	34.6
21	134.8	149.7	34.5	11.8	32.1
22	120.5	113.5	32.9	12.2	30.5
23	114.3	104.8	26.3	12.0	28.8
24	123.4	203.9	23.3	12.2	27.0
25	108.7	209.1	21.9	12.0	25.4
26	90.1	154.7	20.7	12.4	23.9
27	75.8	135.6	19.7	12.6	22.5
28	68.1	130.6	18.9	11.6	21.7
29	62.7	104.4	18.5	10.3	20.8
30	57.4	86.8	18.1	9.8	20.3
31	73.9		17.6		18.7
Mean monthly flow	232.4	138.9	37.8	14.5	53.9

Appendix Table 4. Mean daily discharge of Stequaleho Creek at mouth, March through December, 1972 - continued

Day	August	September	October	November	December
1	17.8 cfs	9.4	25.5	64.6	121.7
2	17.1	9.3	23.9	84.8	93.9
3	16.2	9.3	22.3	133.2	66.6
4	14.9	9.3	20.9	267.4	54.4
5	14.4	9.4	19.7	220.2	47.0
6	14.0	10.2	18.9	216.9	39.7
7	13.6	19.2	18.0	218.7	26.1
8	13.2	15.7	17.3	157.7	23.0
9	12.8	11.4	16.7	141.5	23.0
10	12.6	9.8	16.0	145.2	23.0
11	12.3	9.3	15.3	106.1	23.0
12	12.2	9.1	14.9	80.5	23.0
13	12.3	9.0	14.4	63.0	23.0
14	12.1	9.0	14.1	54.4	23.0
15	11.6	8.8	13.6	51.4	27.3
16	12.1	9.2	13.2	46.1	286.4
17	19.1	9.7	12.8	41.8	286.7
18	16.9	20.0	12.4	50.2	408.2
19	12.5	37.0	12.2	41.3	485.4
20	11.6	63.6	12.2	36.6	289.8
21	11.2	258.2	13.4	40.1	368.9
22	11.0	161.3	12.2	35.8	343.9
23	10.8	114.4	11.8	54.9	376.0
24	10.5	73.9	11.4	51.0	278.3
25	10.4	54.3	14.9	111.3	1,488.0*
26	10.3	44.2	13.8	88.9	704.7*
27	10.1	37.2	20.4	66.4	372.8*
28	9.9	34.2	22.8	55.1	217.2*
29	9.7	30.0	15.4	49.2	154.0*
30	9.6	27.3	13.4	48.0	132.8*
31	9.7		12.7		102.2*
Mean monthly flow	12.7	37.8	16.0	94.1	223.7

*Due to changes in the control riffle, the estimates are very rough from December 25-31.

Appendix Table 5. Comparison of 1-mm- and 0.25-mm-mesh net

	$St\text{-}2_a$		$St\text{-}2_a$		$St\text{-}2_a$		$St\text{-}2_c$		$St\text{-}2_c$		$St\text{-}2_c$		$St\text{-}1_b$		$St\text{-}1_b$		$St\text{-}1_b$		$St\text{-}1_c$		$St\text{-}1_c$		$St\text{-}1_c$		Total		Average	
	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm	1 mm	.25 mm
Ephemeroptera	116	481	26	44	21	31	40	34	18	16	36	39	82	310	37	125	46	80	34	185	15	120	21	121	492	1586	41	132.2
Plecoptera	18	306	11	29	10	17	7	22	2	7	0	58	14	220	12	227	3	242	10	25	10	163	23	131	120	1447	10	120.6
Tricoptera	5	45	2	2	1	0	0	3	3	1	1	1	10	18	6	13	3	10	14	24	52	20	211	51	308	188	25.6	15.7
Chironomidae	3	111	1	74	17	105	45	209	8	116	43	255	26	359	5	57	1	43	29	335	32	249	1	81	211	1994	17.6	166.2
Elmidae (larvae)	14	33	30	137	2	10	4	13	13	19	3	11	18	29	2	7	1	3	0	1	0	0	10	0	97	263	8.1	21.9
Oligochaeta	0	45	0	19	2	0	0	1	0	0	0	0	3	10	1	57	4	141	4	35	4	15	1	62	19	385	1.6	32.1
Acari	1	147	16	872	4	58	2	54	5	3	0	166	0	53	0	34	0	23	0	8	0	62	1	18	29	1498	2.4	124.8
Total Invertebrates	199	1191	104	1227	75	240	113	351	74	176	109	546	165	1032	73	622	82	580	102	644	131	670	277	479	1504	7758	125.3	646.5

A LANDSLIDE SURVEY OF THE STEQUALEHO CREEK WATERSHED

SUPPLEMENTAL REPORT

by

Allen J. Fiksdal

A LANDSLIDE SURVEY OF THE STEQUALEHO CREEK WATERSHED

Allen J. Fiksdal, Geologist

Department of Natural Resources

Abstract

Eighty-three road associated and twenty-five natural landslides were documented in the Stequaleho Creek Drainage, a tributary of the Clearwater River in the Western Olympic Peninsula. Two landslides were found in clearcut areas but are listed as natural events because of the possibility they occurred before clearcutting. The road associated landslides occur at an average rate of 13.3 events per year. Natural landslides occur at an average rate of .3 events per year. The sediment contributed to Stequaleho Creek by road associated landslides is approximately five times the amount contributed by the natural landslides.

Introduction

Landslides are a common occurrence in the western foothills of the Olympic Mountains. They contribute large amounts of sediment to the rivers and streams along the Washington coast.

In May of 1971, after an intensive storm, a massive failure of road sidecast materials occurred causing a large amount of unconsolidated material to move as a debris torrent down two stream channels and to be deposited in Stequaleho Creek, a tributary of the Clearwater River.

This survey was conducted during the summer of 1972 as a part of the study of the effects of logging on aquatic resources being conducted by the Fisheries Research Institute and the College of Forest Resources of the University of Washington. The purpose of this survey was to compare the volume and frequency of the natural and man related mass movements in the Stequaleho Creek Drainage; and attempt to determine the relative volume of sediment being contributed to Sequaleho Creek by man related mass movements.

Detailed geologic investigation of the Clearwater Drainage has not been conducted and information pertaining to the geology of the western foothills of the Olympic Mountains is general. The bedrock is comprised of siltstones and sandstones that have been intensely folded and broken. Individual bedrock layers range in thickness from tens of feet to fractions of inches and are deeply weathered in places.

The soils of the upper Clearwater area are in the Dimal Series. The Soil Conservation Service describes the Dimal Series as a shallow residual soil that is less than 20 inches deep and contains many bedrock fragments. This soil is found on the steep to precipitous mountain slopes.

Literature Review

Many studies have been conducted on the problem of mass soil movement. Man is ever increasingly involved in this problem due to his logging practices. Studies in Alaska and Oregon are of particular interest because of the similarities in climate and vegetation that exists between these areas and the Olympic Peninsula.

In southeast Alaska, Swanston (1967 and 1969) reported landslides most frequently occurred on steep slopes having thin residual soils. The principal causes of these mass movements were steep slopes and excessive soil-water content.

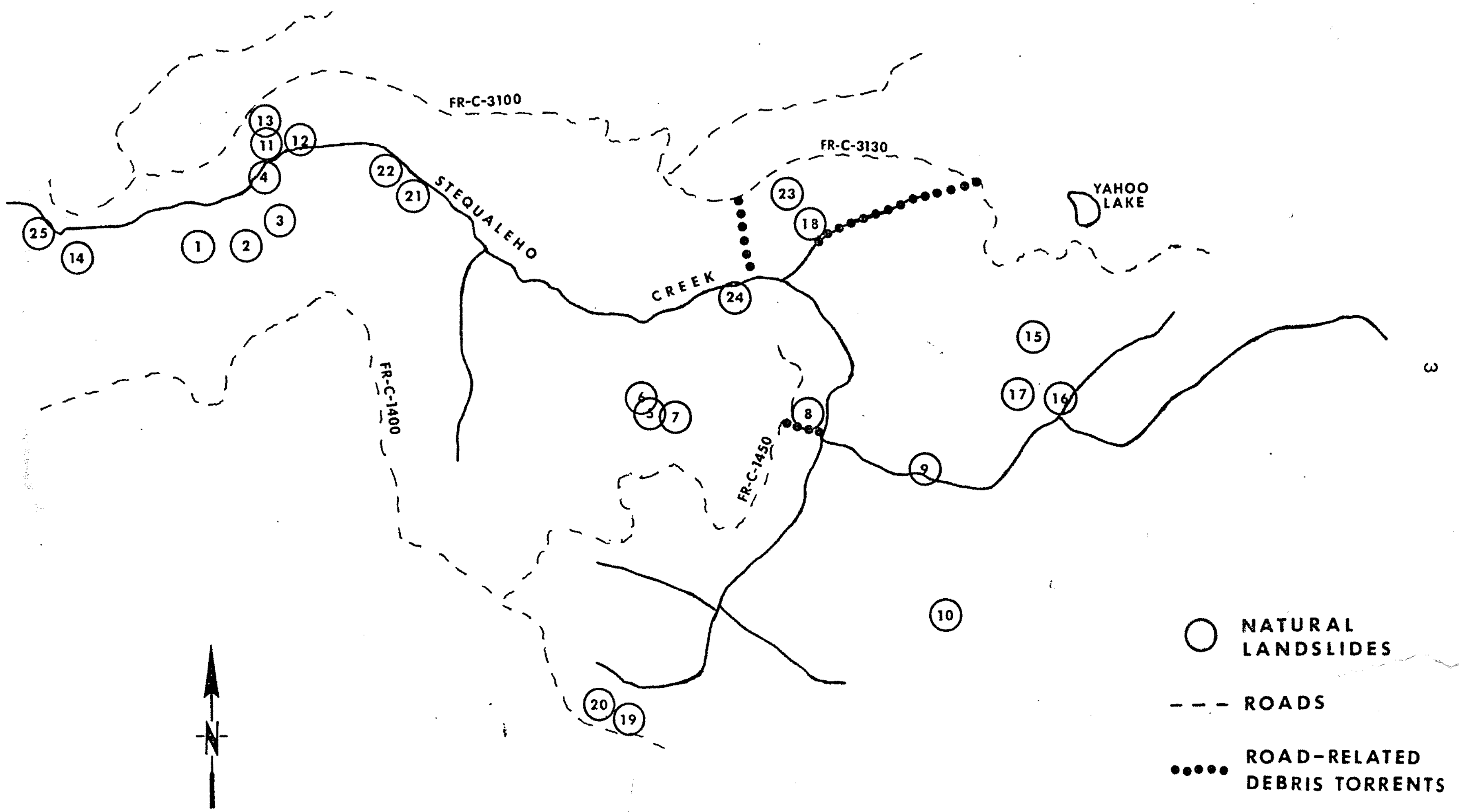
Logging is an important industry in Alaska, Washington, and Oregon and the wide use of the clearcut timber harvesting method has caused some problems associated with mass soil movements. Bishop and Stevens (1964) working in southeast Alaska, concluded that "large-scale clear cutting accelerates debris avalanches and flows during heavy rainfall."

Associated with timber harvesting is road construction. Road construction plays an important role in contributing to landsliding. Dyrness (1967) reported roads and their associated fills, backslopes, and sidecase accounted for approximately 65% of the total mass movements in the H. J. Andrews Experimental Forest during one winter.

Methods:

Information for mapping natural events was recorded by air photo investigation, aerial reconnaissance, and on the ground observations. The lengths and widths of some of the larger events were gathered from air photos taken in 1971. Information regarding man-related events was also recorded from air photo investigation and on the ground documentation. Dating of mass

MAP OF STEQUALEHO CREEK LANDSLIDES



movement events was done by the use of air photos and the boring of trees on the slide path. The ages given are meant only as an approximation of age.

Results

The Stequaleho Creek Watershed contains 6,050 acres. Eighteen percent (1,090 acres) has been logged by clearcut methods. Roads and their associated backslopes and sideslopes account for 3 percent of the total watershed.

Within the Stequaleho Creek Watershed, 25 mass movements were found in the undisturbed areas. Two events were found in a clearcut area, but it is not clear if these events occurred before or after clearcutting. Therefore, they are included with the events occurring in the undisturbed areas of the watershed. (See map).

Of the natural mass movements, 13 were a result of stream erosion, the undercutting of river banks in the process of widening their valleys during storm flow conditions. Eleven events started as debris avalanches (sudden downslope movement of soil and rock material) or debris flows (downslope movement of material with an increased water content), or a combination of both. If the material was water saturated and contained in a small "V" shaped valley a debris torrent was usually formed, scouring the channel to bedrock. There was also one area where downslope movement of unconsolidated material formed a very slow moving slide mass.

Mass movements initiated by road sidecast failure comprised 78 percent of the road-related events. Backslopes failure totaled 17 percent and road drainage water (culver erosion) caused 5 percent of the total road-related mass movements. The mass movements resulting from sidecast failure and road drainage water usually moved as debris flows or debris torrents scouring small drainage channels. Backslope failures usually came to rest on the road as a slump and/or flow, blocking drainage ditches and plugging culverts.

Road construction and clearcut logging in the Stequaleho Creek Area began in 1966. Since that time mass movements associated with these roads have totaled approximately 68,000 cubic yards. This indicates an average movement per year of 11,400 cubic yards of material. The oldest natural slide documented was at least 84 years old. The approximate volume of all the natural mass movements totals 150,000 cubic yards. This indicates an average natural movement of

1,800 cubic yards per year. Natural events tended to be larger, averaging 6,000 cubic yards per event, while mass movements associated with roads averaged 800 cubic yards per event. The frequency of mass movements in the Stequaleho Creek Drainage show that road-related events occur at an average rate of 13.3 events per year while natural events occur at a rate of only .3 events per year. All the natural events landed in drainages and were subject to direct erosion by running water. Thirty-one road associated events or 70 percent of the total volume of road related mass movements also landed in areas subject to direct erosion by running water (Table 1).

Table 1. Comparison of the natural and road associated mass movements in the Stequaleho Creek Drainage

	Number of Events	Volume of Movement
TOTAL:		
Natural	25	150,000 cubic yards
Road	83	68,000 cubic yards
FREQUENCY: (per year)		
Natural	.3	1,800 cubic yards
Road	13.3	11,400 cubic yards
EVENTS REACHING WATER		
Natural	25	150,000 cubic yards
Road	31	47,600 cubic yards

It is important to note that 36 percent of the total volume, or approximately 24,000 cubic yards of material involved with road-related mass movements was related to the massive failures in May 1971.

Discussion

In a natural state, mass soil movements contribute heavily to the sedimentation of rivers and streams. After the massive sidecast failures in May 1971, it was quite obvious that man also contributes heavily to the sediment load of Stequaleho Creek. It is impossible to determine exactly how much sediment is added to the creek by mass movements related to logging activities, but arrival at a relative figure is possible.

There have been no landslides resulting from clearcutting in the Stequaleho Area. This is not to say that none are possible. Bishop and Stevens (1964) reported a lag of several years between the cutting and landsliding of a clearcut area in southeast Alaska. They feel this lag is due to root deterioration. The Stequaleho Drainage may not have had sufficient time to display the total effects of clearcutting.

In trying to determine the relative amounts of sediment contributed to Stequaleho Creek by natural and man-caused landslides, we must make several assumptions. We find that approximately 63% of total material displaced by natural landslide has been removed by Stequaleho Creek. This means that approximately 93,000 cubic yards of material resulting from natural landslide has been removed by Stequaleho Creek in the last 84 years. Because of the nature of most road-associated events, a determination of the percentage of material that has been removed cannot be made, therefore, we must assume it to be similar to the natural landslides, 63%. If this figure is assumed we find that approximately 30,100 cubic yards of material resulting from road-associated mass movements has been removed by Stequaleho Creek over a six year period. Assuming an average rate of removal, we see that natural landslides contribute approximately 1,100 cubic yards per year or about one fifth the 5,000 cubic yards of material that road-associated landslides contribute (Table 2).

Table 2. Volumes of the 25 Natural Events and the 31 Road-Associated Events Reaching Waterways

	Natural	Road
Total Volume	150,000 cubic yards	47,600 cubic yards
Volume Removed (63%)	93,000 cubic yards	30,100 cubic yards
Volume per year	1,100 cubic yards	5,000 cubic yards

Conclusions and recommendations

The Clearwater River Drainage is highly unstable and subject to constant landsliding. The natural process of downcutting and valley widening accounts for the numerous mass movement events involving river and streambanks. Headward erosion by small tributaries oversteepen drainage heads. The deeply weathered bedrock and the tremendous amount of rainfall in this area combine in producing conditions where massive failures are imminent.

Investigation of the Stequaleho Creek Drainage has shown that road construction has accelerated the occurrence of mass movements. These road-related landslides have added approximately five times the amount of sediment normally contributed by landslide occurring in the natural state. Roadbuilding reduces stability by removal of protective vegetation, undercutting, and/or overloading natural slopes, and altering drainage.

In future planning road mileage should be reduced to a minimum - steep slopes, drainage heads; channels and wet areas should be avoided. Adequate road drainage must be provided. Most road associated events were initiated or resulted from the failure of sidecast materials; therefore, extreme care has to be taken in the placement of fills and sidecast. Protection of the fills and sidecast from road drainage by the use of flumes and/or energy dissipators should be used and maintained. Waste materials should be placed in a relatively flat area, away from streams or drainage channels. The sheer weight of waste materials placed as sidecast or fill may be sufficient to cause a landslide. More important, and often the case, the failures of sidecast and/or backslope material causes a chain reaction resulting in movement of not only road-associated material but the soil mantle as well. These events usually move as flows or debris torrents scouring small drainages and being deposited in streams or rivers.

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