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FRY EMERGENCE SURVIVAL OF RAINBOW TROUT, *ONCORHYNCHUS MYKISS* (WALBAUM), FOLLOWING TIMBER HARVEST IN TWO FOOTHILL STREAMS OF WEST-CENTRAL ALBERTA.

by
GEORGE L. STERLING ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

DEPARTMENT OF FOREST SCIENCE

EDMONTON, ALBERTA
FALL 1992

ISBN 0-315-77113-5

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR GEORGE L. STERLING

TITLE OF THESIS FRY EMERGENCE SURVIVAL OF RAINBOW TROUT, *ONCORHYNCHUS MYKISS* (WALBAUM), FOLLOWING TIMBER HARVEST IN TWO FOOTHILL STREAMS OF WEST-CENTRAL ALBERTA.

DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED FALL 1992

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled FRY EMERGENCE SURVIVAL OF RAINBOW TROUT, *ONCORHYNCHUS MYKISS* (WALBAUM), FOLLOWING TIMBER HARVEST IN TWO FOOTHILL STREAMS OF WEST-CENTRAL ALBERTA submitted by GEORGE L. STERLING in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE.

....
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Date. October 8, 1992

Abstract

Spawning and fry escapement of rainbow trout, *Oncorhynchus mykiss* (Walbaum), were studied in two small foothills streams in the Tri-Creeks Experimental Watershed of west-central Alberta between May and September from 1973 to 1985. Study objectives were: (1) to determine the effect of timber harvesting on sediment deposition, interstitial dissolved oxygen, water temperature, and streamflow during spawning and incubation of rainbow trout ova, and (2) to determine the effect of sediment deposition, interstitial dissolved oxygen, water temperature and streamflow on fry emergence survival.

Peak spawning usually occurred during the first 10 days of June, after the accumulation of approximately 10[illegible] to 122 degree days following ice out. Differences in spawning dates were largely due to annual climatic variations and not due to changes in water temperature following timber harvesting. Mean water temperature influenced the length of the embryo incubation period. At a mean temperature of 10°C, fry emergence occurred approximately 59 days (590 degree days) following spawning.

Spawning sites were generally located in pool-riffle transition areas. Sites had mean water velocities and depths of 31.1 ± 0.8 cm s^{-1}, and 14.3 ± 0.5 cm, respectively; and had substrates with a geometric mean particle diameter of 9.9 ± 0.5 mm and less than 12.1 percent fines (<0.841 mm). Mean fredle indices of spawning substrate quality ranged from 0.9[illegible] to 2.68 and did not appear to differ after timber harvesting. Interstitial dissolved oxygen saturation at spawning sites was significantly lower (from mean of 90.3% to 80.5%) following timber harvest.

Mean egg deposition was 88 ± 22 eggs per egg pit and fry escapement averaged 29 ± 5 fry per egg pit or 32.9 percent for the study period. Fry escapement did not appear to differ following timber harvesting, and was not influenced by substrate quality or oxygen content of interstitial water.

Rainbow trout fry density in lower Wampus Creek was highly influenced by water yield exceeding a critical flow of 0.731 m^3 s^{-1} during the incubation period. Streamflow during incubation may be the single most important factor limiting rainbow trout fry survival in streams of west-central Alberta.

Embryo survival to fry emergence in Wampus creek in 1979 was influenced by the intrusion of sediments <2.0 mm. The silt and clay component (<0.62 mm) was a dominant factor. A decrease in trout embryo survival to fry emergence was associated with an increase in the amount of fine sediment <2.0 mm in artificial spawning substrates.

ACKNOWLEDGEMENTS

I thank Mr. Carl Hunt, Regional Fisheries Biologist, Edson, Alberta for his encouragement and dedicated support throughout this study. I am grateful to Dr. B.P. Dancik, Dr. R.L. Rothwell and Dr. J.S. Nelson of The University of Alberta who persevered through the writing of this thesis, and to Dr. D.M. Rimmer and Messrs. M. Kraft, H. Norris, and M. Sullivan of the Alberta Fish and Wildlife Division who offered comments and suggestions. Thanks are also due to the project and seasonal staff of the Alberta Fish and Wildlife Division and Alberta Forest Service who assisted in the collection of data. A special thanks to Catherine Laborderie for her editorial comments and her endurance during the "final days".

This research was funded by the Alberta Fish and Wildlife Division as part of their annual budgetary commitment (from 1965 through 1987) to the Tri-Creeks Experimental Watershed Study.

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I. GENERAL INTRODUCTION

Rainbow trout, *Oncorhynchus mykiss* (Walbaum), in the East slopes of Alberta, like other salmonids, exhibit some flexibility in habitat use. They are, however, environmentally sensitive, requiring very special conditions for successful spawning, incubation of embryos, emergence of fry, and growth and survival of young. Early life history is dependent on the interactions of a diversity of physical, chemical and biological variables within the intragravel environment. This critical life history period is a time when limiting factors can be expected to operate most strongly (Allen 1969).

Forest harvesting often results in a conflict between forest and fish management, because many watersheds with harvestable timber also contain streams supporting salmonid fishes. This conflict is greatest when forest use practices degrade those natural interactions essential to maintaining the quality of salmonid habitat. Research in North America has generally shown that timber harvest has a negative effect on salmonid habitat in streams (Gibbons and Salo 1973; Iwamoto et al. 1978; Hartman and Schrivener 1990). Timber harvesting and associated road construction tend to increase sedimentation rates, turbidity, nutrients, streamflow, water temperature and allochthonous detritus and decrease gravel porosity, percolation rates and dissolved oxygen in streams (Gibbons and Salo 1973; Iwamoto et al. 1978). In some areas these effects result in increased egg and alevin mortality and decreased population size of salmonid stocks (Gibbons and Salo 1973; Reiser and Bjornn 1979).

Sediment transport is a complex relationship involving many variables (Heede 1980). Generally, transport may be by suspension in the water column or by saltation along the stream bottom, the quantity and size of transported sediments is proportional with discharge and channel slope (Hasfurther 1985). The transport of sediments is typically greater on the ascending limb of the hydrograph due to the supply of sediments rather than the hydraulics of flow (Sidle and Campbell 1985; Sidle 1988).

Suspended sediments may directly or indirectly influence the survival of salmonids (Iwamoto et al. 1978). Clogging of, and damage to, respiratory organs result from exposure to suspended sediments. Laboratory and field studies show effects to be highly dependent on the size and composition of the suspended material and on the species of fish (Herbert and Richards 1963; Everhart and Duchrow 1970; Branson and Batch 1972). High levels of suspended sediment elevated physiological stress in juvenile coho salmon and steelhead (Redding et al 1987). Suspended sediment concentrations of about 500 mg l^{-1} caused over 50% mortality in coho and chinook salmon after a 96 hour exposure (Stober et al. 1981 from Marcus et al. 1990), and concentrations above 100 mg l^{-1} reduced the survival of juvenile rainbow trout (Herbert and Merkens 1961). Prolonged exposure to suspended sediments reduced territoriality and caused changes in the use of cover (Gradall and Swenson 1982; Berg and Northcote 1985) and reduced feeding and growth (Sykora et al. 1972; Olson et al. 1973; Berg 1982; Sigler et al. 1984).

The deposition of fine sediments can acutely affect the survival of salmonids during intragravel incubation of eggs and alevins, as fingerlings and throughout winter (Chapman and McLeod 1987 from Marcus et al. 1990). Fine sediments generally are less than 6.3 mm in diameter (Chapman 1988), and timing of deposition, source and quantity affect survival. Sediment deposition influences survival directly by reducing intragravel water flow, thereby decreasing dissolved oxygen concentrations (Chapman 1988; Mason 1969; McNeil and Ahnell 1964) and limits survival to emergence by entrapment of alevins (Koski 1975; Hall and Lantz 1969). Increased proportions of fine sediments in substrates have been associated with the reduced intragravel survival of embryonic brook trout (Hausle and Coble 1976), brown trout (Witzel and MacCrimmon 1983), cutthroat trout (Irving and Bjornn 1984 from Marcus et al. 1990), rainbow trout (Witzel and MacCrimmon 1981), steelhead (Tappel and Bjornn 1983), and various species of Pacific salmon (McNeil and Ahnell 1964; Phillips et al. 1975).

The presence of some fine sediments may be beneficial to salmonids by contributing to increased invertebrate production; consequently it has been suggested that the adverse consequences of sediment introduction to trout streams has been overstated (Everest et al. 1987). Murphy et al. (1981) showed that small Cascade Range streams traversing open clear-cuts had greater rates of microbial respiration, and greater densities or biomass of aufwuchs, benthos, drift, salamanders and trout than did forested sites regardless of sediment composition. They concluded that changes in trophic status and increased primary production resulting from canopy removal masked the effect of sedimentation. Sowden and Power (1985) found no correlation between the amount of fine sediment in redds and the survival of rainbow trout, but they did find that reduced survival was significantly correlated with reductions in intragravel flows and dissolved oxygen concentrations.

Streamflows have subcritical and supercritical velocities (Heede 1980). Subcritical flows exert relatively low energies on banks and beds, while supercritical flows can produce high energies which cause channel erosion. The distinction between flow types is watershed specific and is related to watershed size and channel roughness. Bed armouring and riparian vegetation increase bed and channel roughness which tends to decrease water velocities. Decreased water velocities reduce the ability of water to carry sediment while channel roughness tends to reduce the effect of erosive streamflow and create zones of sediment deposition (Lowrance et al. 1984; Platts 1983a). However, periodic high streamflows that flush fine sediments from the deeper bed layers are necessary to maintain the channel and riparian habitats (Reiser et al. 1987). Timing and quantity of streamflows can affect survival. Peak flows, sediment transport and deposition frequently occur simultaneously with the incubation of eggs and alevins of salmon and steelhead in the Pacific Northwest (Meehan and Swanston 1977). However, when spawning occurs after spring peak flows redd substrates may be little affected by flow (Young et al. 1988 from Marcus et al. 1990).

Preferred water temperatures for salmonids varies by species, and temperatures 10°C to 20°C are generally considered optimal for growth. Water temperatures exceeding 24°C are considered lethal for rainbow and brook trout adults and juveniles while 13°C is considered as the short-term maximum for survival of their embryos (U.S. EPA 1986). Stream water temperatures are generally a function of global and net radiation, convection, conduction, evaporation and storage (Brown et al. 1971). Ninety-five percent of the heat input into Rocky Mountain streams at mid-day during summer is caused directly by solar radiation (Platts 1983b) and stream temperatures are directly proportional to heat input as affected by solar angle, time of day and exposed stream surface area; they are inversely proportional to stream discharge (Meehan et al. 1977). Riparian vegetation provides shading that prevents water temperatures from attaining levels stressful or lethal to salmonids, and it also reduces heat loss during winter which can cause anchor ice formation and substrate disturbances (Platts 1983b). In a Pennsylvania stream, riparian vegetation maintained stream temperatures below lethal temperatures, but after removal water temperatures often exceeded 21°C (Lynch et al. 1984).

A major criteria for successful incubation of salmonid embryos is a dissolved oxygen concentration near saturation levels (McNeil 1962). The delivery of this oxygen to embryos is dependent on substrate composition (i.e. permeability) and the velocity of waterflow in the vicinity of the embryos (Wickett 1954, 1958). Permeability of spawning substrates can also be influenced by the accumulation of fine particulate organic debris following logging. Decomposition of this material can increase the biological oxygen demand (BOD) and cause dissolved oxygen levels in the stream and substrates to fall below concentrations necessary for the survival of incubating embryos (Everest and Meehan 1981; Chamberlin 1982; Everest et al. 1985).

In Alberta, the effect of timber harvesting is not well documented, and the information base is limited. The implementation of forest harvest regulations (often subjectively based on results from other areas) is reluctantly accepted by provincial industry. East slope streams in Alberta also support an ever increasing recreational demand; therefore, the maintenance of stream habitat is essential to sustain the sport fish production potential of these east slope streams.

The goals of this study were to provide an evaluation of forest harvesting effects on the early life history of rainbow trout, thereby providing a regional information base that would allow objectivity in complementing or adjusting current timber management practices in Alberta.

This thesis is divided into four chapters. In the remainder of the introductory chapter I discuss the study site and the general methods used. Chapters II, III, and IV consider rainbow trout spawning and fry production in two streams of the Tri-Creeks Experimental Watershed as influenced by the natural processes of sedimentation, streamflow, water temperature and dissolved oxygen before and after forest harvesting.

A. STUDY SITE DESCRIPTION

Rationale For Choice of Study Streams

The typical approach to watershed studies designed to measure timber harvesting effects is long-term experimentation in a paired-basin approach. Watersheds chosen for such experiments need to be relatively small in size (2-8 km^2), and in close proximity to one another to minimize differences in physiography, geology, climate and vegetation. However, to measure possible changes in the biotic characteristics of trout streams following timber harvesting requires watersheds large enough to contain streams of sufficient size to support healthy populations of trout. The Tri-Creeks Experimental Watershed (TCEW) was initiated in 1965 as a 20 year study to evaluate the impact of timber harvest on the physical, chemical and biotic characteristics of trout streams in west-central Alberta. This watershed study was typical of the paired basin approach.

Streams within TCEW provided a long-term physical, chemical and biotic data base prior to timber harvesting necessary for this comparative work.

Location and Watershed Physiography

Wampus, Deerlick and Eunice Creeks are contained within TCEW, located at 53°09′N, 117°15′W, approximately 40 km southeast of Hinton, Alberta (Figure I.1). The study streams are situated in an area dominated by high foothills of the Brazeau Syncline, characterized by elongate ridges and valleys orientated in a southeast-northwest direction. Range elevations are 1,259 to 1,685 meters above sea level (masl). Bedrock is dominated by clastic rocks of the Brazeau formation of Late Cretaceous age. Surficial material includes glacial tills, glaciolacustrine silts, local ice contact and deltaic deposits, and a minor glacial outwash

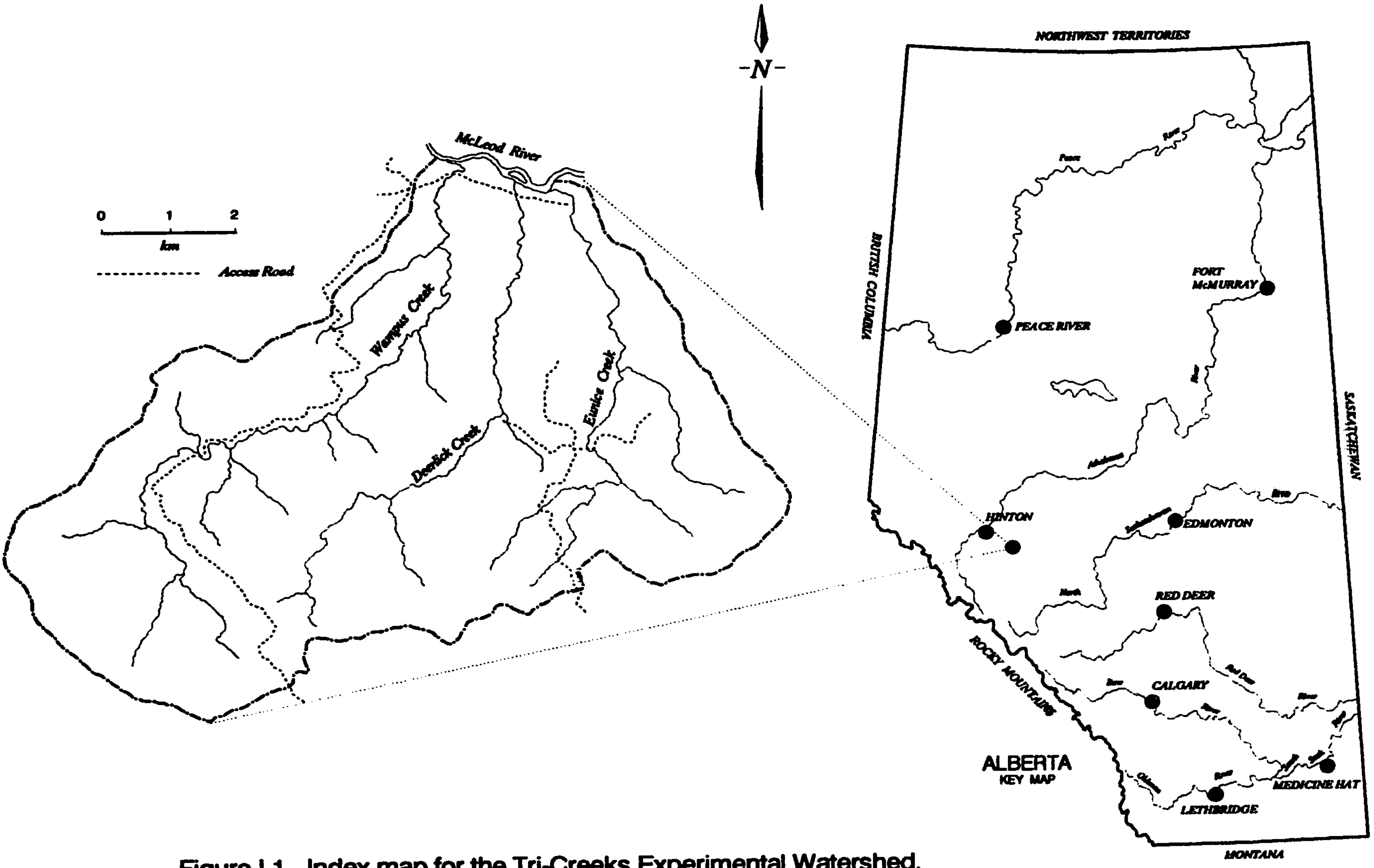

Figure I.1. Index map for the Tri-Creeks Experimental Watershed.

(Currie 1976). Three major soil associations (Brunisolic, Orthic Gray Luvisols and Eluviated Dystric Brunisols) dominate the study area. Soil A horizon materials throughout the study area are classed as highly erodible. Soil B and BC horizon materials are moderately erodible in the lower third of each basin, but are generally highly erodible in the middle and upper portions of each basin (Hudson et al. 1985).

Precipitation varied with location in the study area and averaged 770 to 918 mm annually. Approximately 27 percent of annual precipitation occurs as snow from November through April (Olson and Hastings 1987). July is the wettest month and accounts for approximately 17 percent of the average annual precipitation. The mean annual daily ambient air temperature at TCEW was approximately 1.0°C. July and August were the warmest months with mean maximum ambient air temperatures of 19.8 and 18.3°C, respectively. Freezing temperatures can occur in all months of the year. Warm Chinook winds frequently raise ambient air temperatures above freezing in winter months. The highest air temperature recorded in the study area was 34.4°C, and the lowest was -43.0°C.

The study area occurs in the subalpine forest zone and is dominated by coniferous forests of lodgepole pine, *Pinus contorta* Dougl., white spruce, *Picea glauca* (Moench) Voss, black spruce, *Picea mariana* (Mill.) B.S.P., and sub-alpine fir, *Abies lasiocarpa* (Hook.) Nutt.. Meadows of willows, *Salix* spp., sedges, *Carex* spp., and swamp birch, *Betula glandulifera* (Regel) Butler, occur in areas of moist soil and riparian zones adjacent to streams.

Description of Study Streams

The streams at TCEW are relatively small 2nd and 3rd order streams. Mainstem channel lengths range from 9.0 to 15.7 km, mean widths range from 2.4 to 4.9 m, and mean depths range from 0.14 to 0.29 m (Table I.1). Mainstem channel gradients are relatively high and range from 18.8 to 34.9 m km^{-1} (Figure I.2).

Streamflow during trout spawning periods (approximately May 20

Table I.1. Basin characteristics for the Tri-Creeks Experimental Watershed.

	Sub-Basin		
	Wampus	Deerlick	Eunice
Area	28.2 km^2	14.8 km^2	16.1 km^2
Basin Elevation			
Maximum	1707 masl*	1680 masl	1680 masl
Minimum	1259 masl	1265 masl	1271 masl
Length of Channel	15.8 km	10.1 km	9.0 km
Sinuosity	1.564	1.161	1.268
Channel Gradient	18.9 m/km	25.6 m/km	34.9 m/km
Drainage Density	2.8 km/km^2	2.1 km/km^2	2.9 km/km^2
Mean Stream Width			
Upper Basin	2.44 m	2.75 m	2.53 m
Lower Basin	4.94 m	3.12 m	3.26 m
Mean Channel Depth			
Upper Basin	0.22 m	0.24 m	0.17 m
Lower Basin	0.14 m	0.21 m	0.29 m
Pool/Riffle Ratio			
Upper Basin	1.50:1	0.40:1	0.34:1
Lower Basin	0.24:1	0.82:1	0.32:1
Mean Pool Length			
Upper Basin	15 m	8 m	11 m
Lower Basin	12 m	12 m	9 m

*Meters above sea level.

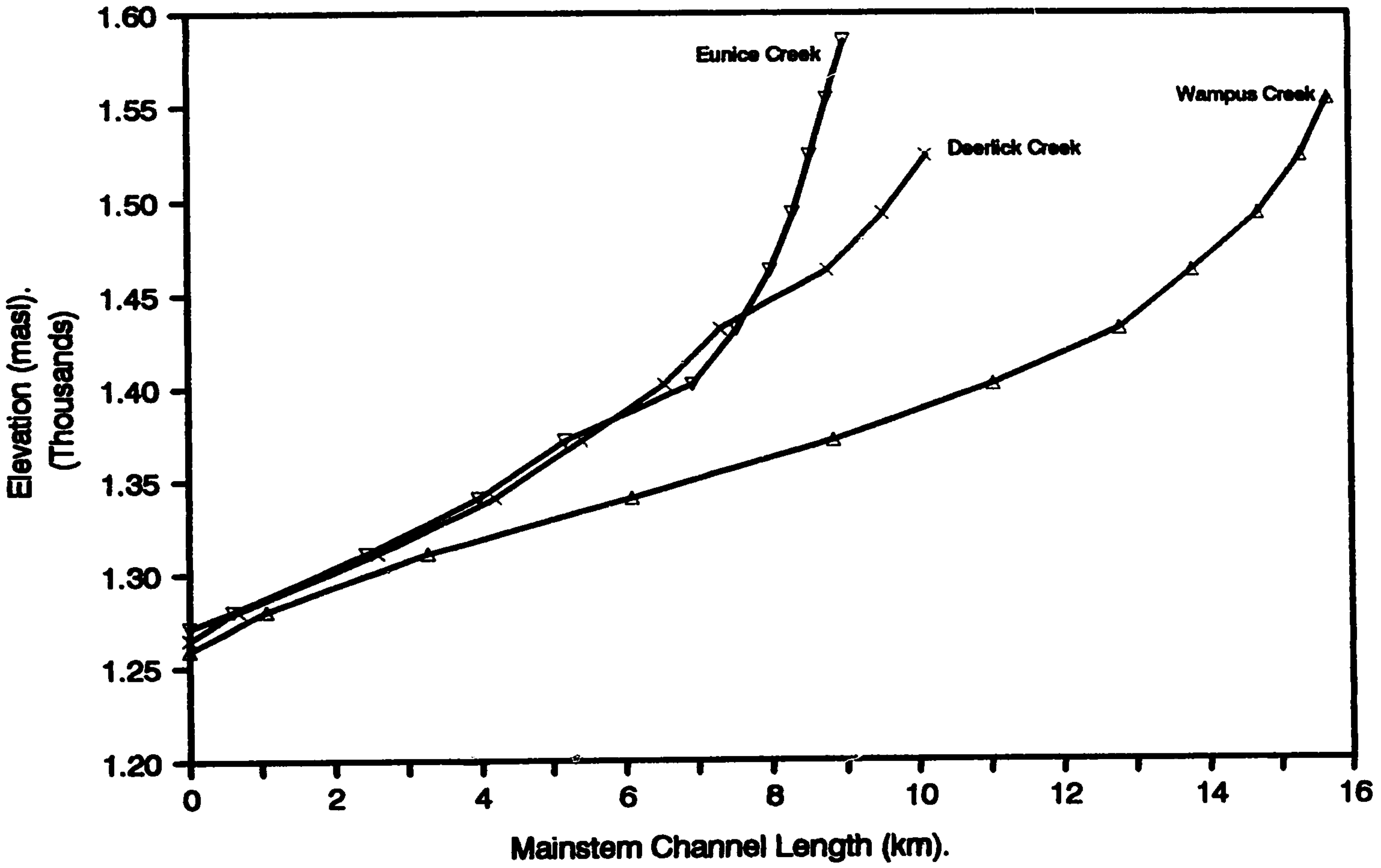

Figure I.2. Gradient profile for the study streams in the Tri-Creeks Experimental Watershed.

to June 10) ranges from 0.147 to 0.687 $m^3 s^{-1}$. Mean streamflow for the months of May and June ranges from 0.200 to 0.850 $m^3 s^{-1}$ (Andres et al. 1987). Annual maximum daily discharges, usually associated with mid-summer rainfall, range from 0.850 to 15.500 $m^3 s^{-1}$ in Wampus Creek; 0.782 to 8.760 $m^3 s^{-1}$ in Deerlick Creek, and 0.490 to 7.000 $m^3 s^{-1}$ in Eunice Creek.

Mean monthly water temperatures during the ice free period (May through October) range from <1.0 to 13.4°C. July and August are the warmest months with maximum water temperatures of 7.7 to 21.0°C. The highest water temperature (21.0 °C) recorded was in Deerlick Creek in 1984.

Many dissolved chemical constituents exhibit seasonal variability that is highly correlated with stream discharge; highest values coincide with late winter low streamflow and lowest values coincide with high spring and summer streamflow (Korchinski and Sneddon 1987). Mean pH ranges from 7.4 to 8.5, total dissolved solids (TDS) range from 38 to 195 ppm, and bicarbonate alkalinity ranges from 25 to 165 ppm.

The fish populations in the study streams are dominated by endemic, resident rainbow trout distributed throughout the TCEW drainages (Sterling 1978). Rainbow trout from the McLeod River utilize the lower reaches of the study streams for spawning and rearing (Dietz 1971, Sterling 1980). Bull trout, *Salvelinus confluentus* (Suckley), juveniles occur in the lower reaches of the study streams and dominate in the lower reaches of Eunice Creek (Sterling 1990). Mature bull trout spawners occur in the lower reaches only in August and September. Mountain whitefish, *Prosopium williamsoni* (Girard), adults and juveniles, are seasonally abundant in the lower reaches. Eastern Brook trout, *Salvelinus fontinalis* (Mitchill), burbot, *Lota lota* (Linnaeus), white sucker, *Catostomus commersoni* (Lacepède), longnose sucker, *C. catostomus* (Forster), spoonhead sculpin, *Cottus ricei* (Nelson), and longnose dace, *Rhinichthys cataractae* (Valenciennes), are scarce and limited in distribution to the lower reaches of TCEW.

B. GENERAL METHODS

Location of Study Sections

Field studies for spawning and escapement of rainbow trout were conducted in 10 sections (Figure I.3) of Wampus and Deerlick Creeks (seven and three sections respectively). Two sections in each stream coincided with the 1000 m study sections established for estimating population densities. Eunice Creek, the control stream, was omitted from spawning and escapement studies because of low spawner densities. Study sections were variable in length (Table I.2) depending on annual spawner densities.

Location of Spawning Areas

Between 1974 and 1985 (except 1980, 1982 & 1983), commencing in mid-May, known spawning areas were visited daily to establish the first and last day of spawning. Periods of intense spawning activity were also recorded. When spawning commenced, each study section was walked daily and individual egg pits were located by observing females spawning or by locating completed redds in known spawning areas (Plate I.1). Completed redds were easily distinguished by their characteristic structure, which was gradually obscured over a period of two to three weeks through the sorting of bed materials by streamflow. Each egg pit was confirmed by gently removing the overlying gravel until the eggs were observed, and were then re-covered. Egg pits were bench-marked by driving one flagged 15 cm spike into the streambed approximately 0.3 m downstream from the egg pit center, and a second spike at 90° either to the left or right, approximately 0.3 m from the egg pit center (Plate I.2). Up to 15 egg pits were located in each section.

Water depth and velocity was measured over each site. Five egg pits in each section were randomly selected for fry escapement and physical/chemical studies. A maximum of five egg pits were

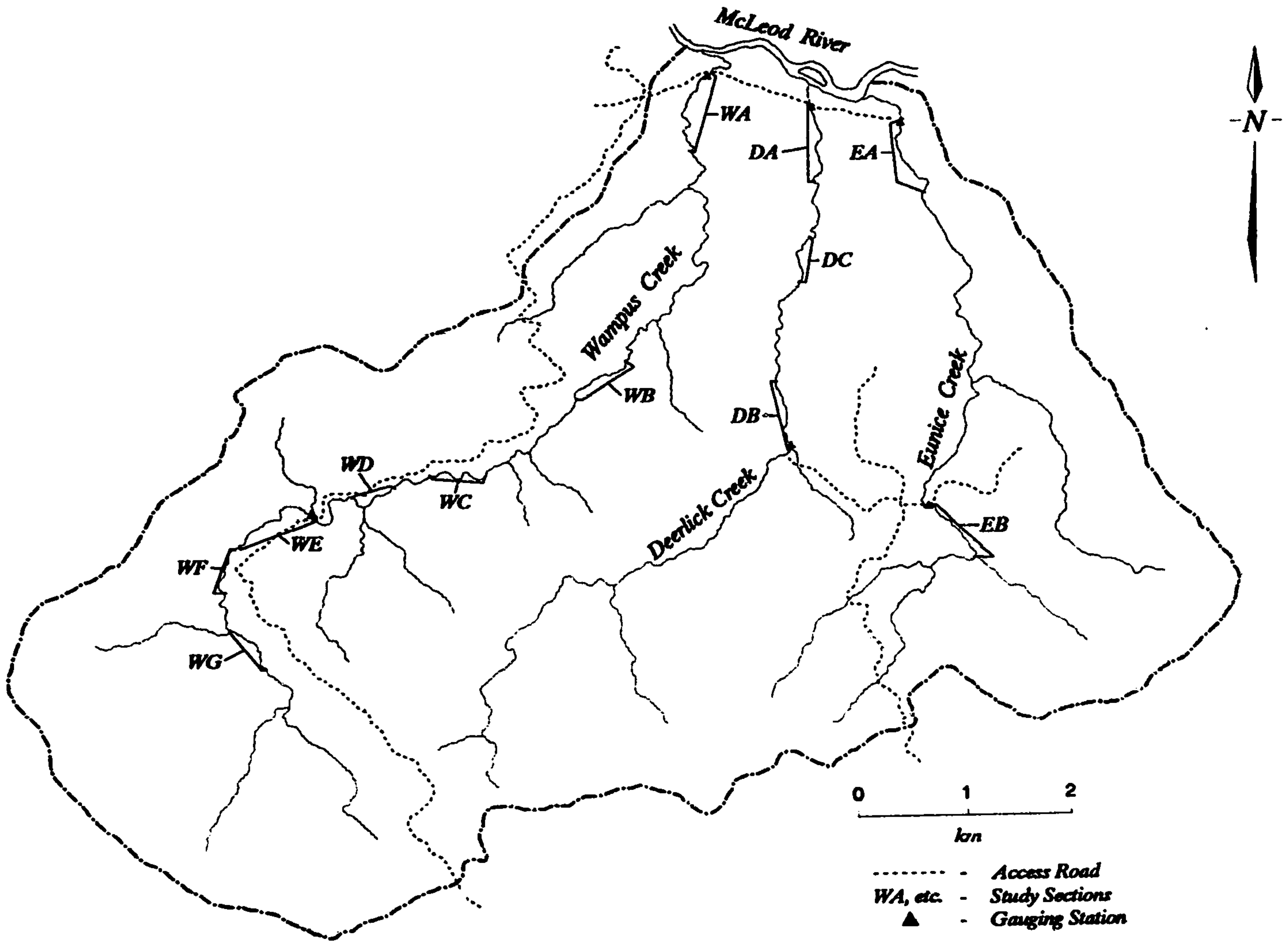

Figure I.3. Study Sections in the Tri-Creeks Experimental Watershed.

Table I.2. Length of study sections (meters) in the Tri-Creeks Experimental Watershed, 1973 - 1985.

	Study Sections									
	Wampus Creek							Deerlick Creek		
	WA	WB	WC	WD	WE	WF	WG	DA	DB	DC
1973	750			200	500			1000		
1974	750			800	800			1000		
1975	750	300	250	250	400		500			
1976			250	200	400		500	1500	1500	
1977				250	400		500	1000	1500	
1978	750	300	250	250	400		750	1000	1500	
1979	500	300	300	250	400	300	500	1000	1500	400
1981	500	300	250	250	400	300	500	1000		
1984	750	300	250		350	300	500	1000		400
1985	750	300	250		350		500	1000	1000	400

Plate I.1. Locating and marking egg pits in Wampus Creek, Tri-Creeks Experimental Watershed.

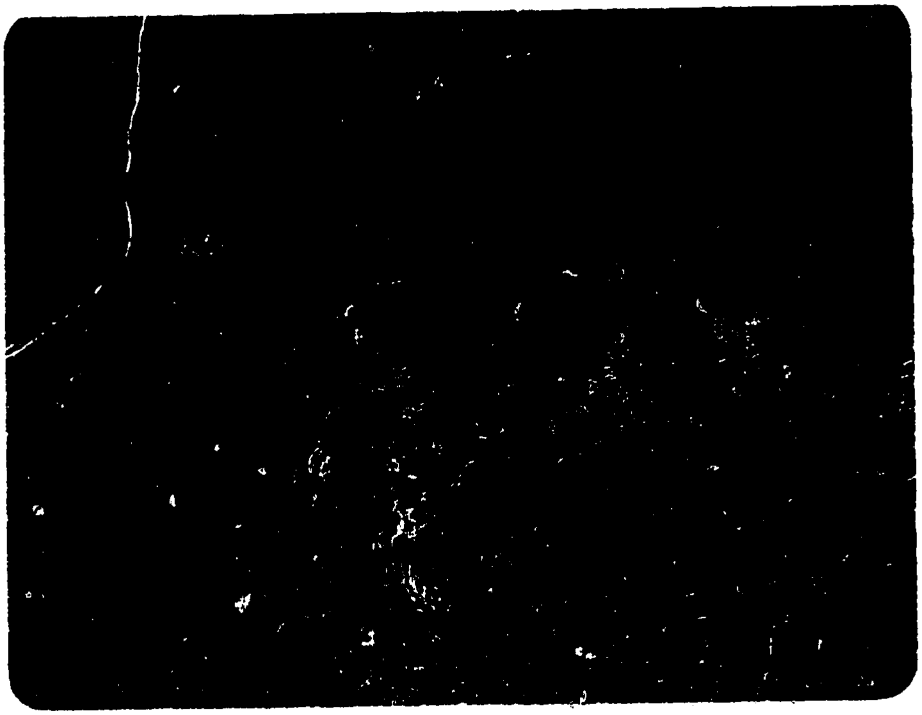

Plate I.2. Egg pit "bench-marked" with flagged spikes. Wampus Creek, Tri-Creeks Experimental Watershed Study.

randomly selected from each section and excavated to estimate mean egg deposition.

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II. FRY EMERGENCE SURVIVAL OF RAINBOW TROUT, *ONCORHYNCHUS MYKISS* (WALBAUM), IN THE TRI-CREEKS EXPERIMENTAL WATERSHED OF WEST-CENTRAL ALBERTA; A POSTLOGGING EVALUATION[1].

A. INTRODUCTION

East slope rainbow trout in west-central Alberta are unique in that they represent a rare natural occurrence of *O. mykiss* (Walbaum) east of the Continental Divide. Electrophoretic screening of trout from Wampus Creek demonstrated that they are distinctive, resembling neither inland, coastal nor hatchery strains of rainbow trout (Seeb and Wishart 1984; Carl et al. 1992, unpubl.).

Like other salmonids, they require special conditions for successful spawning, incubation of embryos, emergence of fry, and growth and survival of young. Successful spawning and incubation of embryos is dependent on factors such as suitable water temperature, water depth, water velocity, stream discharge, dissolved oxygen, and substrate composition (Marcus et al. 1990; Reiser and Bjornn 1979).

Timber harvesting (clear-cutting in particular) and associated activities increase stream sedimentation rates, turbidity, nutrients, waterflow, water temperatures and allochthonous detritus, and decrease gravel porosity, percolation rates, and dissolved oxygen (Gibbons and Salo 1973; Iwamoto et al. 1978; Hartman and Scrivener 1990). These effects can subsequently increase egg and alevin mortality and decrease salmonid stocks (Cordone and Kelley 1961; Gibbons and Salo 1973; Iwamoto et al. 1978; Wydoski 1978).

Sediments, by virtue of natural processes, are a fact of life in most streams and rivers, and in fact have played an important role in the development of streams and stream life (Hynes 1970).

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[1] A version of this chapter will be submitted for publication. Sterling, G.L. 1992. Transactions of the American Fisheries Society.

Aquatic life forms have adapted to these natural sediment regimes and are able to compensate for variations in sediment concentrations within this regime, but may fail to do so when natural sediment regimes are changed by anthropogenic factors.

Increased sediment loads, within the bed or suspended in the water column, usually follow logging. These increased sediment loads generally are associated with roads (Rothwell 1983; Fredrikson 1970; Yee and Roelofs 1980; Packer 1966), but also can be associated with decreased slope stability and mass erosion in cutover areas (Swanston 1974; Lyons and Beschta 1983). Additionally, decreased bank stability and buffering action of riparian vegetation increases sediment delivery to streams when riparian vegetation is removed during logging (Everest et al. 1985).

Sedimentation is a principle factor affecting salmonid embryo survival and has been the subject of intense study elsewhere (Hartman and Scrivener 1990; Irving and Bjornn 1984; Tappel and Bjornn 1983; Witzel and MacCrimmon 1983a; Witzel and MacCrimmon 1981; Hausle and Coble 1976; Phillips et al. 1975; McNeil and Ahnell 1964). Sedimentation influences embryo survival by decreasing porosity which reduces percolation rates (intragravel flow) and decreases dissolved oxygen (Chapman 1988), and by entrapment of alevins (Koski 1975).

Water temperatures regulate stream energetics and are critical for all salmonid life processes, including spawning and egg incubation. Water temperatures are regulated by solar radiation, stream surface area, streamflow and groundwater discharge, and are often affected by logging. The most dramatic changes occur when riparian vegetation is cut adjacent to small streams. Levno and Rothacher (1967) reported mean monthly water temperature increases of 3.9°C to 6.7°C following removal of riparian vegetation and flooding in two experimental Oregon watersheds. In the Needle Branch of the Alsea Watershed Study, Brown and Krygier (1970) reported increases in mean monthly maximum temperatures of 7.8°C and an increase in annual maximum water temperature from 13.9°C to

29.4°C one year after clear-cut logging.

Adult and juvenile salmonids can accommodate water temperatures ranging from near freezing to 20 °C with activity reduced or stopped at either extreme. Water temperatures of 13°C to 15 °C are considered optimal for growth. For rainbow trout 24°C is considered lethal for adults and juveniles, while 13°C is considered the short-term maximum for survival of embryos (U.S. EPA 1986).

Dissolved oxygen concentrations above 7 mg l^{-1}, or, at or near saturation are essential for most salmonid life processes. Although the survival of adults and juveniles is not greatly affected at concentrations above 3 mg l^{-1}, impairment of function is apparent when oxygen is reduced to levels below 6 mg l^{-1} (Davis 1975). As water temperatures increase oxygen content near saturation is vital and lowered concentrations of oxygen are tolerated only at reduced water temperatures (Whitmore et al. 1960). For incubating embryos, reduced oxygen concentrations may lead to a longer development period and/or the incidence of anomalies (Shumway et al. 1964; Alderdice et al. 1958), or smaller and weaker fry at hatching (Shumway et al 1964; Silver et al. 1963). Phillips and Campbell (1961) concluded that intragravel oxygen concentrations must average 8 mg l^{-1} for high survival of coho and steelhead embryos. Reiser and Bjornn (1979) recommend that for successful incubation, oxygen concentrations near saturation, with temporary reductions no lower than 5 mg l^{-1}, be maintained. Organic matter in a stream may decrease the oxygen content but the effect is regulated by the chemical, physical and hydraulic characteristics of the stream. The addition of fine particulate organic matter to a stream following logging results in increased biochemical oxygen demand in the interstitial environment and may lead to decreased survival of embryos.

Streamflow and the timing of streamflow delivery are critical to embryo survival. During spawning, streamflow is an important determinant as it dictates those areas within the stream that are suitable for spawning. During embryo incubation, low flows contribute to reduced intragravel flow, which effects the efficiency of oxygen delivery and metabolic waste removal. High streamflows contribute to bed scour and sediment deposition, both of which contribute to increased embryo mortality.

In Alberta, timber harvesting is a major activity in a diversified forest industry with an estimated 1987 market value of over $1 billion dollars. Pulp wood harvesting and production of bleached kraft pulp comprise slightly more than one-third of this total revenue (Renewable Resources Sub-Committee, Public Advisory Committees to the Environment Council of Alberta, 1990). Much of this industry is concentrated on (but not limited to) the harvest of softwoods (principally pine) in the east slope watersheds and supports a growing pulp industry. Many of these watersheds contain populations of salmonids sensitive to the effects of (particularly sedimentation) logging. However, no studies in Alberta have documented natural sediment regimes within spawning areas or the changes that may occur following logging.

The goals of this study were: (1) to determine if timber harvesting increased sediment deposition, streamflow and water temperature, and decreased interstitial dissolved oxygen during the the incubation period of rainbow trout embryos in streams of west-central Alberta, and (2) to determine if increased sediment deposition, streamflow and water temperature, and decreased interstitial dissolved oxygen reduced fry recruitment.

B. MATERIALS AND METHODS

Spawning and Fry Escapement

Commencing in mid-May, from 1974 to 1985 (except 1980, 1982 & 1983), known spawning areas were visited daily to establish the first day of spawning. Periods of intense spawning activity were recorded, as was the last day of observed spawning.

Up to 15 egg pits were located in each study section and water depth and velocity were measured over each site. Five egg pits in each section were randomly selected for fry escapement studies.

Additional egg pits were randomly selected from each study section and excavated to estimate mean egg deposition. Excavated eggs were captured in a Surber sampler (Surber 1937) and live and dead eggs enumerated (D_e). Live eggs were held in a streamside incubator until they hatched, and then released.

Fry escapement was estimated by using a fry trap (Plate II.1) similar to Phillips and Koski (1969), but modified to compensate for the smaller redd size of salmonids in the Tri-Creeks Experimental Watershed. The trap apron measured 1 m^2, and the access sleeve and capture bag measured approximately 30 x 30 x 40 cm. The trap was constructed of 100% Dupont woven soft mesh having a circular mesh opening of 1 mm. A draw string closed the access sleeve and capture bag and the apron was buried 20 to 25 cm below the bed surface by excavating trenches upstream, laterally and downstream around each egg pit, placing the apron and then back filling with excavated materials. Efficiency was not determined; however, Phillips and Koski (1969) found their traps captured 99.6% of emerging fry. Timing of trap installation was achieved by rearing eggs in a streamside incubator (Plate II.2) supplied with stream water via gravity feed. Installation of fry traps occurred when a 50% hatch was achieved in the incubator, providing a 10 to 14 day buffer before escapement commenced. Traps were monitored twice weekly, and following peak emergence, were removed if no fry were captured in a one week period.

Total fry escapement (S_e) from spawning gravel in each study section was estimated as the ratio:

$$S_e = \sum_{i=1}^{n} F^i/D_e*n$$

where: F_i = the number of fry captured in the i^{th} site,

D_e = the estimated mean egg deposition per site, and

n = the number of sites per section.

Substrate Composition

The composition of spawning substrates, particularly the

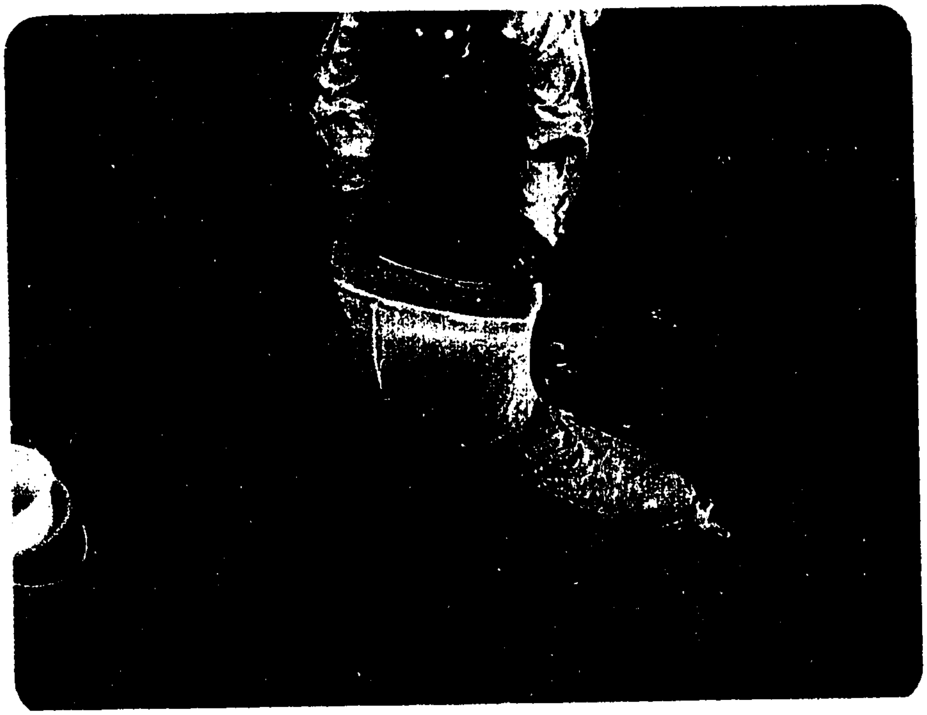

Plate II.1. Installed fry trap being inspected for newly emerged fry. Wampus Creek, Tri-Creeks Experimental Watershed.

Plate II.2. Streamside settling tank, incubation chamber and fry catchment basin. Wampus Creek, Tri-Creeks Experimental Watershed.

amount of fine sediment, affects salmonid embryo survival and fry escapement (McNeil and Ahnell 1964; Koski 1975; Bjornn 1969; Hall and Lantz 1969). To quantify substrate composition in the Tri-Creeks Experimental Watershed, natural spawning substrates were sampled in June at sites randomly selected for escapement studies. Rainbow trout ova were seldom found deeper than 12 cm so core samples of approximately 15 cm in depth were chosen to represent the substrate used by trout for spawning. A 15 cm diameter core sample was collected from each site using a McNeil (type) sampler (McNeil and Ahnell 1964). The sampler was forced into the substrate to a depth of 15 cm and the gravel within excavated. Following the excavation of coarse particles, a tight fitting plunger was inserted into the sampler to retain the finer silts and clays and the entire sampler was lifted from the substrate. Samples were transported from the field in heavy gauge polyethylene bags. For samples collected from 1973 to 1978, material was washed through a series of 11 standard Tyler sieves of mesh sizes 76.2, 50.8, 25.4, 12.7, 6.35, 3.36, 1.68, 0.841, 0.420, 0.210, and 0.105 mm (1.68 and 0.105 mm sieve omitted in 1978). Excess water was drained from each sieve, displaced volume (to the nearest ml) of materials retained was determined (McNeil and Ahnell 1964) and expressed as a percent of total sample volume. To increase the accuracy of sample analysis for samples collected from 1979 through 1985, sediment fractions (0.105 omitted) were dried, weighed (to the nearest g) and expressed as a percent of total weight. For samples collected from 1978 to 1985, the tailings (material < 0.210 mm) from each sample washing were allowed to settle for 24 hours, excess water removed, and oven dried at 121°C. A mechanical soil analysis (Bouyoucos Method) of these samples was used to determine the fraction of fine sand, silt and clay. For those samples lacking certain sieve fractions in the analysis series, the percent passing each sieve was plotted on semilog paper and the percentage passing the missing sieve fractions interpolated from the plots (Platts et al. 1979).

Platts et al. (1983) discusses the use of several measures of substrate quality in spawning areas. Percent fines, less than a specified particle size, ignores the textural composition of the remaining particles that can effect survival. The geometric mean diameter (d_g) method, although it has statistical advantages over "percent fines", is insensitive to changes in substrate composition; i.e., samples with a common geometric mean may have widely divergent distributions of particle sizes. A modification of the d_g method (Platts et al. 1983) also ignores the effect of the larger particles in a sample.

A fourth substrate quality index, termed the "fredle index", combines a measure of central tendency (d_g) and particle distribution in relation to d_g to provide an indicator of sediment permeability and pore size (Platts et al. 1983). Intragravel water velocity and oxygen transport are key elements in salmonid embryo survival to emergence and are regulated by pore size (permeability) which is directly proportional to mean grain size. The magnitude of the fredle index (f) numbers is a measure of relative permeability and pore size. An increasing index (f) reflects increasing pore size and permeability, hence, increased salmonid embryo survival to emergence.

The relationship between (f) values and salmonid embryo survival has not been documented experimentally. However, Platts et al. (1983), using the data of others, demonstrated the sensitivity of (f) to slight changes in substrate composition, embryo survival and variations in the intragravel habitat requirements of individual salmonid species. Consequently, I chose the fredle index to describe the quality of spawning gravel and to compare gravel quality within and between streams following timber harvesting in the Tri-Creeks Experimental Watershed.

Calculation of the fredle index (f) for individual samples of spawning gravel is described in Appendix I.

Water Temperature

Water temperatures were recorded continuously at six locations (Figure I.3). Nygretti chart recorders, located near the confluence of each stream, and Ryan submersible thermographs, located in the upper reaches, recorded stream temperatures during the open water season. Water temperatures were also collected routinely during the monitoring of dissolved oxygen and pH.

Dissolved Oxygen

A standpipe constructed of an open cylinder of ABS plastic tubing (3.8 cm X 75 cm) was located downstream and to one side (approximately 35 cm) of each site selected for escapement studies (Plate II.3). Standpipes were driven into the substrate with a pointed steel insert (McNeil 1962) so that a series (24) of 3.0 mm perforations were located at a bed depth of 8 to 12 cm, and capped to prevent atmospheric gas exchange. Dissolved oxygen (to the nearest 0.1 mg/l) and pH (to the nearest 0.1 unit) of mainstem and interstitial water were measured weekly at all sites using a Hach kit (Model OX-2-P) or YSI meter (Model 51A) and a Hellige comparator (185D or 170D) or Hach pH meter (Model 1975), respectively.

Streamflow

Streamflow and stage levels at the outlets of Eunice, Deerlick and Wampus creeks were monitored during the open water season between spring run-off and fall freeze-up of each year for the duration of the study by Alberta Forest Service Research Branch. Streamflow sampling frequency varied, with a greater number of measurements taken during the postharvest phase, spring runoff and storm events. Daily flows, estimated from stage-discharge rating curves, were provided by the Alberta Forest Service Research Branch.

Plate II.3. Sampling site with fry trap, standpipe and sediment traps installed. Wampus Creek, Tri-Creeks Experimental Watershed.

C. RESULTS

Spawning and Egg Deposition

Spawning generally occurred during late May and early June, however, spawning was observed as early as May 15, and isolated spawning events were observed as late as July (Figure II.1). Fry escapement was usually completed by the third week of August. Water temperatures at first spawning were highly variable (Table II.1) and no consistent pattern was found. Dietz (1971) and Sterling (1986) report that temperatures of at least 8°C and 6°C, respectively, were needed before spawning was initiated. The long-term trend data, however, showed spawning was not triggered by any specific temperature but was related to the mean water temperature during the pre-spawn period (Figure II.2, $r=-0.9077$, $p<0.05$). At a mean temperature of 3.5°C, peak spawning occurred approximately 33 days (or 115 degree days) following ice out. First spawning and peak spawning in Wampus and lower Deerlick Creeks occurred at earlier dates during the postharvest years of 1983 to 1985 (Table II.1) but could not be attributed to altered water temperature regimes as no consistent increase in mean monthly water temperatures occurred following logging (Andres et al. 1987).

One hundred egg pits were excavated between 1973 and 1985 (Table II.2). There was no significant difference ($F=0.7382$, $p>0.05$) in mean annual egg counts, which varied from 72 to 97 eggs. The overall mean annual egg count of 88 ± 22 eggs/egg pit represents 3 to 4 excavations per female (based on an average fecundity of 293 ± 16 eggs, Sterling 1986).

Water Velocities and Depths

Redds were generally located just upstream of the riffle crest where stream hydraulics provided appropriate particle size distribution and interstitial waterflow. Spawning was not restricted to these locations, and redds were often well separated with individual egg pits of any one female located wherever suitable water velocities and substrate occurred. From 1973 to

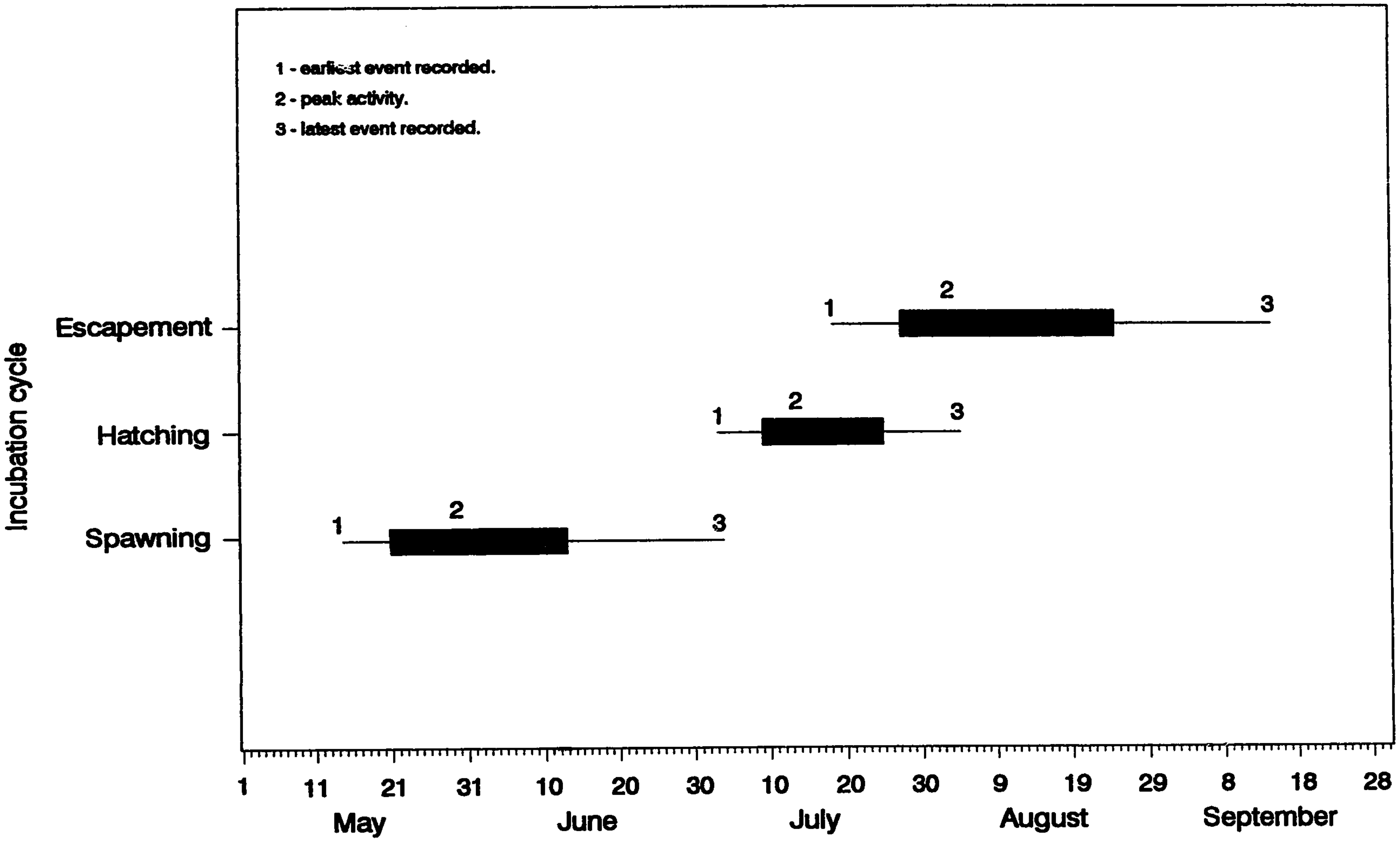

Figure II.1. Spawning, hatching and escapement of rainbow trout fry in the Tri-Creeks Experimental Watershed, 1973 - 1985.

Table II.1. Maximum pre-spawn water temperatures and spawning dates for Wampus and Deerlick Creeks, 1973 - 1985.

Section	Year	First Day of Spawning	Peak Spawning	Maximum Water Temperature (^{o}C) (Pre-spawn)
WE	1974	June 1	June 7	5.7
	1975	May 23	June 3	4.8
	1976	May 21	June 1	6.3
	1977	June 3	June 13	7.1
	1978	June 2	June 12	8.8
	1981	June 1	June 5	9.1
	1982	June 12	June 18	6.6
	1983	May 25	June 5	13.3
	1985	May 15	May 25	8.8
WA	1973	June 1	June 10	7.9
	1974	June 3	June 10	7.5
	1975	May 30	June 3	8.8
	1978	June 1	June 11	7.5
	1979	June 2	June 10	8.3
	1981	June 1	June 5	7.9
	1982	June 12	June 18	8.0
	1983	May 25	June 6	10.5
	1984	May 25	June 1	8.3
	1985	May 17	May 25	12.4
DA	1973	**	June 10	8.8
	1974	**	June 10	6.8
	1976	**	June 6	7.9
	1977	**	June 20	9.0
	1978	**	June 14	8.7
	1979	**	June 12	7.0
	1981	**	June 8	8.4
	1984	**	June 1	12.3
	1985	**	May 25	13.5

**Date of first spawning unknown.

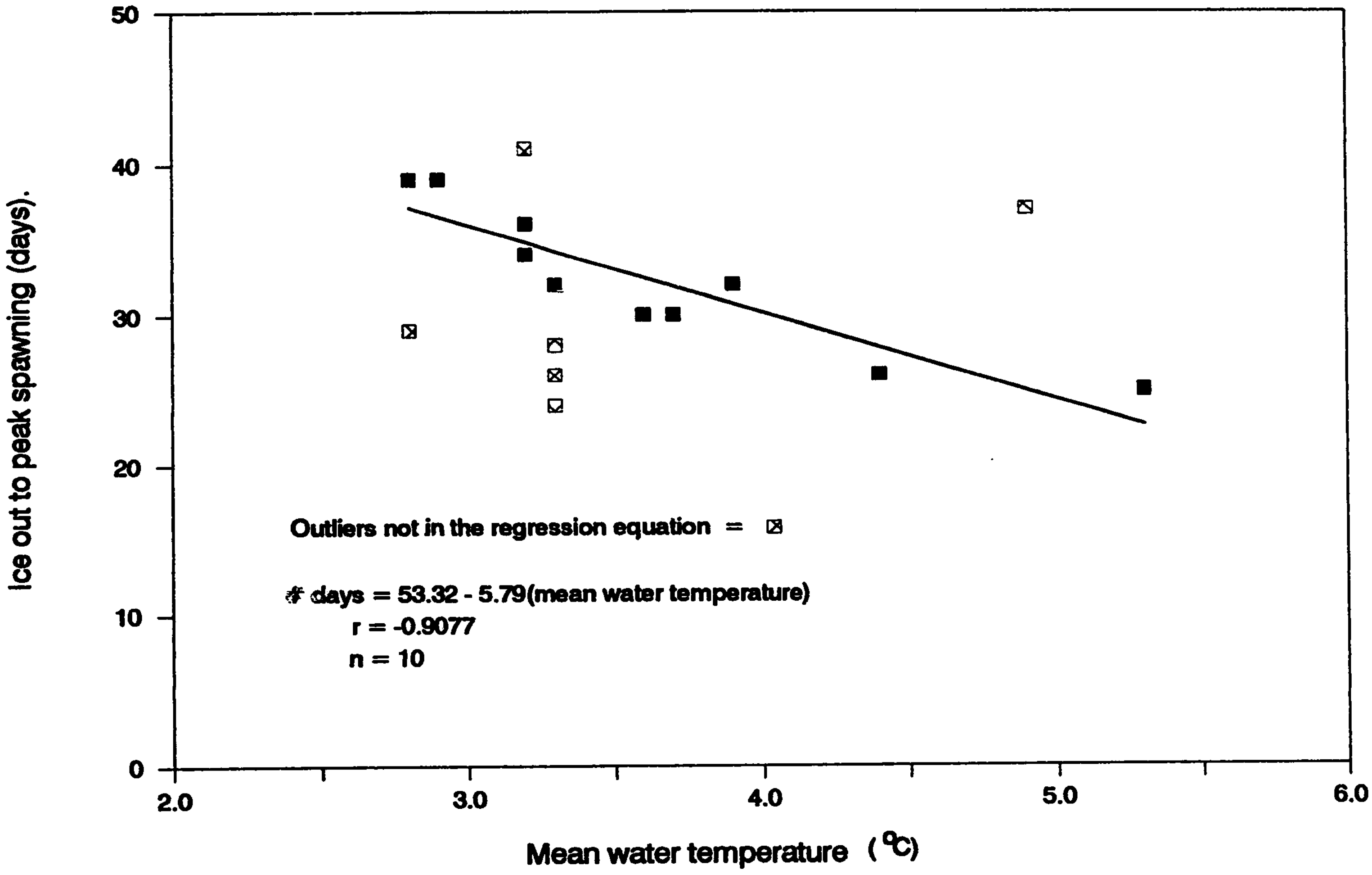

Figure II.2. Relationship between mean water temperature and number of days to peak spawning following ice out in the Tri-Creeks Experimental Watershed, 1973 - 1985.

Table II.2. Mean egg deposition of rainbow trout (per egg pit) in the Tri-Creeks Experimental Watershed, 1973 - 1977 and 1985.

	Sample Size	Mean (±C.L.)*	Standard Deviation
1973	10	89 ± 27	37.44
1974	17	86 ± 21	40.69
1975	12	73 ± 25	39.59
1976	32	97 ± 17	48.43
1977	18	77 ± 19	38.23
1985	11	94 ± 41	61.07
Entire Sample	100	88 ± 22	110.28

*Ninety-five percent confidence interval, n-1 degrees of freedom.

1985, water velocities and depths (Appendix II) measured at 474 confirmed spawning sites averaged 31.1 ± 0.8 cm s^{-1} and 14.3 ± 0.5 cm, respectively (Figure II.3).

Fry Escapement

Fry escapement generally commenced 10 to 14 days following hatching with the interval from peak spawning to peak escapement regulated by water temperature (Figure II.4, $r=-0.7540$). Mean water temperatures during the incubation period (1973 to 1985) ranged from 5.3 to 11.6°C. At a mean temperature of 10°C, peak emergence occurred approximately 59 days following spawning. Water temperatures in upper Deerlick Creek were significantly colder (t test, $p<0.05$) than other sections and contributed to later spawning, prolonged incubation periods, and fry escapement as late as mid-September.

Mean percent fry escapement ranged from 0.0 to 75.0 % (Table II.3) and did not differ significantly between sections (excluding upper Deerlick) during the prelogging or postlogging phases. Mean fry escapement (all sections) for prelogging (26 ± 5 fry/egg pit) was not significantly different than postlogging fry escapement (34 ± 10 fry per egg pit).

Substrate Composition

Spawning substrates were composed of angular to subangular fragments of local bedrock (particularly in the upper reaches) and rounded pebbles and gravel of glacial deposits. The particle size distribution (Figure II.5) of 242 samples collected (Appendix III) from 1973 to 1985 had a geometric mean (dg) of 9.95 ± 0.51 mm and a fredle index (f) of 1.54 ± 0.13. Approximately 72 % of particles used for spawning were less than 25.4 mm (dia.) and percent fines (particles < 0.841 mm) averaged 12.1 ± 0.6 percent. The fredle index (range 0.2 to 5.9) did not differ significantly ($F=$, $p>0.05$) within sections by years, between sections or between years during the prelogging phase. During the postlogging phase, the fredle index had a similar range (0.1 to 5.7); however, two-way analysis

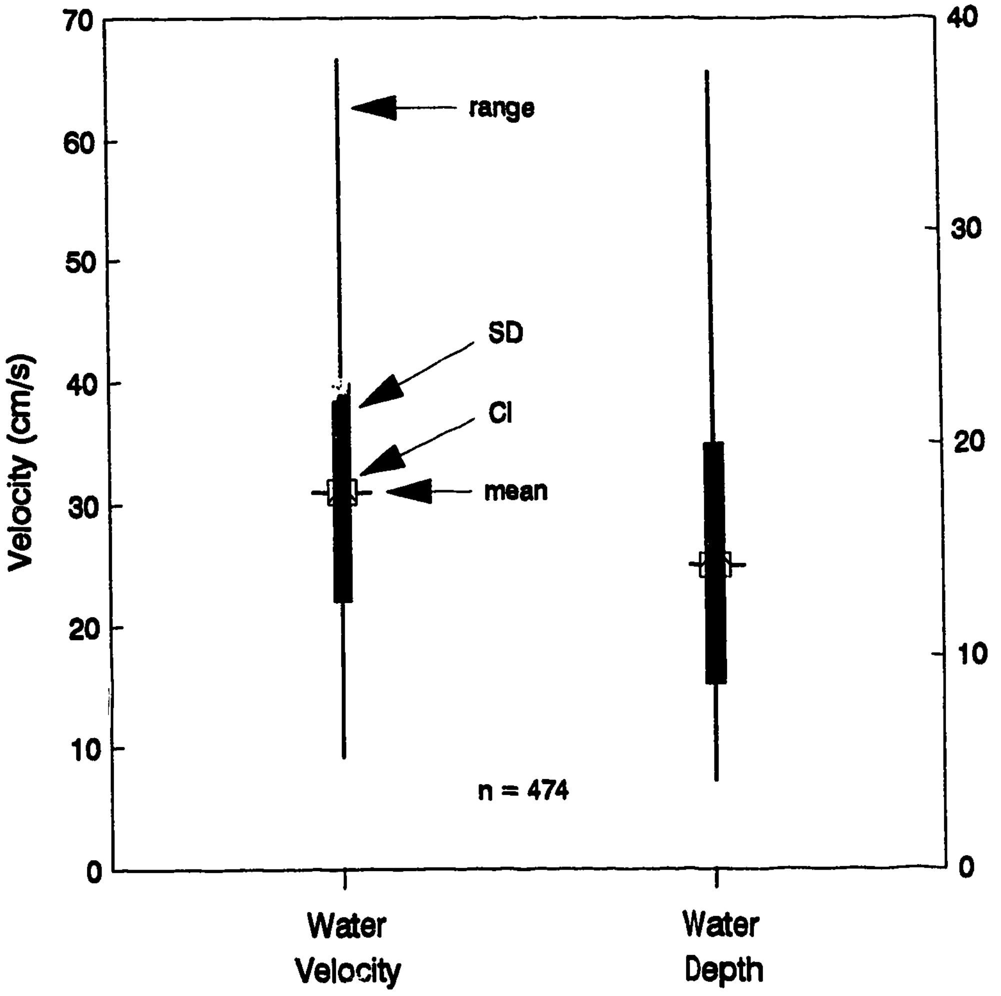

Figure II.3. Water velocity and depth at rainbow trout spawning sites in the Tri-Creeks Experimental Watershed, 1973 - 1985.

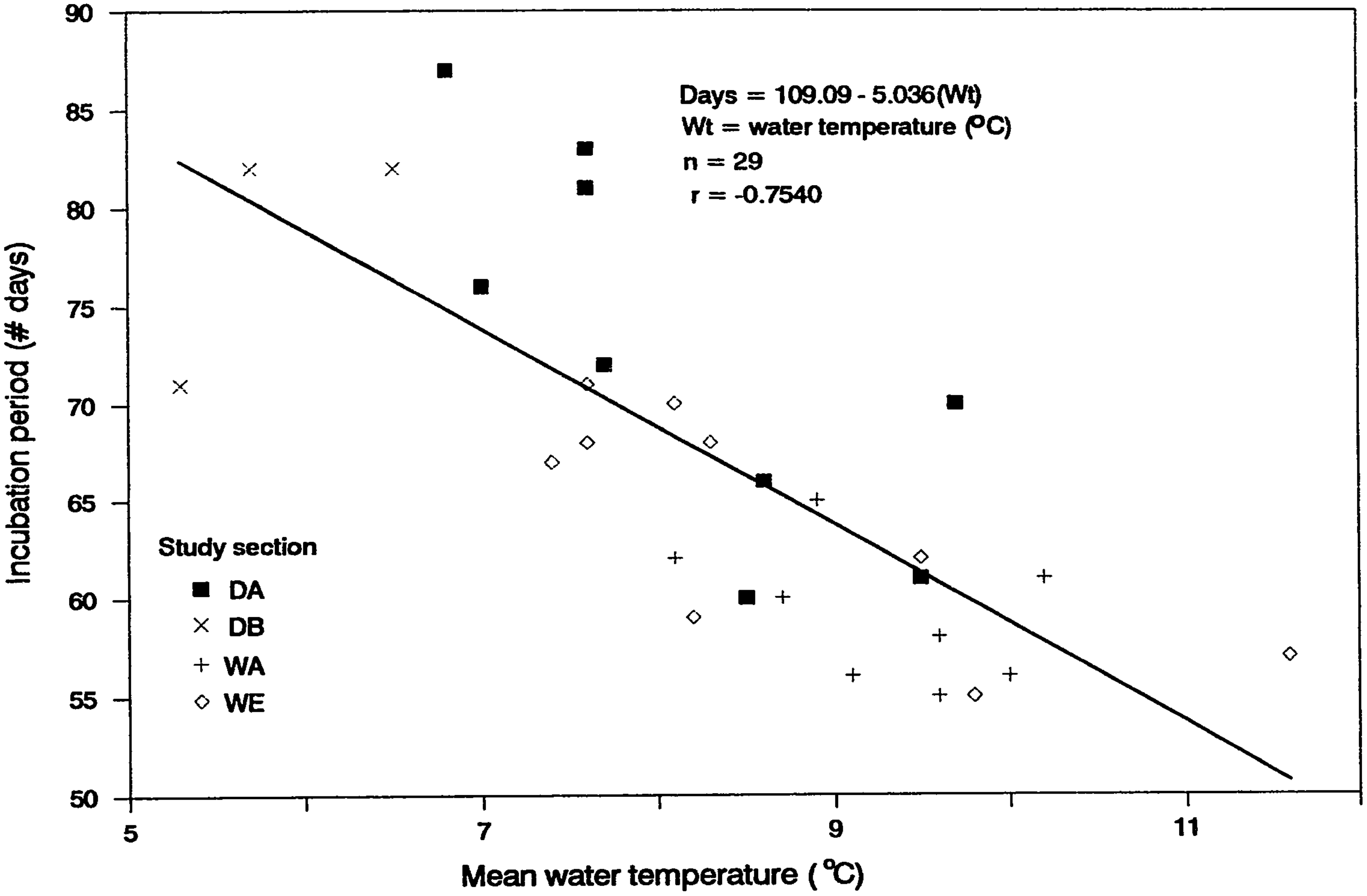

Figure II.4. Relationship of the rainbow trout embryo incubation period to the mean water temperature during incubation in the Tri-Creeks Experimental Watershed, 1973 - 1985.

Table II.3. Mean fry escapement of rainbow trout (from spawning gravels) in the Tri-Creeks Experimental Watershed, 1973 - 1985.

	Fry Escapement					
	Prelogging			Postlogging		
Study Section	Mean Fry	n	SD	Mean Fry	n	SD
WA	52 (59.1)[1]	13	70.13	35 (39.8)	18	51.68
WB	18 (20.5)	9	16.41	29 (32.9)	18	30.30
WC	23 (26.1)	19	26.80	27 (30.7)	13	44.98
WD	32 (36.4)	31	32.29	4 (4.5)	5	5.43
WE	29 (33.0)	34	35.28	40 (45.5)	12	66.17
WF	24 (27.3)	9	30.18	66 (75.0)	5	50.16
WG	21 (23.9)	22	31.00	1 (1.1)	10	2.38
DA	24 (27.3)	28	36.54	60 (68.2)	10	46.03
DB	6 (6.8)	18	13.76	0 (0.0)	1	0.00
DC	10 (11.4)	3	13.44	64 (72.3)	7	80.62
Entire Sample	26 (29.5)	186	36.37	34 (38.7)	99	51.41

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[1] Value in brackets is percent survival.

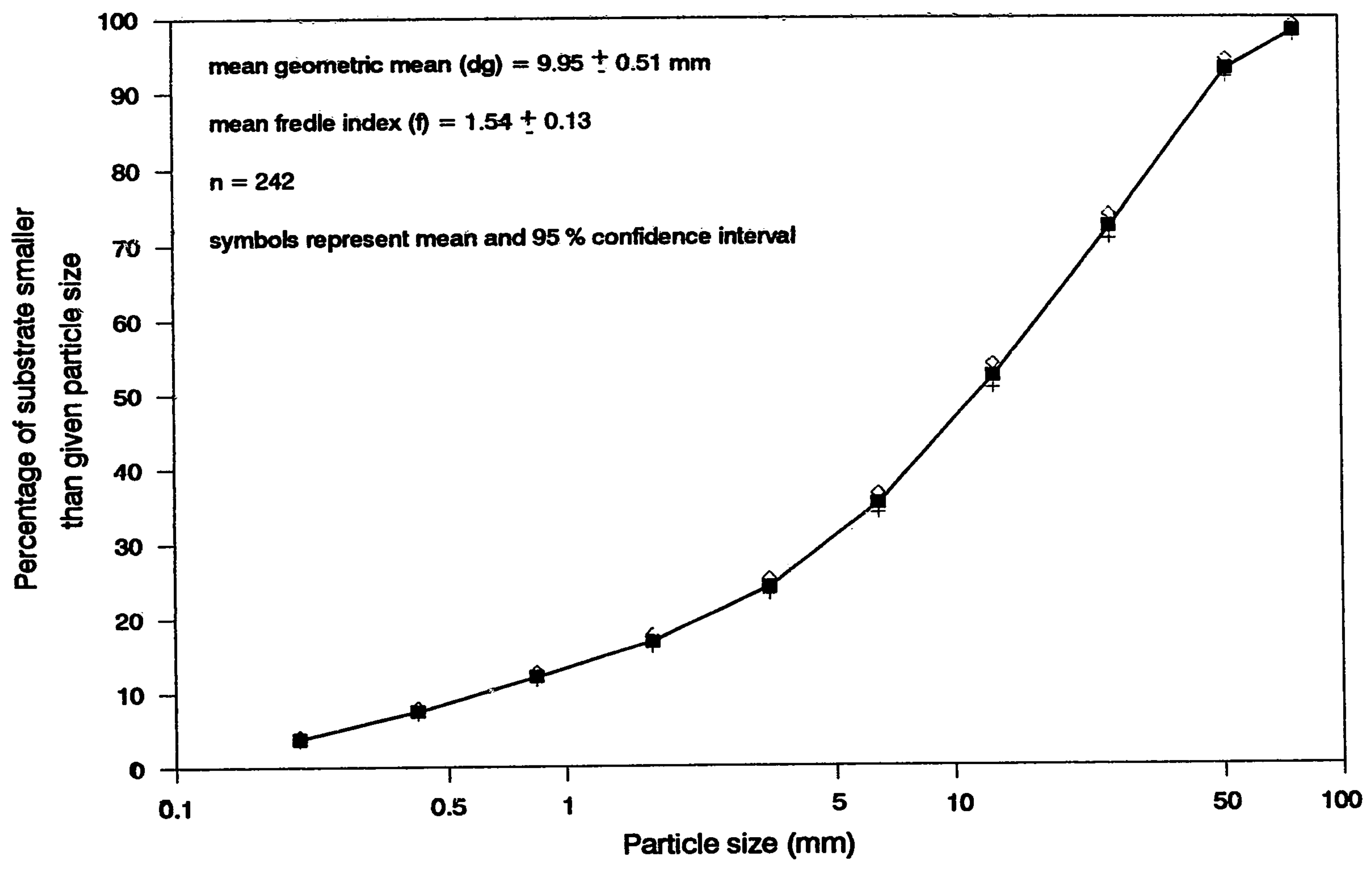

Figure II.5. Semilog-probability plot of spawning substrates in the Tri-Creeks Experimental Watershed, 1973 - 1985.

of variance with comparison of treatment means showed significant differences between sections and between years (F-test; $p<0.001$, $p<0.001$, respectively). During the postlogging phase, WA, DA and DC had larger fredle indices than other sections and the index in 1984 was higher than in 1983 and in 1985 (Table II.4). The mean fredle index (Table II.5) after logging (1.62 ± 0.17) was not significantly different than the prelogging mean (1.47 ± 0.19, $p>0.05$).

Interstitial Dissolved Oxygen and pH

Interstitial dissolved oxygen and pH (Appendix II) during the period of egg incubation and fry escapement (1973 to 1985) varied little from mainstem values. Weekly observations of interstitial oxygen and pH varied from 0.5 to 13 mg l^{-1}, and 6.0 to 9.5, respectively. As measurements were obtained once weekly, the duration of extremes for both parameters was difficult to assess. An upper extreme pH of 9.5 was recorded only once and a lower extreme value of pH 6.0 only three times. Mean oxygen saturation below 80% was observed during the incubation period in 24% of the sections monitored from 1973 to 1985. Hydrogen ion concentration (pH) was not significantly different (F-test, $p>0.05$) between sections before logging, but differed significantly between sections following logging (F-test, $p<0.05$). Mean pH during prelogging (7.8 ± 0.1) was not significantly different than mean pH (7.7 ± 0.1) after logging. Oxygen saturation differed significantly between sections before logging (F-test; $p<0.001$) but not after logging (F-test; $p>0.05$). Mean postlogging oxygen saturation (Table II.6) at incubation sites (80.5 ± 3.6 %) was significantly less (F-test; $p<0.001$) than mean prelogging oxygen saturation (90.3 ± 2.4 %). Interstitial oxygen saturation and pH were not correlated with substrate fredle indices (F-test, $p>0.05$).

Streamflow

Critical velocity and discharge to initiate movement of spawning substrates in the Tri-Creeks Experimental Watershed were

Table II.4. Multiple range test (Least Significant Difference) for postlogging spawning substrate fredle indices (f), by section and year for the Tri-Creeks Experimental Watershed. (*) denotes pairs significantly different at the 0.05 level.

Mean (f)	Study Section	Study Section WD	 WC	 WG	 WB	 WF	 WE	 WA	 DA	 DC
1.14	WD									
1.15	WC									
1.23	WG									
1.33	WB									
1.40	WF									
1.52	WE									
2.10	WA		*	*	*					
2.31	DA	*	*	*	*	*	*			
2.42	DC	*	*	*	*	*	*			

Mean (f)	Study Year	Study Year 1985	 1983	 1984
1.19	1985			
1.49	1983			
2.08	1984	*	*	

Table II.5. Mean fredle indices (f) of spawning substrates in the Tri-Creeks Experimental Watershed, 1973 - 1985.

Study Section	Fredle Index					
	Prelogging			Postlogging		
	(f)	n	SD	(f)	n	SD
WA	1.41	15	1.171	2.01	15	1.235
WB	1.27	7	1.546	1.33	15	0.740
WC	1.37	16	0.893	1.15	11	0.281
WD	1.51	21	1.170	1.14	5	0.336
WE	1.43	31	1.152	1.52	12	0.726
WF	NO SAMPLE			1.40	10	0.380
WG	1.46	13	0.977	1.23	14	0.741
DA	0.98	15	0.971	2.31	15	1.372
DB	1.44	16	1.447	NO SAMPLE		
DC	2.68	5	0.870	2.42	6	0.835
Entire Sample	1.47	139	1.150	1.62	103	0.889

Table II.6. Mean oxygen saturation (%) and pH of interstitial water at spawning sites in the Tri-Creeks Experimental Watershed, 1973 - 1985.

	Oxygen Saturation (%)					
	Prelogging			Postlogging		
Study Section	%	n	SD	%	n	SD
WA	97.6	12	5.76	84.4	23	17.01
WB	95.9	9	6.44	79.5	22	20.31
WC	72.5	19	22.54	77.9	15	23.14
WD	89.3	30	21.09	89.5	10	11.24
WE	90.4	31	14.88	84.6	16	22.47
WF	87.6	10	23.91	76.6	10	29.21
WG	92.1	21	14.12	75.1	20	22.86
DA	95.0	26	13.47	73.5	10	25.00
DB	91.7	28	14.39	104.0	1	0.00
DC	97.6	8	7.67	82.3	7	17.56
Entire Sample	90.3	194	16.33	80.5	134	21.31

	pH					
	Prelogging			Postlogging		
Study Section	pH	n	SD	pH	n	SD
WA	7.9	5	0.35	7.7	13	0.41
WB	7.7	4	0.05	7.6	12	0.51
WC	7.6	8	0.21	7.4	10	0.13
WD	7.7	19	0.48	8.1	5	0.08
WE	7.9	19	0.44	7.7	9	0.37
WF	NO SAMPLE			7.9	10	0.21
WG	7.7	13	0.23	7.6	15	0.41
DA	7.9	10	0.15	7.6	10	0.23
DB	8.0	16	0.28	7.4	1	0.00
DC	NO SAMPLE			7.6	7	0.13
Entire Sample	7.8	94	0.35	7.7	92	0.34

estimated by Andres et al.(1987) to be 1.4 m s^{-1} and 1.7 m^3s^{-1}, respectively. These values, however, were associated with a median bed material size of 57 mm, which is almost 6 times greater than the median spawn bed material found in this study. Based on the mean cross-sectional area of spawning riffles and the water velocity required to move particles approximately 10 mm in diameter, a critical discharge of 0.731 m^3s^{-1} was used to determine water yield potentially contributing to bed movement at spawning sites. An example is provided in Figure II.6, where that portion of the hydrograph above critical discharge between spawning and fry escapement was used to determine water yield contributing to bed movement. In WA, water yield above critical flow (Appendix IV) during embryo incubation ranged from 0.0 to 3402.4 dam^3 for the years 1973 to 1984. Annual fry production (number per 0.10 ha) in WA estimated (Sterling 1990) for nine years ranged from 52 to 934 fry per 0.10 ha. Trout fry abundance was inversely correlated ($r=-0.8219$; $F=14.5772$, $p=0.0066$) with water yield exceeding critical flow (Figure II.7).

D. DISCUSSION

Indigenous rainbow trout in the east slopes of west-central Alberta principally occupy small, high gradient headwater tributaries of the Athabasca River drainage. Their "uniqueness", exhibited in genetic divergence, habitat occupancy and small size at maturity, dictates unique physical criteria (water velocity, depth and substrate composition) at spawning.

In the Tri-Creeks Experimental Watershed, mean water temperatures during the incubation period generally encompassed the optimum range of 7 to 10°C for rainbow trout reported by Kwain (1975). Spawning and the duration of the incubation period were highly regulated by water temperatures. Significant increases in maximum water temperatures in Deerlick creek (DA) were observed following logging and removal of the riparian canopy (Andres et al. 1987), and were consistent with results reported in other studies

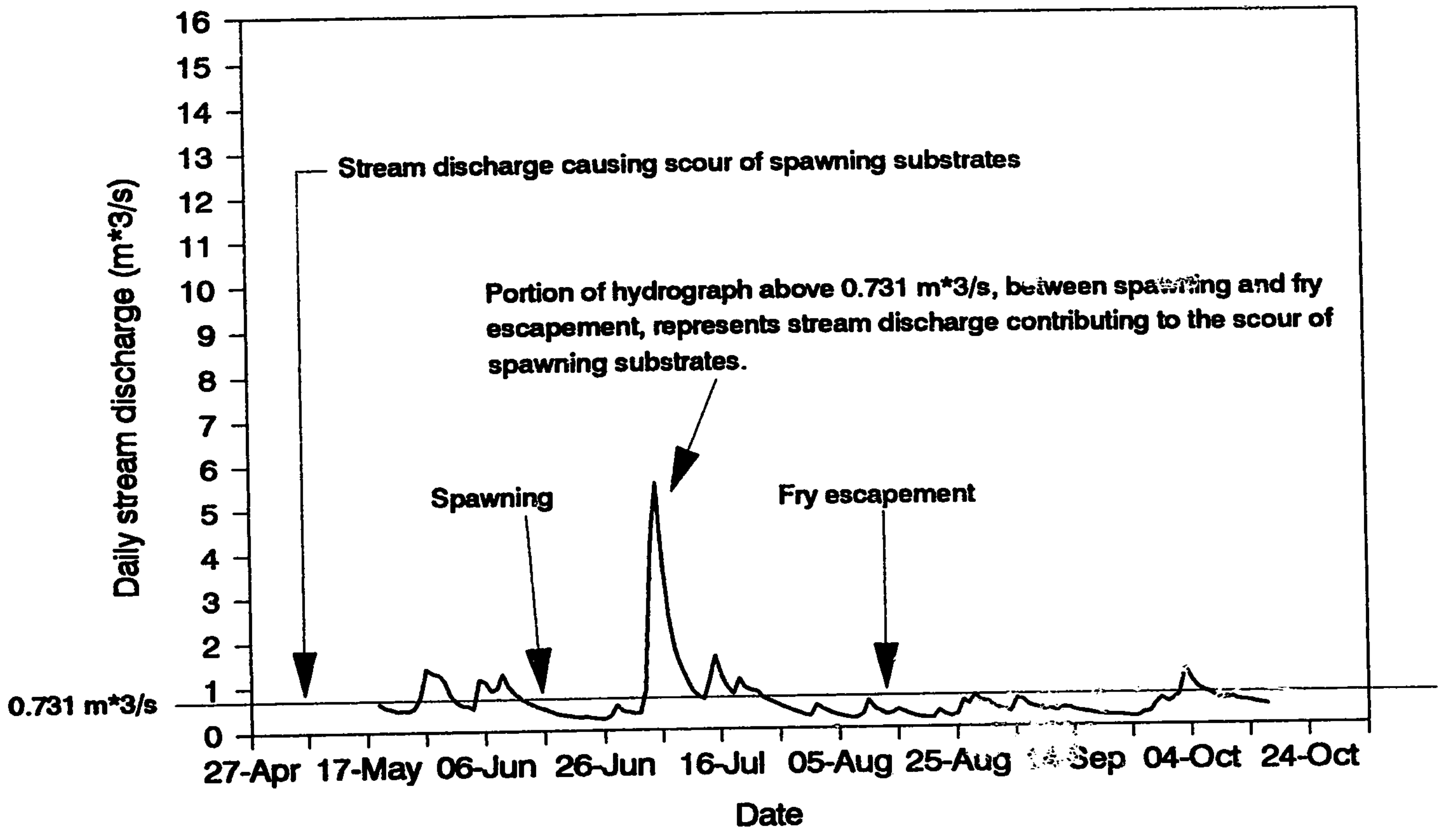

Figure II.6. Wampus Creek hydrograph, 1982. Illustration of stream discharge contributing to erosion of spawning substrates.

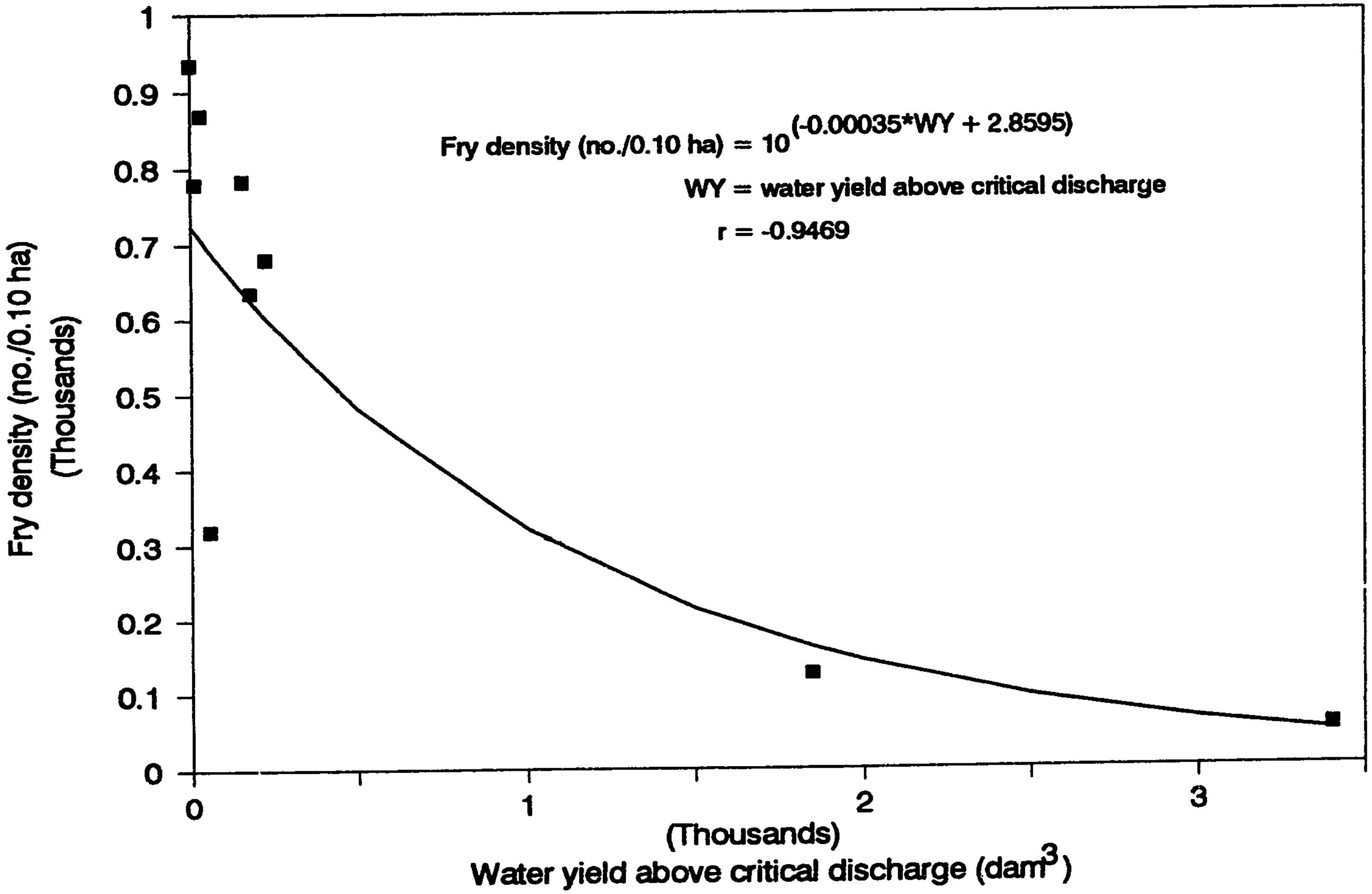

Figure II.7. Relationship of fry density to water yield during the incubation period in Wampus Creek, Tri-Creeks Experimental Watershed, 1969 - 1985.

(Meehan et al. 1969; Kopperdahl et al. 1971; Ringler and Hall 1975). However, changes in the water temperature regime in DA did not generally shift the occurrence of spawning or the duration of embryo incubation as the increases observed occurred largely during July and August; well after spawning and near the end of the incubation period. Other increases in water temperature were not related to logging but were associated with ambient air temperature, particularly in Wampus Creek (Andres et al. 1987). In some stream reaches (DB, EA and EB), water temperatures were highly buffered by ground water (Andres et al. 1987) and therefore riparian canopy removal in the upper Deerlick Creek basin did not significantly modify temperature regimes (Andres et al. 1987). The controlled manipulation of riparian vegetation to increase water temperatures (Brown 1980) has little value for enhancing salmonid production in streams where ground water flow is a regulating mechanism.

In this study, mean fry escapement (32.9%) of rainbow trout was considerably less than the 89% survival of embryos (eyed egg stage) reported by Hatch (1957) for the Finger Lakes region of New York, but considerably higher than the 7.6% survival of embryos reported by Sowden and Power (1985) for Young Creek in southwestern Ontario. Variations in fecundity (Sterling 1986), differing ability to excavate redds based on female size, and differing egg deposition between first and last egg pit constructed were not evaluated and contributed to the large relative variability seen in the egg pit excavation and fry escapement data.

The lack of a direct relationship between fry escapement and substrate quality as expressed by the fredle index and oxygen content contrasts with results for most other studies (Gibbons and Salo 1973; Iwamoto et al. 1978; and Platts et al. 1983), where low embryo survival was attributed to decreased gravel permeability (which influences oxygen concentration) and/or entrapment of alevins and fry. Streams in the Tri-Creeks Experimental Watershed may have remained within the natural regime of substrate composition because road reclamation following logging was much more intensive (Jarvis 1984). Detectable changes in substrate quality due to timber harvesting may have been obscured by the large natural variation observed in "f", and the collection of small sample sizes.

Factors which may have obscured the relationship between fry escapement, oxygen content and substrate composition in the Tri-Creeks Experimental Watershed include: (1) higher water velocities which contributed to coarser and better sorted substrates with higher mean particle diameter than reported for other similar-sized salmonid redds (Witzel and MacCrimmon 1983b); (2) mean percent sediment fines of approximately 12 percent which may have failed to plug up substrates, and which is considerably lower than the critical level of approximately 20 percent reported by Reiser and Bjornn (1979) to significantly influence embryo survival; (3) small sample sizes which failed to address the observed large site to site and annual variation in fry emergence; and (4) streamflows at spawning appeared to regulate redd locations (pers. observ.) within the channel.

Spawning typically occurred between peaks in stream discharge in May (snowmelt) and June (heaviest annual precipitation). At higher than average flows during spawning, redds were observed nearer the edges of the channel in suitable substrates with appropriate velocity and depth criteria. Under these circumstances, the shallowest sites were often dewatered during the incubation period. Conversely, spawning at lower than average flows (same requirements) was observed nearer the riffle crest making any increases in flow during the incubation period disruptive in terms of bed erosion. Under these circumstances some sites, regardless of substrate composition, failed to produce any fry. It was not possible to select redds during spawning to exclude this variation.

In the high gradient streams of the Tri-Creeks Experimental Watershed streamflows during the incubation period appeared significant in regulating escapement. Snowmelt before spawning provides streamflow sufficient to move spawning substrates and naturally cleanse the streambed substrate, with the subsequent intrusion of fines affecting embryo survival and fry escapement (Beschta and Jackson 1979). However, in Wampus Creek, critical flow was only 0.731 m^3s^{-1} and streamflow exceeded this critical level approximately 25-30 percent of each incubation cycle. Flows of this frequency caused bed erosion and contributed to embryo mortality (by crushing and exposure) and may have masked possible sedimentation effects.

No statistically significant increases in streamflow were detected in the Tri-Creeks Experimental Watershed after logging (Andres et al. 1987) because of poor control in flow measurements, and the short postharvest evaluation period. This result contrasts with results reported elsewhere (McNeil 1966; Hibbert 1967). The observed increases in water yield; 7% in Wampus Creek and 22% in Deerlick Creek, respectively, were similar to increases observed for other logged areas near Hinton, Alberta (Swanson and Hillman 1977) and for increases reported by Hartman and Scrivener (1990) for Carnation creek, British Columbia. Although the increases in water yield in the Tri-Creeks Experimental Watershed were not significant they are potentially harmful as they are contributory to erosive flows already occurring with high frequency. The short-term results observed in this study are not indicative of potential long-term streamflow effects. This is particularly true when second cutting (of residual timber) of watersheds generally occurs 20 years (2 m regeneration rule applicable) following initial timber harvest; before the effects of initial timber harvesting have been mitigated by forest regrowth.

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III. FINE SEDIMENT INTRUSION INTO ARTIFICIAL SPAWNING SUBSTRATES AND RAINBOW TROUT FRY SURVIVAL IN WAMPUS CREEK, 1979; TRI-CREEKS EXPERIMENTAL WATERSHED.

A. INTRODUCTION

Substrate composition is an important factor regulating salmonid embryo survival and has been studied intensively. Specifically, the amount of fine sediments variously described as material <6.35 mm (Bjornn 1969), <3.3 mm (Koski 1966), 1-3 mm (Hall and Lantz (1969), 0.105- 3.327 mm (Koski 1975), <0.833 mm (McNeil and Ahnell 1964) and percent fines have been shown to be determinants in salmonid embryo survival. Various parameters (geometric mean [d_g], modified d_g method, percent fines, and "fredle index") have been used to describe spawning substrate composition. Platts et al. (1983) recommends the use of the fredle index (f) as it incorporates the central tendency (d_g) of a distribution of particle sizes with a measure of the dispersion of particles in relation to d_g to characterize spawning substrates (Appendix II). Pore size and, hence, permeability is directly proportional to mean particle size, and regulates intragravel water flow and the delivery of oxygen to and the removal of metabolic wastes from incubating embryos (Platts et al. 1979; Platts et al. 1983; Reiser and Bjornn 1979).

Salmonids use a variety of substrates with differing site characteristics of water velocity and depth (Smith 1973; Reiser and Bjornn 1979) for spawning. Although different salmonids choose habitat within a specific range of substrate, velocity and depth criteria for spawning (Reiser and Bjornn 1979), individual site location within this range is likely dependent on female size. Each site is cleaned of fine sediments by the act of redd excavation. The size of sediments removed from the gravel is determined by the carrying capacity of the water velocity at a particular site. The subsequent deposition of sediments following logging, and the movement of fines through the interstitial environment into the redd reduce permeability and degrade the incubating environment. Although velocity and depth may dictate redd locations, Beschta and Jackson (1979) concluded the particle size of fine sediments introduced, rather than hydraulic variables, may have a more important influence on the total amount of intrusion.

The goals of this study were to: (1) determine the amount of fine sediment intrusion (as percent sediment of void space) into spawning substrates following spawning, (2) determine the effect of fine sediment intrusion on rainbow trout embryo survival, and (3) determine the range of particle sizes influencing embryo survival.

B. MATERIALS AND METHODS

Sediment Intrusion

Fine sediment intrusion at spawning sites was measured in 1979 by using a sediment trap and an artificial substrate approximating natural spawning substrates.

Sediment traps (Plate III.1) consisted of an open circular ring of ABS plastic pipe measuring 15 cm in diameter and 1.5 cm in depth. An impervious nylon bag measuring 15 X 15 cm was attached to this ring with a hose clamp, and provided a sample volume of approximately 350 cm^3. Three wires, measuring 30 cm in length were attached to the ABS ring to facilitate removal.

An artificial substrate approximating natural spawning substrates was used at spawning riffles to facilitate installation and reduce field time, and was prepared and transported to known spawning areas prior to the field season. Artificial substrates consisted of a mix of crushed rock ranging in particle size from 6.35 to 25.4 mm, from which all material less than 6.35 mm was washed.

Two sediment traps were installed (Plate III.2) at each site by forcing a 45 cm circular crib into the substrate to a depth of 15 cm, excavating the bed material within the crib, collapsing the nylon bag and placing the trap in the center of the excavation with

Plate III.1. Configuration of sediment traps used in the Tri-Creeks Experimental Watershed, 1979.

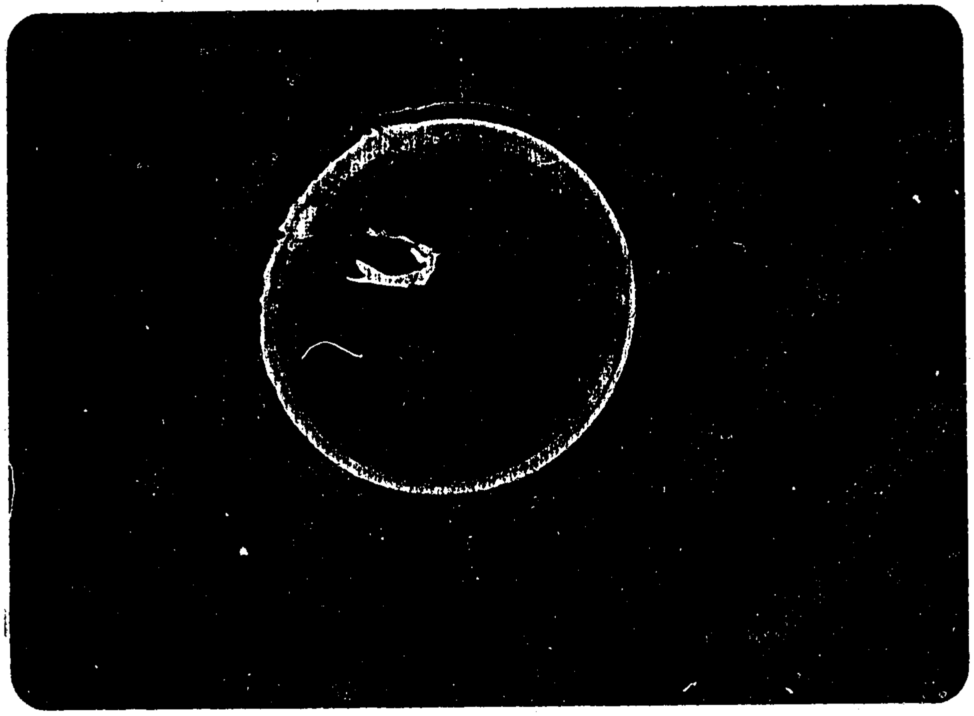

Plate III.2 Sediment trap placement in channel excavation prior to placement of artificial substrate. Tri-Creeks Experimental Watershed, 1979.

the wire handles facing upward. The excavation was then backfilled with prepared substrate , the crib removed, and the handle flagged and folded so that it lay flat on the bed of the stream (Plate III.3). To characterize fine sediment intrusion over time, one trap containing a sample of substrate and sediments (Plate III.4) was removed at mid-incubation, the other was removed when fry emergence was complete. Water velocities and depths were measured at all sediment trap sites.

Prior to placement in spawning riffles samples of artificial substrates were analyzed to determine the total volume of solids and voids or bulk volume (Vb), the displaced volume (Vs) of substrate particles, and sample void volume (Vv). Porosity (e) is defined as the ratio (or percentage of voids) of void volume to bulk volume (Vv/Vb)(Yong and Warkentin 1966). Porosity was determined for samples of artificial substrates to characterize the space occupied as voids.

Sediment deposition was described based on a standard soil sieve analysis for material greater than 2.00 mm and a mechanical soil analysis (Bouyoucos analysis) of material less than 2.00 mm in diameter to determine the fraction of sediments by dry weight. Material less than 2.00 mm in diameter was chosen to represent those fines potentially influencing embryo survival, as particles of this size were prone to transport by the water velocities typically found at spawning sites in the Tri-Creeks Experimental Watershed (Appendix V).

The ratio of percent by dry weight to percent by dry volume in substrate analysis is nearly equal to 1.00 (Shepard and Graham 1982). Hence, the ratio of percent fine sediment fractions to porosity represents the percentage of void space occupied by fine sediment and quantifies the intrusion of fine sediments.

Trout Embryo to Fry Escapement Survival

Methods for estimating trout embryo to fry escapement survival are described in Chapter II.

Plate III.3 Completed sampling site following removal of crib. Tri-Creeks Experimental Watershed, 1979.

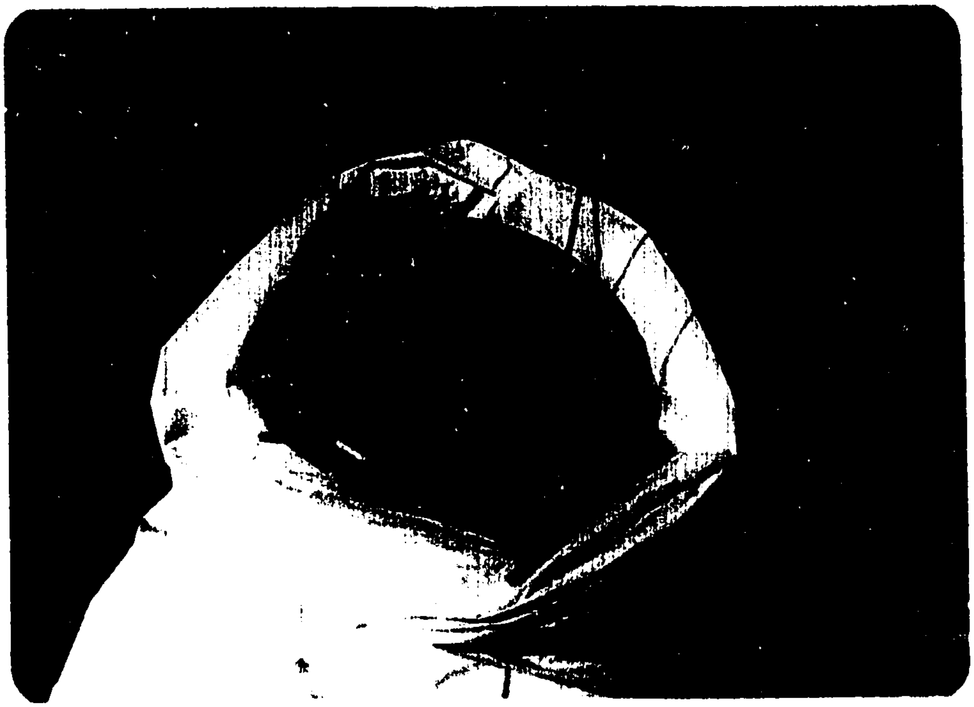

Plate III.4. Sediment trap containing sample of artificial substrate and fine sediments following removal. Tri-Creeks Experimental Watershed, 1979.

C. RESULTS

Composition of Artificial Substrates

Thirty samples of artificial substrate (Appendix VI) free of fine sediments <6.35 mm, and ranging in bulk volume (Vb) from 600 to 3450 ml, were analyzed to determine displaced volume of solids (Vs), void volume (Vv), and porosity (e). Bulk sample volume (Vb) was highly correlated ($r=0.9967$; $p<0.05$) with displaced volume of solids (Vs) (F-test; $p<0.01$), hence, Vb could be estimated from Vs (Figure III.1) for samples taken at mid and end-incubation. The mean porosity (Vv/Vb), or percentage of voids, for the artificial substrate used was 0.418 ± 0.008 (Appendix VI).

Sediment Intrusion

A total of 61 samples were analyzed for sediment intrusion into artificial spawning substrates in the Tri-Creeks Experimental Watershed, 1979. Twenty-eight samples were collected at mid-incubation (Appendix VII.1), and 33 samples were collected when fry escapement was complete (Appendix VII.2).

Mean total sediments <2.0 mm in 6 study sections occupied 8.4 to 28.5 percent of the void space at mid-incubation (Table III.1). At the conclusion of fry escapement, the percentage of mean total sediments <2.00 mm ranged from 10.1 to 24.8 percent (Table III.2). The mean percentage of sediments in artificial substrates reached peak or near peak levels by mid-incubation in Wampus Creek, and were reduced or had increased slowly by the end of incubation and fry escapement (Figure III.2). The amount of fine sediment intrusion into artificial spawning substrates was not correlated (F-test; $p>0.05$) with the hydraulic variables of water velocity and depth at sample sites.

For samples collected in 1979, the fredle index (f) was highly correlated with the geometric mean ($r=0.9971$; $p<0.05$), but was a poorer predictor of fine sediments <2.0 mm ($r=0.8882$; $p<0.05$) than was the geometric mean ($r=0.9065$; $p<0.05$) (Figures III.3 and III.4, respectively).

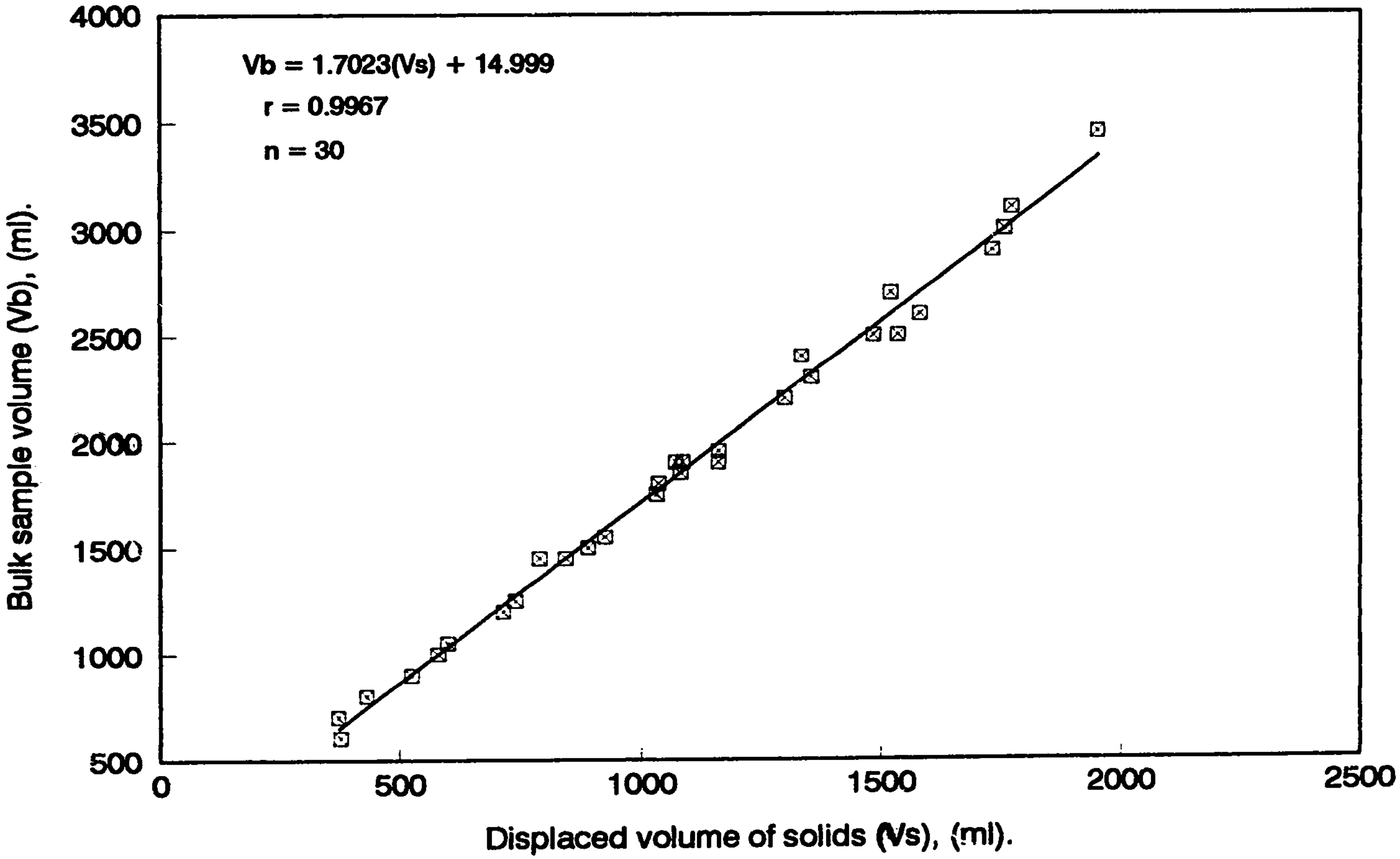

Figure III.1. Relationship of bulk volume to displaced volume of particles >6.35 mm in samples of artificial substrates, Wampus Creek, 1979.

Table III.1. Summary for descriptive parameters of artificial substrate samples collected during mid-incubation of rainbow trout embryos in Wampus Creek, 1979.

Ss	Days	e	Percent by volume of voids Gravel	Sand	Si/Cl	Tot. <2.0 mm	f	d_g
WA	31	0.417	2.5	4.5	3.9	8.4	6.2	12.6
WB	30	0.415	0.7	6.1	4.3	10.4	6.0	12.2
WC	29	0.415	3.2	17.3	11.2	28.5	4.5	9.5
WD	29	0.416	4.4	11.3	10.6	21.9	4.5	9.6
WE	-----------------no samples collected--------------------							
WF	45	0.416	9.8	13.6	8.7	22.3	4.7	10.0
WG	45	0.416	1.5	8.1	7.1	15.2	5.5	11.3

Ss - study section
Days - days from sediment trap installation to mid-incubation
e - porosity
Gravel - sediment particles 2.0 - 6.35 mm
Sand - sediment particles 0.062 - 2.0 mm
Si/Cl - silt and clay <0.062 mm
f - fredle index
d_g - geometric mean of sediment particle distributio.

Table III.2. Summary for descriptive parameters of artificial substrate samples, fry survival and percent oxygen saturation at the end of trout embryo incubation and fry emergence in Wampus Creek, 1979.

			Percent by volume of voids							
Ss	Days	e	Gravel	Sand	Si/Cl	Tot. <2.0 mm	f	d_g	% fry	% O2
WA	68	0.418	2.8	6.0	4.1	10.1	6.1	12.4	64.8	83.7
WB	69	0.416	0.6	9.4	4.7	14.1	5.7	11.7	43.2	70.5
WC	73	0.415	3.2	14.4	7.5	21.9	4.5	9.6	11.4	62.9
WD	75	0.415	5.4	15.3	9.5	24.8	4.2	9.1	33.0	76.4
WE	75	0.415	1.9	11.7	8.7	20.4	5.2	10.7	2.3	81.5
WF	80	0.416	4.2	11.3	6.0	17.3	5.3	11.0	35.2	86.2
WG	95	0.416	4.7	9.8	8.0	17.8	4.6	9.9	31.8	86.2

Ss - study section
Days - days from sediment trap installation to mid-incubation
e - porosity
Gravel - sediment particles 2.0 - 6.35 mm
Sand - sediment particles 0.062 - 2.0 mm
Si/Cl - silt and clay <0.062 mm
f - fredle index
d_g - geometric mean of sediment particle distribution
% fry - fry escapement survival from natural substrates in the same study section
% O2 - oxygen saturation of interstitial water.

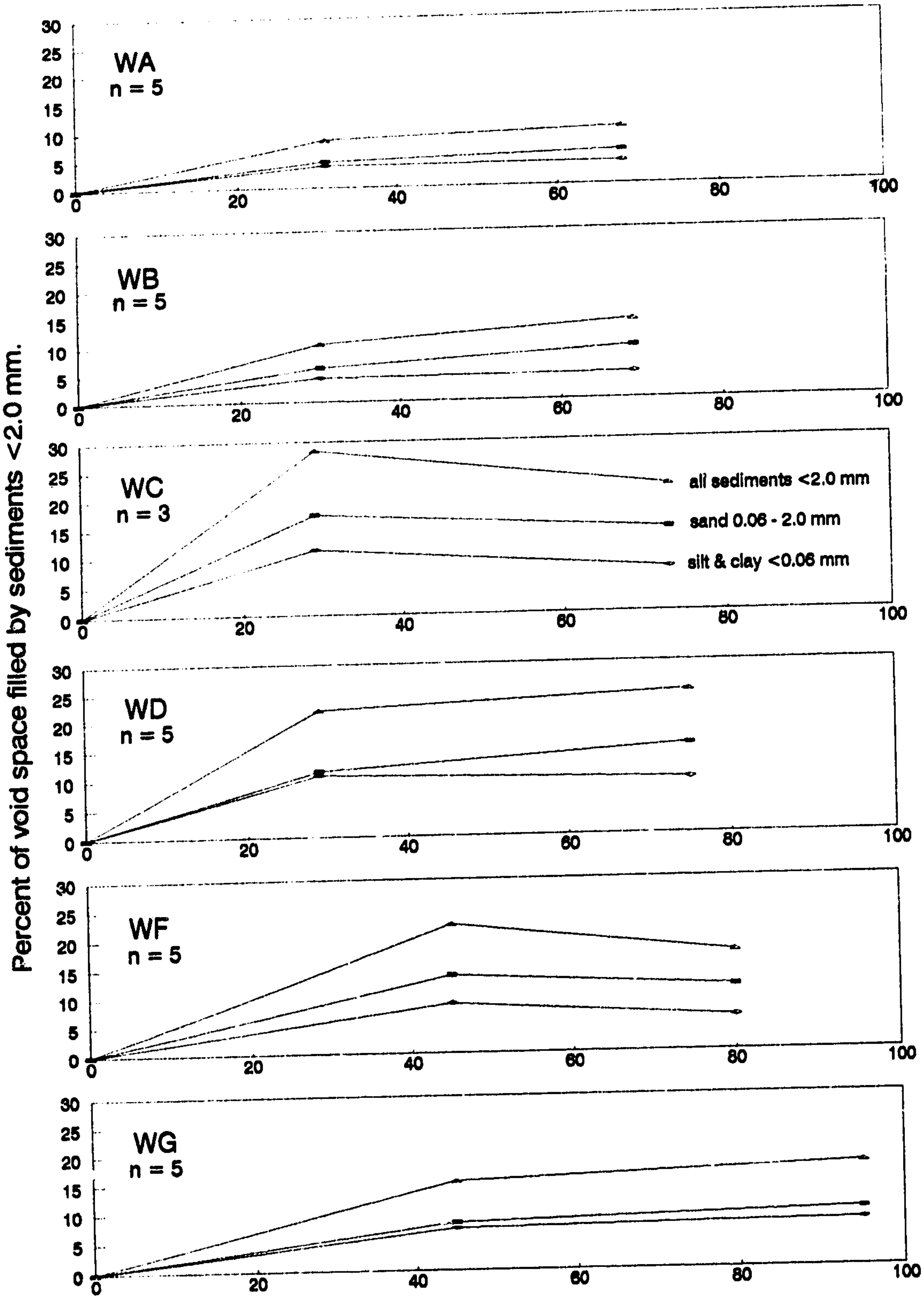

Figure III.2. Percent sediment intrusion into artificial spawning substrates during trout embryo incubation in six study sections in Wampus Creek, 1979.

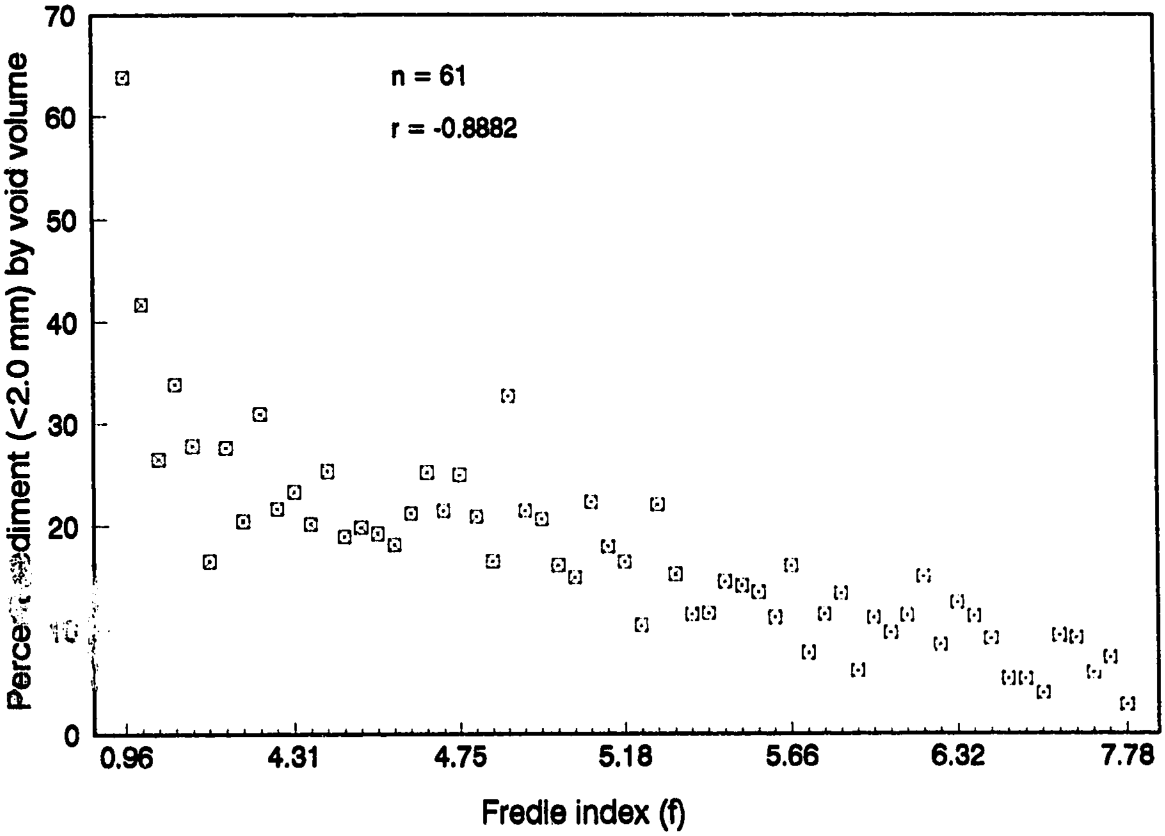

Figure III.3. Relationship of percent sediment <2.0 mm in artificial substrates to fredle indices of artificial substrate samples at the end of trout embryo incubation in Wampus Creek, 1979.

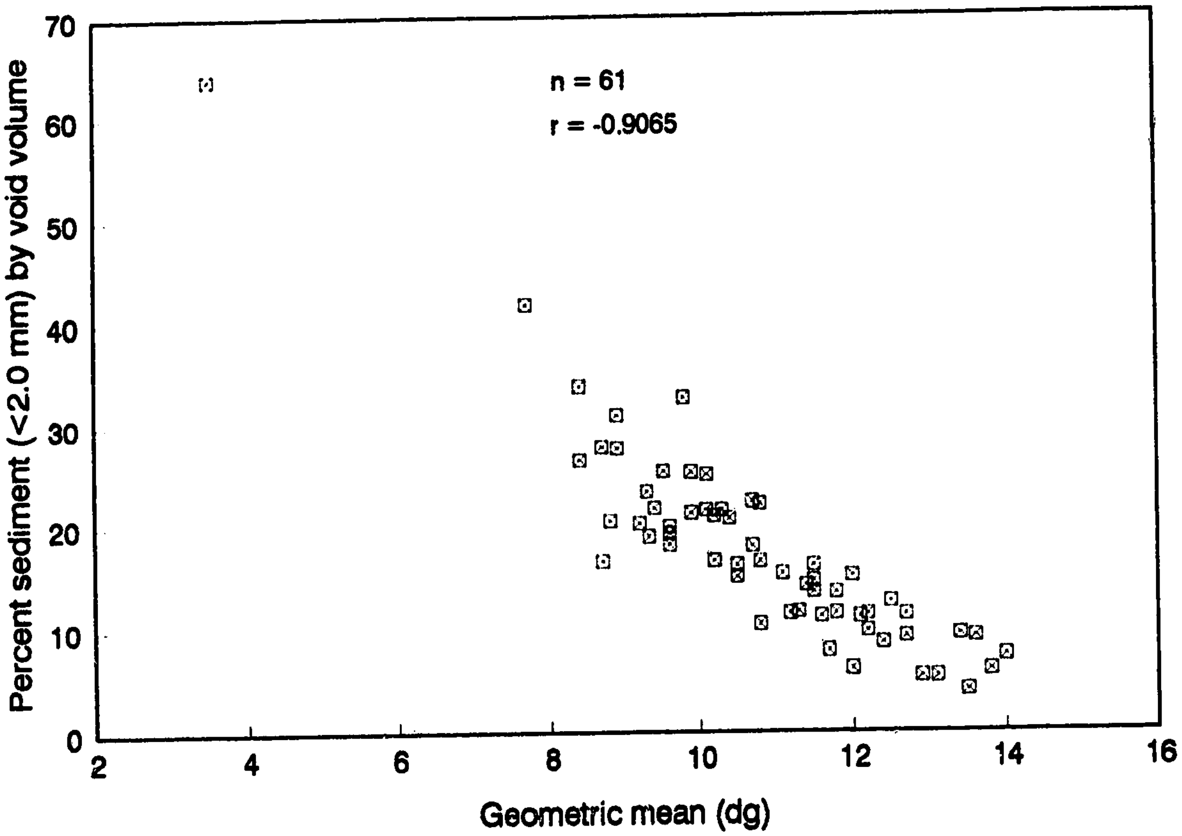

Figure III.4. Relationship of percent sediment <2.0 mm in artificial substrates to the geometric mean of artificial substrate samples at the end of trout embryo incubation in Wampus Creek, 1979.

Effects of Sediment Intrusion

In Wampus Creek during 1979, interstitial dissolved oxygen (Table III.2) was not correlated with the mean percent of fine sediment <2.0 mm, "f", or "d_g" (n=7; r=0.3251, 0.2648 and 0.2777, p>0.05, respectively).

For Wampus Creek in 1979, comparisons of percent fry survival (Table III.2) to the mean percent of fine sediment <2.0 mm, "f" and "d_g" indicated no significant relationships (n=7; r=0.7436, 0.5771 and 0.6132, p>0.05, respectively). However, the deletion of a single outlier (in this case the data for WD) provided a significant correlation (n=6; r=0.9547, p<0.05) between fry survival and the mean percent of fine sediments <2.0 mm occupying the available void space (Figure III.5). Although the correlations of fry survival to "f" and "d_g" improved (n=6; r=0.7218 and 0.7675, respectively) with the deletion of the outlier, the relationships remained nonsignificant.

Stepwise regression analysis of the data in Table III.2 for study sections WA, WB, WC, WE, WF, and WG supports the assumption that the intrusion of fine sediment <2.0 mm was a factor influencing fry survival in the Tri-Creeks Experimental Watershed in 1979. The percent of fine gravel (2.00-6.35 mm) was not correlated with fry survival (F-test; r=0.01, p>0.05), and this factor was removed from the stepwise regression analysis. Silt and clay, however, accounted for 80 % of the variation observed in fry survival (F=16.534; r=0.8973, p<0.05). Adding sand (<2.0 mm) to the equation accounted for an additional 11.5% of the variation in fry survival (F=17.395; r=0.9595, p<0.05). Fry survival in 1979 for Wampus creek was a function of the relationship:

Fry survival=114.839 - 6.748(% silt/clay) - 3.787(% sand).

D. DISCUSSION

The use of artificial substrates in the Tri-Creeks Experimental Watershed in 1979 described fine sediment (<2.0 mm) intrusion into spawning substrates during embryo incubation.

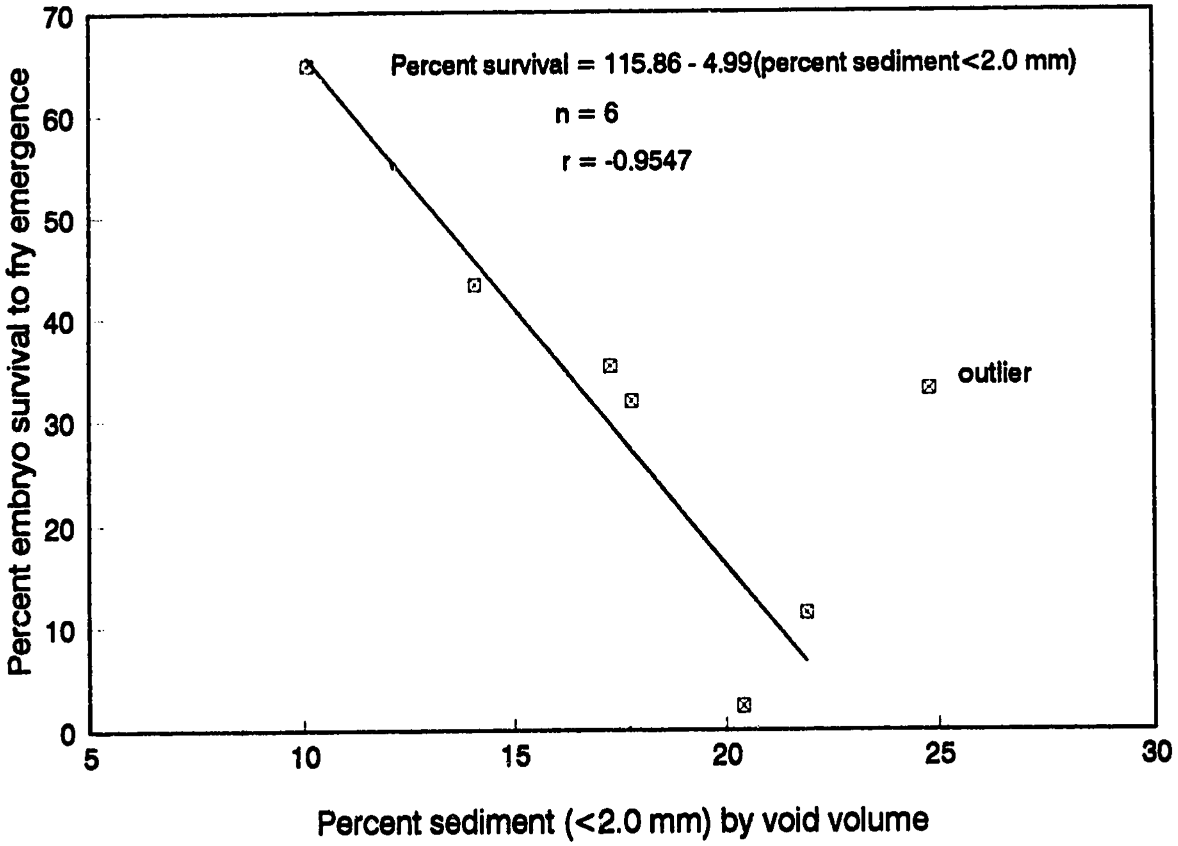

Figure III.5. Relationship of trout embryo survival to the intrusion of fine sediments <2.0 mm during the incubation period in Wampus Creek, 1979.

Although efforts were taken to ensure similarity to natural spawning substrates, a comparison of f and d_g to the same values in Chapter II suggest that the artificial substrates used were not a good approximation of natural spawning substrates. Additionally, the relationship of fry survival to fine sediment intrusion into artificial spawning substrates may not be real. Estimates of fry survival in 1979 were obtained from sites adjacent to artificial substrates, but located in natural spawning substrates. The cause and effect relationship (between sediment intrusion and fry survival) apparent in this work needs to be confirmed by further study. Such a study should: (1) use natural spawning substrates from which fine sediment has been washed, (2) use a known number of fertilized trout ova placed within each sample site, and (3) use a larger cluster of sample sites to better define fine sediment intrusion over time.

The artificial substrates used in this study were similar to those described by Beschta and Jackson (1979). Mean particle size (12.6 mm) was slightly less; however, mean porosity (0.418) was approximately 16 percent greater. The percentages of intrusion reported in this study were considerably greater than the 2-8 % reported by Beschta and Jackson, and reflect the greater length of this study (in excess of 2 months compared to minutes). The intrusion of 2-8 % after a short exposure period, however, is significant in that it supports the hypothesis that the bulk of fine sediment intrusion may occur after initial exposure (i.e., shortly after redd completion). The percent of sediment intrusion following mid-incubation appeared to stabilize and may have been a function of the moderate to low flows experienced during the 1979 incubation period.

Analysis of sediment intrusion in Wampus Creek in 1979 showed that the silt and clay component (particles <0.062 mm) was a dominant factor influencing embryo survival. Sand (0.062-2.0 mm) was less of a determinant, and small gravel (2.0-6.35 mm) was not a factor contributing to embryo mortality. Although these results are not inconsistent with results reported for other studies

(<0.833 mm for pink salmon, McNeil and Ahnell 1964; <3.3 mm for coho salmon, Koski 1966; <6.35 mm for chinook salmon and steelhead, Bjornn 1969; 1-3 mm for coho and steelhead, Hall and Lantz 1969; and 0.105-3.327 mm for chum salmon, Koski 1975), the particle sizes influencing rainbow trout survival in the Tri-Creeks Experimental Watershed are at the lower extreme of this range. In Wampus creek (1979), a decrease in fry survival (to escapement) was associated with an increase in fine sediments <2.0 mm in the interstitial voids.

The percentage of fine sediment <2.0 mm intruding into spawning substrates reported here is not directly comparable with other studies. Typically, percent fines is expressed as a percentage by weight or volume of solids for a sample of spawning substrates; which ignores the textural composition (i.e, porosity), hence, the mitigating effect on survival of the remaining particles (Platts et al. 1983). In this study, the percentage of fine sediments represents the percentage of fine sediments as they relate to void space and reflects degradation (i.e., reduced porosity) of the incubating environment by the intrusion and layering effects of fine sediments (Beschta and Jackson 1979).

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IV. GENERAL DISCUSSION AND CONCLUSIONS

Andres et al. (1987), Sneddon (1990), and Sterling (1990) reported measurable changes in physical, chemical and biological parameters following timber harvesting in the Tri-Creeks Experimental Watershed. Increases in annual water yield following logging, significant increases in suspended sediment yield following road construction and logging, and significant increases in maximum water temperatures following logging and experimental removal of riparian canopies, were reported (Andres et al. 1987). These changes are consistent with results reported for other studies (Swanson and Hillman 1977; Beschta 1978; Hartman and Scrivener 1990; papers cited by Marcus et al. 1990). Water chemistry in the Tri-Creeks Experimental Watershed remained largely unchanged (Sneddon 1990); however, a significant increase in total phosphate loading was observed following timber harvesting. Increases in nutrients following timber harvesting were reported for other studies (Hartman and Scrivener 1990; papers cited by Marcus et al. 1990). Sterling (1990) reported significant increases in the growth of juvenile rainbow trout following timber harvesting in the Tri-Creeks Experimental Watershed. Increased production of aquatic biota following logging and riparian canopy modification have been reported elsewhere (Murphy and Hall 1981; Hawkins et al. 1983; Hartman and Scrivener 1990).

Water temperatures in the Tri-Creeks Experimental Watershed regulated the occurrence of spawning and the duration of the incubation cycle. These results are consistent within the general regime of salmonid habitat requirements (Reiser and Bjornn 1979). Although significant changes in maximum water temperatures were observed following logging (Andres et al. 1987), these changes did not generally shift the occurrence (earlier) of spawning or the duration (shorter) of embryo incubation. Mean water temperature regimes were unchanged by timber harvesting, and the significant increases observed in maximum water temperatures occurred largely during July and August, well after spawning and near the end of the incubation cycle.

Most studies that have defined salmonid spawning substrate quality have used the parameters of percent fines less than a specified particle size, or the geometric mean "d_g". A standardized approach (Platts et al. 1983) using the fredle index, "f", (Lotspeich and Everest 1981) and a determination of the percent intrusion of fines into spawning substrates (Beschta and Jackson 1979) were used during this study. Results in Chapter III showed that f was the parameter that least reflected change following intrusion of fine sediments. Similarly, d_g did not accurately reflect sediment intrusion, and both parameters were not good predictors of embryo survival. These results may be an artifact of the artificial substrates used. A general comparison of mean f and d_g reported in Chapters II and III, indicate that the artificial substrates used were substantially different from naturally occurring spawning substrates. Mean fredle indices reported in Chapter III were 3-4 times larger, and d_g was approximately 8 percent larger, than those reported in Chapter II. The use of artificial substrates to characterize fine sediment deposition in natural spawning substrates may be inappropriate unless they conform to the distribution of the larger particles in the natural spawning substrates being studied.

The relationship of substrate quality (as defined by percent fines, d_g, and f) to salmonid embryo survival has been well documented (McNeil and Ahnell 1964; Koski 1966, 1975; Bjornn 1969; Hall and Lantz 1969, Platts et al. 1979). Using the data of others, Platts et al. (1983) demonstrated that percent survival to emergence of coho salmon and steelhead embryos was highly correlated with fredle indices ranging from 1 to 11. His analysis also demonstrated that the range of fredle indices is descriptive of the variations in the intragravel habitat requirements of individual species. In the Tri-Creeks Experimental Watershed fredle indices ranged from 0.1 to 5.9, indicating that rainbow trout in these streams are adapted to the use of much smaller substrates for spawning. Use of smaller substrates for spawning is also confirmed by the lack of influence on embryo survival of sediment particles ranging in size from 2.0-6.35 mm. Sediment particles of this size are reported as determinants in embryo survival for larger salmonids such as chinook and coho salmon and steelhead (Koski 1966; Bjornn).

Embryo survival to emergence was not correlated to substrate quality (f) in the Tri-Creeks Experimental Watershed and may be partially explained by the fact that percent fines (<0.841 mm) averaged approximately 12 percent. This percentage of fine sediment (12%) is considerably lower than the allowable criteria of 25 percent established by Reiser and Bjornn (1979) in their evaluation of salmonid habitat requirements.

Evaluation of spawning substrate quality (f) following logging in the Tri-Creeks Experimental watershed showed considerable year-to-year variation and did not confirm spawning habitat degradation following logging. Although significant increases were observed in suspended sediments, this increase did not appear to influence sediment deposition in spawning habitat. As suspended sediment increases were associated with higher streamflows during snowmelt and summer precipitation, those fine sediments potentially harmful to incubating embryos were likely transported out of the study streams. Additionally, the occurrence of several major floods during the postlogging phase may have enhanced substrate quality by flushing fine sediments thereby masking the effects of observed increases in suspended sediments.

A factor most likely regulating embryo survival to emergence in the Tri-Creeks Experimental Watershed is streamflow. The small particle sizes of spawning gravel (relative to substrates used by larger salmonids) result in a low critical streamflow threshold. As egg deposition is shallow (<15 cm), incubating trout embryos are vulnerable to the erosive forces of streamflow exceeding this threshold level. In the Tri-Creeks Experimental Watershed, streamflow exceeded critical flow during 25-30 percent of the embryo incubation period and accounted for approximately 70 percent of the variation observed in fry production.

In summary, the evaluation of factors potentially limiting rainbow trout embryo survival to emergence in the Tri-Creeks Experimental Watershed has provided essential regional information useful to fisheries and land managers in the Eastern Slopes of Alberta. Described differences provided a clearer understanding of the biology and habitat requirements during the early life history of this unique salmonid. The effects of timber harvesting on trout embryo survival to emergence, however, may not have been adequately addressed because of the extremely short post treatment phase (<5 years) of this study. As other studies have shown that the effects of timber harvesting may last for several decades (Hartman and Scrivener 1990), fisheries and land managers must be cognizant of the potential long-term effects that altered streamflow and sediment regimes may have on this indigenous east slope salmonid.

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V. APPENDIX I.

Appendix I. Calculation of the fredle index.

The fredle index (f) for individual samples of spawning substrate was determined by calculating:

$$f = d_g/S_o$$

where: $d_g = (d_1^{W1} \times d_2^{W2} \times \ldots\ldots\ldots\ldots d_n^{Wn})$.

d_n = midpoint diameter of particles on the n^{th} sieve,

w_n = decimal fraction by weight of particles retained on the n^{th} sieve,

$S_o = d_{75}/d_{25}$ = sorting coefficient, and

d_{75}, d_{25} = particle size diameters at which either 75 or 25 percent of the sample is finer on a weight basis (Platts et al. 1983).

Regression of the log-probability distribution for each sample of spawning substrate was used to find d_{75} and d_{25}.

VI. APPENDIX II.

Appendix II. Data summary for spawning substrate and fry escapement evaluations in the Tri-Creeks Experimental Watershed, 1973 - 1985.

Variable labels

Site - stream/section/site/year of study.
Phs - encoded; (1) prelogging, (2) postlogging.
Yr - encoded; (1) 1973, (2) 1974, (3) 1975, (4) 1976, (5) 1977, (6) 1978, (7) 1979, (8) 1981, (9) 1982, (10) 1983, (11) 1984, (12) 1985.
Sec - encoded; (1) WA, (2) WB, (3) WC, (4) WD, (5) WE, (6) WF, (7) WG, (8) DA, (9) DB, (10) DC.
dg - geometric mean of spawning substrate.
f - fredle index of spawning substrate.
Vel - mean water velocity at spawning site.
Dpth - mean water depth at spawning site.
Sat - mean percent oxygen saturation during incubation period.
Fry - number of emerging fry captured.
Intr - mean interstitial pH during incubation period.
999 - missing values

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
WA1 73	1	1	1	17.4	1.3	0.39	0.11	99.8	2	999.0
WA2 73	1	1	1	13.6	1.2	999.00	999.00	90.2	17	999.0
WA3 73	1	1	1	31.3	4.0	0.33	0.09	999.0	999	999.0
WA1 74	1	2	1	7.1	0.7	0.21	0.12	999.0	999	999.0
WA2 74	1	2	1	5.5	0.4	0.21	0.09	86.0	112	8.3
WA3 74	1	2	1	6.0	0.4	0.29	0.14	999.0	999	999.0
WA4 74	1	2	1	10.8	1.3	0.48	0.25	999.0	999	999.0
WA5 74	1	2	1	19.3	4.0	0.66	0.18	101.1	4	8.3
WA6 74	1	2	1	7.6	0.6	0.36	0.17	999.0	999	999.0
WA1 75	1	3	1	12.0	1.7	0.58	0.16	103.4	61	7.6
WA2 75	1	3	1	12.0	1.7	0.61	0.20	999.0	4	999.0
WA5 75	1	3	1	13.1	1.9	0.44	0.15	102.0	9	7.7
WA7 75	1	3	1	8.1	0.8	0.25	0.17	96.1	43	7.7
WA1 78	1	6	1	8.0	0.9	999.00	999.00	102.7	39	999.0
WA2 78	1	6	1	999.0	999.0	999.00	999.00	90.9	0	999.0
WA4 78	1	6	1	999.0	999.0	999.00	999.00	100.3	248	999.0
WA5 78	1	6	1	4.2	0.2	999.00	999.00	96.4	4	999.0
WA9 78	1	6	1	999.0	999.0	999.00	999.00	102.5	132	999.0
WB1 75	1	3	2	8.9	1.2	0.27	0.08	96.8	2	7.7
WB3 75	1	3	2	15.6	4.4	0.47	0.13	85.9	54	7.7
WB4 75	1	3	2	11.6	4.4	0.32	0.18	91.7	20	7.8
WB5 75	1	3	2	13.6	1.8	0.27	0.10	97.0	27	7.7

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
WB6 75	1	3	2	10.2	1.7	999.00	999.00	999.0	999	999.0
WB1 78	1	6	2	999.0	999.0	999.00	999.00	86.9	0	999.0
WB2 78	1	6	2	999.0	999.0	999.00	999.00	99.3	0	999.0
WB3 78	1	6	2	999.0	999.0	999.00	999.00	100.8	25	999.0
WB4 78	1	6	2	10.1	2.0	999.00	999.00	104.3	10	999.0
WB6 78	1	6	2	5.3	0.4	999.00	999.00	100.9	23	999.0
WC2 75	1	3	3	10.0	0.3	0.25	0.19	99.7	33	7.8
WC4 75	1	3	3	6.3	0.8	0.38	0.15	90.9	25	7.8
WC6 75	1	3	3	9.3	1.3	0.28	0.11	69.7	42	7.8
WC8 75	1	3	3	7.9	1.1	0.31	0.09	89.3	37	999.0
WC1 76	1	4	3	10.6	1.7	0.28	0.08	74.1	18	7.6
WC3 76	1	4	3	9.4	1.2	0.20	0.09	84.9	43	7.7
WC5 76	1	4	3	18.7	3.6	0.28	0.15	95.8	0	7.6
WC6 76	1	4	3	11.7	2.2	0.41	0.19	61.0	0	7.3
WC8 76	1	4	3	7.5	0.7	0.34	0.15	65.1	50	7.3
WC3 77	1	5	3	13.6	0.7	999.00	999.00	999.0	999	999.0
WC4 77	1	5	3	7.8	1.1	999.00	999.00	999.0	999	999.0
WC1 78	1	6	3	10.0	1.1	0.46	0.19	76.5	0	999.0
WC5 78	1	6	3	13.0	2.3	0.48	0.23	91.3	0	999.0
WC6 78	1	6	3	5.9	0.5	0.30	0.26	15.1	0	999.0
WC8 78	1	6	3	9.1	0.7	999.00	999.00	93.5	46	999.0
WC9 78	1	6	3	11.6	2.6	999.00	999.00	45.1	107	999.0
WC1 79	1	7	3	999.0	999.0	999.00	999.00	55.3	0	999.0
WC3 79	1	7	3	999.0	999.0	0.29	0.14	74.3	11	999.0
WC4 79	1	7	3	999.0	999.0	0.25	0.11	33.0	3	999.0
WC6 79	1	7	3	999.0	999.0	999.00	999.00	82.1	1	999.0
WC7 79	1	7	3	999.0	999.0	0.24	0.27	81.5	16	999.0
WD1 73	1	1	4	11.5	1.0	0.19	0.10	99.3	52	999.0
WD2 73	1	1	4	6.5	1.0	0.23	0.09	999.0	26	999.0
WD2 74	1	2	4	6.3	0.4	0.13	0.07	40.4	0	7.6
WD4 74	1	2	4	8.6	1.6	0.33	0.07	96.2	8	8.5
WD19 74	1	2	4	5.7	0.4	0.37	0.22	32.0	4	6.5
WD20 74	1	2	4	5.7	0.4	0.33	0.18	38.9	32	6.5
WD32 74	1	2	4	7.0	1.7	0.24	0.06	92.3	65	8.4
WD1 75	1	3	4	8.7	1.5	0.16	0.24	97.4	1	7.7
WD4 75	1	3	4	999.0	999.0	999.00	999.00	100.8	0	7.8
WD6 75	1	3	4	5.5	0.6	0.28	0.18	104.1	156	7.7
WD8 75	1	3	4	5.0	1.7	0.28	0.12	97.5	4	7.5
WD10 75	1	3	4	7.1	1.7	0.32	0.12	106.6	55	7.8
WD1 76	1	4	4	4.2	0.9	0.26	0.15	96.4	0	7.7
WD4 76	1	4	4	19.5	3.2	0.26	0.13	93.0	39	7.6
WD7 76	1	4	4	6.9	1.4	0.28	0.15	94.4	61	7.7
WD11 76	1	4	4	8.7	1.0	0.33	0.14	96.4	0	7.6
WD12 76	1	4	4	11.7	1.1	0.27	0.16	94.9	20	7.7

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
WD3 77	1	5	4	999.0	999.0	999.00	999.00	109.6	54	7.9
WD5 77	1	5	4	999.0	999.0	999.00	999.00	107.3	47	7.8
WD11 77	1	5	4	999.0	999.0	999.00	999.00	108.6	5	7.8
WD12 77	1	5	4	999.0	999.0	999.00	999.00	109.7	18	7.9
WD1 78	1	6	4	16.1	5.6	999.00	999.00	99.1	49	999.0
WD3 78	1	6	4	12.6	1.9	999.00	999.00	95.0	0	999.0
WD6 78	1	6	4	10.2	2.6	999.00	999.00	93.2	82	999.0
WD8 78	1	6	4	6.0	1.2	999.00	999.00	96.8	46	999.0
WD10 78	1	6	4	7.0	0.9	999.00	999.00	98.2	23	999.0
WD3 79	1	7	4	999.0	999.0	0.32	0.18	54.6	8	999.0
WD5 79	1	7	4	999.0	999.0	0.32	0.14	86.5	43	999.0
WD6 79	1	7	4	999.0	999.0	0.27	0.14	72.0	20	999.0
WD8 79	1	7	4	999.0	999.0	0.36	0.15	94.7	39	999.0
WD10 79	1	7	4	999.0	999.0	0.30	0.14	74.1	38	999.0
WE5 73	1	1	5	6.3	0.9	0.47	0.14	98.2	7	999.0
WE7 73	1	1	5	21.8	4.4	0.39	0.10	99.9	8	999.0
WE9 73	1	1	5	21.1	3.1	0.31	0.11	87.7	30	999.0
WE10 73	1	1	5	8.7	1.0	0.45	0.15	999.0	35	999.0
WE11 73	1	1	5	7.6	0.5	0.22	0.04	999.0	999	999.0
WE13 73	1	1	5	5.6	0.6	0.26	0.06	999.0	8	999.0
WE15 73	1	1	5	7.0	0.7	0.28	0.08	999.0	999	999.0
WE16 73	1	1	5	9.7	1.1	0.25	0.07	999.0	999	999.0
WE17 73	1	1	5	6.8	0.9	0.25	0.09	999.0	999	999.0
WE18 73	1	1	5	6.9	0.7	0.29	0.15	999.0	84	999.0
WE20 73	1	1	5	12.5	1.0	0.35	0.19	999.0	999	999.0
WE7 74	1	2	5	9.3	1.4	0.22	0.09	95.5	0	8.5
WE8 74	1	2	5	5.0	0.5	0.46	0.25	94.6	101	8.5
WE10 74	1	2	5	6.6	1.1	0.33	0.15	94.9	90	8.3
WE12 74	1	2	5	5.2	0.3	0.23	0.10	88.5	80	8.2
WE25 74	1	2	5	7.1	0.8	0.46	0.21	92.5	4	8.5
WE28 74	1	2	5	10.6	1.7	0.36	0.12	92.6	2	8.5
WE34 74	1	2	5	7.1	1.8	0.51	0.15	96.9	0	8.3
WE2 75	1	3	5	5.6	0.4	0.46	0.15	999.0	999	999.0
WE3 75	1	3	5	5.3	0.7	0.38	0.13	95.3	77	7.8
WE5 75	1	3	5	12.5	2.6	0.32	0.11	95.3	124	7.8
WE7 75	1	3	5	8.9	0.9	0.23	0.06	82.1	51	7.6
WE9 75	1	3	5	16.6	5.4	0.43	0.15	102.7	35	7.7
WE3 76	1	4	5	5.7	1.0	0.41	0.14	56.8	4	7.2
WE5 76	1	4	5	9.1	1.6	0.36	0.17	38.4	0	7.1
WE7 76	1	4	5	6.8	0.9	0.33	0.11	86.3	7	7.5
WE11 76	1	4	5	11.2	2.2	0.34	0.15	93.5	2	7.7
WE1 77	1	5	5	999.0	999.0	999.00	999.00	109.1	62	7.8
WE6 77	1	5	5	999.0	999.0	999.00	999.00	109.3	5	7.8
WE8 77	1	5	5	999.0	999.0	999.00	999.00	109.7	76	7.6

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
WE10 77	1	5	5	999.0	999.0	999.00	999.00	109.9	16	7.6
WE2 78	1	6	5	11.1	1.6	999.00	999.00	87.5	26	999.0
WE3 78	1	6	5	5.4	0.5	999.00	999.00	88.9	11	999.0
WE7 78	1	6	5	12.3	2.2	999.00	999.00	107.1	4	999.0
WE9 78	1	6	5	12.3	1.8	999.00	999.00	82.9	42	999.0
WE1 79	1	7	5	999.0	999.0	0.44	0.15	81.8	1	999.0
WE7 79	1	7	5	999.0	999.0	0.29	0.16	81.5	2	999.0
WE8 79	1	7	5	999.0	999.0	0.36	0.09	86.4	1	999.0
WE9 79	1	7	5	999.0	999.0	0.36	0.20	77.7	5	999.0
WE10 79	1	7	5	999.0	999.0	0.38	0.17	80.1	1	999.0
WF1 79	1	7	6	999.0	999.0	0.21	0.21	86.0	2	999.0
WF3 79	1	7	6	999.0	999.0	0.20	0.18	89.4	999	999.0
WF4 79	1	7	6	999.0	999.0	0.31	0.09	80.2	75	999.0
[illegible]	1	7	6	999.0	999.0	0.23	0.20	82.1	8	999.0
[illegible]	1	7	6	999.0	999.0	0.34	0.10	93.3	69	999.0
[illegible]	1	8	6	999.0	999.0	999.00	999.00	107.3	52	999.0
WF2 81	1	8	6	999.0	999.0	999.00	999.00	25.7	0	999.0
WF3 81	1	8	6	999.0	999.0	999.00	999.00	104.2	6	999.0
WF4 81	1	8	6	999.0	999.0	999.00	999.00	104.7	0	999.0
WF5 81	1	8	6	999.0	999.0	999.00	999.00	102.9	0	999.0
WG1 75	1	3	7	8.0	0.5	0.40	0.08	999.0	999	999.0
WG3 75	1	3	7	999.0	999.0	999.00	999.00	88.6	84	7.8
WG5 75	1	3	7	6.4	0.4	0.21	0.18	95.1	17	7.9
WG7 75	1	3	7	5.1	0.4	0.19	0.28	103.9	1	7.9
WG9 75	1	3	7	8.6	1.3	0.29	0.14	100.0	1	8.0
WG1 76	1	4	7	12.3	2.4	0.28	0.26	52.3	0	7.3
WG4 76	1	4	7	6.7	0.9	0.30	0.17	91.7	0	7.7
WG5 76	1	4	7	7.0	1.1	0.25	0.31	76.0	0	7.4
WG6 76	1	4	7	13.5	2.1	0.23	0.26	999.0	0	999.0
WG10 76	1	4	7	16.9	2.9	0.15	0.08	84.8	0	7.6
WG2 77	1	5	7	999.0	999.0	999.00	999.00	109.6	39	7.8
WG3 77	1	5	7	999.0	999.0	999.00	999.00	106.6	88	7.8
WG4 77	1	5	7	999.0	999.0	999.00	999.00	104.1	4	7.3
WG6 77	1	5	7	999.0	999.0	999.00	999.00	101.8	3	7.7
WG8 77	1	5	7	999.0	999.0	999.00	999.00	110.1	59	7.8
WG1 78	1	6	7	9.2	1.3	999.00	999.00	100.8	0	999.0
WG4 78	1	6	7	16.1	3.5	999.00	999.00	93.0	0	999.0
WG6 78	1	6	7	9.8	1.1	999.00	999.00	999.0	999	999.0
WG10 78	1	6	7	8.3	1.1	999.00	999.00	85.7	33	999.0
WG2 79	1	7	7	999.0	999.0	0.21	0.16	88.4	0	999.0
WG3 79	1	7	7	999.0	999.0	0.27	0.10	69.3	62	999.0
WG5 79	1	7	7	999.0	999.0	0.40	0.18	81.6	78	999.0
WG6 79	1	7	7	999.0	999.0	0.32	0.17	96.8	0	999.0
WG10 79	1	7	7	999.0	999.0	0.17	0.19	95.0	0	999.0

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
DA1 73	1	1	8	7.3	0.5	0.21	0.08	999.0	999	999.0
DA2 73	1	1	8	8.0	0.5	0.20	0.15	100.9	8	999.0
DA3 73	1	1	8	4.7	0.6	0.34	0.13	999.0	0	999.0
DA4 73	1	1	8	8.3	0.5	0.19	0.12	999.0	999	999.0
DA1 74	1	2	8	7.3	0.8	0.33	0.12	999.0	2	999.0
DA2 74	1	2	8	5.8	0.4	0.32	0.19	999.0	92	999.0
DA1 76	1	4	8	11.8	2.1	0.44	0.17	91.3	1	8.0
DA4 76	1	4	8	5.5	1.0	0.30	0.24	95.5	1	7.8
DA5 76	1	4	8	999.0	999.0	999.00	999.00	93.1	32	7.9
DA12 76	1	4	8	11.1	2.1	0.33	0.13	91.7	101	7.7
DA15 76	1	4	8	5.4	0.9	0.21	0.12	88.0	26	7.8
DA5 77	1	5	8	999.0	999.0	999.00	999.00	107.5	29	8.1
DA6 77	1	5	8	999.0	999.0	999.00	999.00	108.2	75	8.1
DA7 77	1	5	8	999.0	999.0	999.00	999.00	108.8	999	7.7
DA8 77	1	5	8	999.0	999.0	999.00	999.00	105.7	0	7.9
DA9 77	1	5	8	999.0	999.0	999.00	999.00	107.3	31	8.0
DA1 78	1	6	8	4.9	0.3	0.32	0.24	99.9	6	999.0
DA2 78	1	6	8	14.8	3.8	0.47	0.15	104.0	53	999.0
DA5 78	1	6	8	6.1	0.2	0.39	0.26	98.0	0	999.0
DA6 78	1	6	8	4.5	0.4	0.33	0.10	107.5	148	999.0
DA10 78	1	6	8	6.0	0.6	0.23	0.18	77.5	1	999.0
DA3 79	1	7	8	999.0	999.0	0.15	0.12	88.4	1	999.0
DA4 79	1	7	8	999.0	999.0	0.18	0.21	84.4	6	999.0
DA5 79	1	7	8	999.0	999.0	0.32	0.14	83.3	0	999.0
DA8 79	1	7	8	999.0	999.0	0.30	0.20	63.1	6	999.0
DA9 79	1	7	8	999.0	999.0	0.15	0.10	57.8	19	999.0
DA1 81	1	8	8	999.0	999.0	999.00	999.00	93.4	11	999.0
DA2 81	1	8	8	999.0	999.0	999.00	999.00	105.9	11	999.0
DA3 81	1	8	8	999.0	999.0	999.00	999.00	107.3	9	999.0
DA4 81	1	8	8	999.0	999.0	999.00	999.00	104.6	0	999.0
DA6 81	1	8	8	999.0	999.0	999.00	999.00	96.3	0	999.0
DB4 76	1	4	9	22.9	5.9	999.00	999.00	91.2	16	7.9
DB7 76	1	4	9	7.9	0.8	999.00	999.00	76.3	36	7.6
DB10 76	1	4	9	4.6	0.3	999.00	999.00	72.9	0	7.6
DB11 76	1	4	9	6.2	0.7	999.00	999.00	86.7	0	7.8
DB14 76	1	4	9	4.6	0.8	999.00	999.00	85.1	0	7.8
DB15 76	1	4	9	12.1	2.1	999.00	999.00	85.7	50	7.8
DB2 77	1	5	9	999.0	999.0	999.00	999.00	94.8	0	8.0
DB3 77	1	5	9	999.0	999.0	999.00	999.00	105.6	1	8.0
DB5 77	1	5	9	999.0	999.0	999.00	999.00	104.8	0	7.8
DB8 77	1	5	9	999.0	999.0	999.00	999.00	104.9	2	8.0
DB10 77	1	5	9	999.0	999.0	999.00	999.00	104.9	1	7.8
DB2 78	1	6	9	3.2	0.2	999.00	999.00	90.9	0	999.0
DB3 78	1	6	9	6.7	0.7	999.00	999.00	91.7	0	999.0

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
DB4 78	1	6	9	8.9	1.0	999.00	999.00	87.9	0	999.0
DB5 78	1	6	9	2.7	0.3	999.00	999.00	86.2	0	999.0
DB7 78	1	6	9	14.4	3.6	999.00	999.00	87.4	0	999.0
DB2 79	1	7	9	999.0	999.0	0.29	0.23	83.9	0	999.0
DB3 79	1	7	9	999.0	999.0	0.17	0.07	89.5	10	999.0
DB1 81	1	8	9	999.0	999.0	999.00	999.00	102.5	999	999.0
DB2 81	1	8	9	999.0	999.0	999.00	999.00	37.8	999	999.0
DB3 81	1	8	9	999.0	999.0	999.00	999.00	102.7	999	999.0
DB4 81	1	8	9	999.0	999.0	999.00	999.00	104.5	999	999.0
DB5 81	1	8	9	999.0	999.0	999.00	999.00	103.4	999	999.0
DB1 82	1	9	9	999.0	999.0	999.00	999.00	107.3	999	8.4
DB2 82	1	9	9	999.0	999.0	999.00	999.00	103.1	999	8.4
DB3 82	1	9	9	999.0	999.0	999.00	999.00	100.0	999	8.4
DB4 82	1	9	9	999.0	999.0	999.00	999.00	96.0	999	8.3
DB5 82	1	9	9	999.0	999.0	999.00	999.00	80.0	999	8.3
DB1 83	1	10	9	8.6	1.3	999.00	999.00	999.0	999	999.0
DB2 83	1	10	9	12.0	1.3	999.00	999.00	999.0	999	999.0
DB3 83	1	10	9	8.3	1.2	999.00	999.00	999.0	999	999.0
DB4 83	1	10	9	11.3	1.6	999.00	999.00	999.0	999	999.0
DB5 83	1	10	9	8.5	1.2	999.00	999.00	999.0	999	999.0
DC1 79	1	7	10	999.0	999.0	0.20	0.16	90.8	29	999.0
DC3 79	1	7	10	999.0	999.0	0.40	0.10	86.5	1	999.0
DC4 79	1	7	10	999.0	999.0	0.29	0.10	89.7	0	999.0
DC1 81	1	8	10	999.0	999.0	999.00	999.00	107.6	999	999.0
DC2 81	1	8	10	999.0	999.0	999.00	999.00	104.1	999	999.0
DC3 81	1	8	10	999.0	999.0	999.00	999.00	98.2	999	999.0
DC4 81	1	8	10	999.0	999.0	999.00	999.00	100.9	999	999.0
DC5 81	1	8	10	999.0	999.0	999.00	999.00	102.7	999	999.0
DC1 83	1	10	10	11.1	2.5	999.00	999.00	999.0	999	999.0
DC2 83	1	10	10	12.0	3.9	999.00	999.00	999.0	999	999.0
DC3 83	1	10	10	12.1	1.8	999.00	999.00	999.0	999	999.0
DC4 83	1	10	10	14.8	2.0	999.00	999.00	999.0	999	999.0
DC5 83	1	10	10	12.7	3.2	999.00	999.00	999.0	999	999.0
WA2 79	2	7	1	999.0	999.0	0.39	0.15	79.9	6	999.0
WA6 79	2	7	1	999.0	999.0	0.33	0.16	80.8	31	999.0
WA7 79	2	7	1	999.0	999.0	0.28	0.12	83.5	77	999.0
WA8 79	2	7	1	999.0	999.0	0.29	0.09	87.7	163	999.0
WA9 79	2	7	1	999.0	999.0	0.33	0.12	86.7	6	999.0
WA2 81	2	8	1	999.0	999.0	999.00	999.00	106.7	11	999.0
WA3 81	2	8	1	999.0	999.0	999.00	999.00	105.6	0	999.0
WA5 81	2	8	1	999.0	999.0	999.00	999.00	97.2	0	999.0
WA7 81	2	8	1	999.0	999.0	999.00	999.00	106.9	999	999.0
WA8 81	2	8	1	999.0	999.0	999.00	999.00	56.0	999	999.0
WA1 82	2	9	1	999.0	999.0	999.00	999.00	85.3	999	8.3

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
WA2 82	2	9	1	999.0	999.0	999.00	999.00	90.5	999	8.2
WA3 82	2	9	1	999.0	999.0	999.00	999.00	103.8	999	8.2
WA1 83	2	10	1	12.9	2.6	999.00	999.00	999.0	999	999.0
WA2 83	2	10	1	10.4	1.6	999.00	999.00	999.0	999	999.0
WA3 83	2	10	1	13.7	1.3	999.00	999.00	999.0	999	999.0
WA4 83	2	10	1	17.7	3.7	999.00	999.00	999.0	999	999.0
WA5 83	2	10	1	9.2	1.2	999.00	999.00	999.0	999	999.0
WA1 84	2	11	1	16.8	3.7	0.47	0.15	67.4	67	7.9
WA5 84	2	11	1	4.4	0.1	0.39	0.15	54.9	0	7.8
WA10 84	2	11	1	15.1	2.4	0.09	0.06	68.8	166	8.0
WA14 84	2	11	1	21.4	4.0	0.20	0.09	87.0	42	8.2
WA15 84	2	11	1	13.4	3.3	0.39	0.11	52.0	0	7.7
WA3 85	2	12	1	7.2	0.9	0.32	0.12	94.5	53	7.1
WA4 85	2	12	1	9.8	1.0	0.26	0.08	106.3	12	7.4
WA5 85	2	12	1	13.4	1.9	0.34	0.10	69.4	0	7.3
WA8 85	2	12	1	6.0	0.5	999.00	999.00	75.2	0	7.4
WA9 85	2	12	1	14.1	2.0	999.00	999.00	95.8	0	7.4
WB2 79	2	7	2	999.0	999.0	0.33	0.12	75.0	4	999.0
WB3 79	2	7	2	999.0	999.0	0.46	0.15	81.3	4	999.0
WB4 79	2	7	2	999.0	999.0	0.35	0.15	70.8	67	999.0
WB7 79	2	7	2	999.0	999.0	0.32	0.13	46.8	50	999.0
WB9 79	2	7	2	999.0	999.0	0.22	0.16	79.2	65	999.0
WB1 81	2	8	2	999.0	999.0	999.00	999.00	105.6	19	999.0
WB2 81	2	8	2	999.0	999.0	999.00	999.00	105.1	999	999.0
WB3 81	2	8	2	999.0	999.0	999.00	999.00	66.1	0	999.0
WB4 81	2	8	2	999.0	999.0	999.00	999.00	103.7	0	999.0
WB5 81	2	8	2	999.0	999.0	999.00	999.00	102.3	999	999.0
WB4 82	2	9	2	999.0	999.0	999.00	999.00	102.8	999	8.3
WB5 82	2	9	2	999.0	999.0	999.00	999.00	101.8	999	8.3
WB1 83	2	10	2	8.2	2.4	999.00	999.00	999.0	999	999.0
WB2 83	2	10	2	8.3	1.4	999.00	999.00	999.0	999	999.0
WB3 83	2	10	2	7.0	0.8	999.00	999.00	999.0	999	999.0
WB4 83	2	10	2	5.6	1.0	999.00	999.00	999.0	999	999.0
WB5 83	2	10	2	8.0	0.9	999.00	999.00	999.0	999	999.0
WB2 84	2	11	2	12.8	1.1	0.18	0.06	54.1	0	7.7
WB4 84	2	11	2	8.8	1.0	0.36	0.12	66.7	55	7.8
WB10 84	2	11	2	14.5	2.4	0.27	0.08	60.1	0	7.7
WB13 84	2	11	2	15.6	2.1	0.33	0.17	65.2	44	7.9
WB15 84	2	11	2	15.7	2.3	0.29	0.09	43.2	52	7.7
WB1 85	2	12	2	8.9	1.9	0.28	0.08	81.6	1	7.3
WB4 85	2	12	2	5.9	0.7	0.21	0.17	89.1	3	7.1
WB6 85	2	12	2	7.0	1.4	0.38	0.14	94.4	73	6.5
WB7 85	2	12	2	5.4	0.1	0.23	0.20	57.4	1	7.2
WB8 85	2	12	2	8.0	0.4	0.26	0.19	97.3	84	7.4

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
WC1 81	2	8	3	999.0	999.0	999.00	999.00	101.5	4	999.0
WC2 81	2	8	3	999.0	999.0	999.00	999.00	102.0	4	999.0
WC3 81	2	8	3	999.0	999.0	999.00	999.00	99.7	0	999.0
WC4 81	2	8	3	999.0	999.0	999.00	999.00	96.4	999	999.0
WC5 81	2	8	3	999.0	999.0	999.00	999.00	77.1	999	999.0
WC3 84	2	11	3	9.6	1.1	0.21	0.12	56.4	0	7.6
WC5 84	2	11	3	11.9	1.0	0.32	0.14	33.3	89	7.4
WC7 84	2	11	3	10.8	1.7	0.37	0.14	45.8	157	7.4
WC9 84	2	11	3	17.5	1.4	0.31	0.11	48.1	0	7.3
WC11 84	2	11	3	10.7	1.3	0.26	0.06	67.0	27	7.5
WC1 85	2	12	3	7.1	0.9	0.15	0.11	73.6	24	7.5
WC2 85	2	12	3	8.1	1.1	0.22	0.10	999.0	999	999.0
WC4 85	2	12	3	10.8	1.5	0.26	0.15	82.7	0	7.2
WC5 85	2	12	3	7.9	0.9	0.17	0.09	85.7	0	7.3
WC6 85	2	12	3	9.1	0.9	0.26	0.14	99.2	1	7.4
WC8 85	2	12	3	8.3	0.9	0.22	0.07	100.2	40	7.2
WD1 81	2	8	4	999.0	999.0	999.00	999.00	71.1	0	999.0
WD3 81	2	8	4	999.0	999.0	999.00	999.00	84.6	10	999.0
WD4 81	2	8	4	999.0	999.0	999.00	999.00	82.3	12	999.0
WD6 81	2	8	4	999.0	999.0	999.00	999.00	85.5	0	999.0
WD7 81	2	8	4	999.0	999.0	999.00	999.00	85.6	0	999.0
WD1 82	2	9	4	999.0	999.0	999.00	999.00	101.1	999	8.1
WD2 82	2	9	4	999.0	999.0	999.00	999.00	104.5	999	8.0
WD3 82	2	9	4	999.0	999.0	999.00	999.00	99.2	999	8.0
WD4 82	2	9	4	999.0	999.0	999.00	999.00	101.3	999	8.1
WD5 82	2	9	4	999.0	999.0	999.00	999.00	79.6	999	8.2
WD1 83	2	10	4	8.6	0.9	999.00	999.00	999.0	999	999.0
WD2 83	2	10	4	7.7	0.9	999.00	999.00	999.0	999	999.0
WD3 83	2	10	4	10.1	1.4	999.00	999.00	999.0	999	999.0
WD4 83	2	10	4	7.8	1.6	999.00	999.00	999.0	999	999.0
WD5 83	2	10	4	5.3	0.9	999.00	999.00	999.0	999	999.0
WE1 81	2	8	5	999.0	999.0	999.00	999.00	106.8	1	999.0
WE2 81	2	8	5	999.0	999.0	999.00	999.00	106.8	0	999.0
WE3 81	2	8	5	999.0	999.0	999.00	999.00	95.2	10	999.0
WE4 81	2	8	5	999.0	999.0	999.00	999.00	95.2	26	999.0
WE5 81	2	8	5	999.0	999.0	999.00	999.00	107.0	999	999.0
WE6 81	2	8	5	999.0	999.0	999.00	999.00	95.2	999	999.0
WE7 81	2	8	5	999.0	999.0	999.00	999.00	87.1	999	999.0
WE4 82	2	9	5	999.0	999.0	999.00	999.00	104.3	8	8.2
WE5 82	2	9	5	999.0	999.0	999.00	999.00	97.2	999	8.3
WE1 83	2	10	5	9.5	0.9	999.00	999.00	999.0	999	999.0
WE2 83	2	10	5	7.6	0.8	999.00	999.00	999.0	999	999.0
WE3 83	2	10	5	9.3	0.7	999.00	999.00	999.0	999	999.0
WE4 83	2	10	5	7.8	0.9	999.00	999.00	999.0	999	999.0

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
WE5 83	2	10	5	13.7	2.7	999.00	999.00	999.0	999	999.0
WE2 84	2	11	5	9.9	1.8	0.49	0.14	64.3	92	7.6
WE4 84	2	11	5	13.8	1.7	0.28	0.13	69.0	2	7.7
WE9 84	2	11	5	12.4	1.9	0.23	0.09	54.7	6	7.6
WE11 84	2	11	5	11.5	2.9	0.37	0.09	60.9	75	7.7
WE12 84	2	11	5	13.6	1.5	0.43	0.12	30.2	21	7.3
WE2 85	2	12	5	9.5	1.0	0.31	0.07	84.4	0	7.3
WE14 85	2	12	5	10.2	1.4	0.30	0.10	95.8	237	7.3
WF1 82	2	9	6	999.0	999.0	999.00	999.00	102.1	999	8.1
WF2 82	2	9	6	999.0	999.0	999.00	999.00	102.3	999	8.0
WF3 82	2	9	6	999.0	999.0	999.00	999.00	101.7	999	8.0
WF4 82	2	9	6	999.0	999.0	999.00	999.00	97.2	999	8.1
WF5 82	2	9	6	999.0	999.0	999.00	999.00	101.3	999	8.2
WF1 83	2	10	6	5.9	1.1	999.00	999.00	999.0	999	999.0
WF2 83	2	10	6	8.6	1.2	999.00	999.00	999.0	999	999.0
WF3 83	2	10	6	9.3	1.6	999.00	999.00	999.0	999	999.0
WF4 83	2	10	6	7.9	1.8	999.00	999.00	999.0	999	999.0
WF5 83	2	10	6	8.4	1.3	999.00	999.00	999.0	999	999.0
WF1 84	2	11	6	7.7	1.2	999.00	999.00	43.4	110	7.7
WF2 84	2	11	6	9.8	2.0	999.00	999.00	84.0	41	7.8
WF3 84	2	11	6	8.8	1.8	999.00	999.00	38.1	140	7.8
WF4 84	2	11	6	8.6	1.2	999.00	999.00	62.8	11	7.9
WF5 84	2	11	6	7.2	0.8	999.00	999.00	33.3	27	7.5
WG1 81	2	8	7	999.0	999.0	999.00	999.00	90.6	999	999.0
WG2 81	2	8	7	999.0	999.0	999.00	999.00	95.1	999	999.0
WG3 81	2	8	7	999.0	999.0	999.00	999.00	104.6	999	999.0
WG4 81	2	8	7	999.0	999.0	999.00	999.00	47.3	999	999.0
WG5 81	2	8	7	999.0	999.0	999.00	999.00	106.1	999	999.0
WG1 82	2	9	7	999.0	999.0	999.00	999.00	98.5	999	8.3
WG2 82	2	9	7	999.0	999.0	999.00	999.00	87.4	999	8.1
WG3 82	2	9	7	999.0	999.0	999.00	999.00	86.1	999	8.1
WG4 82	2	9	7	999.0	999.0	999.00	999.00	81.9	999	8.1
WG5 82	2	9	7	999.0	999.0	999.00	999.00	88.1	999	8.2
WG1 83	2	10	7	8.6	0.7	999.00	999.00	999.0	999	999.0
WG2 83	2	10	7	7.3	0.4	999.00	999.00	999.0	999	999.0
WG3 83	2	10	7	12.4	1.5	999.00	999.00	999.0	999	999.0
WG4 83	2	10	7	7.3	0.8	999.00	999.00	999.0	999	999.0
WG5 83	2	10	7	11.2	1.0	999.00	999.00	999.0	999	999.0
WG1 84	2	11	7	14.5	1.3	0.32	0.15	42.7	0	7.4
WG2 84	2	11	7	13.1	2.0	999.00	999.00	50.5	0	7.7
WG3 84	2	11	7	7.7	1.4	999.00	999.00	63.0	0	7.7
WG4 84	2	11	7	9.7	1.3	999.00	999.00	54.6	1	7.4
WG5 84	2	11	7	7.1	1.3	999.00	999.00	31.7	0	7.3
WG1 85	2	12	7	999.0	999.0	999.00	999.00	69.2	0	7.3

Appendix II. Continued.

Site	Phs	Yr	Sec	dg (mm)	f	Vel (m/s)	Dpth (m)	Sat %	Fry (#)	Intr pH
WG2 85	2	12	7	8.6	0.5	999.00	999.00	100.3	0	7.3
WG4 85	2	12	7	5.8	0.6	999.00	999.00	87.3	8	7.3
WG5 85	2	12	7	11.4	1.1	999.00	999.00	49.1	0	7.2
WG6 85	2	12	7	15.1	3.3	999.00	999.00	67.8	0	7.2
DA1 83	2	10	8	15.6	3.8	999.00	999.00	999.0	999	999.0
DA2 83	2	10	8	15.7	2.3	999.00	999.00	999.0	999	999.0
DA3 83	2	10	8	10.1	2.6	999.00	999.00	999.0	999	999.0
DA4 83	2	10	8	13.1	2.1	999.00	999.00	999.0	999	999.0
DA5 83	2	10	8	9.2	1.3	999.00	999.00	999.0	999	999.0
DA1 84	2	11	8	14.9	3.0	0.29	0.14	60.5	119	7.8
DA2 84	2	11	8	17.0	5.7	0.40	0.10	41.4	26	7.6
DA3 84	2	11	8	10.7	2.0	0.66	0.13	70.5	75	8.0
DA4 84	2	11	8	20.1	4.0	0.39	0.17	42.7	0	7.3
DA5 84	2	11	8	12.6	2.0	0.40	0.18	45.5	6	7.5
DA1 85	2	12	8	7.6	1.4	0.20	0.11	98.3	105	7.8
DA5 85	2	12	8	8.7	0.9	0.25	0.10	102.9	84	7.4
DA7 85	2	12	8	7.0	0.4	0.25	0.17	95.6	1	7.4
DA11 85	2	12	8	7.9	1.1	999.00	999.00	78.0	121	7.8
DA12 85	2	12	8	10.7	2.1	999.00	999.00	99.9	63	7.8
DB1 85	2	12	9	999.0	999.0	999.00	999.00	104.0	0	7.4
DC1 84	2	11	10	12.5	2.9	0.43	0.15	77.2	8	7.8
DC2 84	2	11	10	15.3	3.3	0.37	0.16	60.7	122	7.5
DC3 84	2	11	10	12.9	3.3	999.00	999.00	61.9	235	7.7
DC1 85	2	12	10	9.4	1.7	999.00	999.00	77.5	0	7.6
DC2 85	2	12	10	999.0	999.0	999.00	999.00	103.2	19	7.4
DC3 85	2	12	10	9.9	1.6	999.00	999.00	96.8	58	7.7
DC4 85	2	12	10	9.1	1.7	999.00	999.00	98.8	4	7.6

VII. APPENDIX III.

Appendix III. Spawning substrate particle size analysis in the Tri-Creeks Experimental Watershed, 1973 - 1985.

		Sieve mesh size (mm)									
		76.2	50.8	25.4	12.7	6.35	3.36	1.68	0.84	0.42	0.21
Ss	'Yr	Percent passing									
WA1	73	65.0	62.6	51.6	36.4	25.5	17.5	14.3	11.0	5.3	1.0
WA2	73	75.9	75.9	54.2	42.5	29.4	23.0	15.3	11.9	6.5	0.9
WA3	73	40.1	40.1	33.9	26.1	19.2	10.9	7.3	5.2	3.7	1.9
WA1	74	100.0	100.0	78.0	60.4	43.2	30.6	20.3	12.2	4.6	1.7
WA2	74	100.0	100.0	80.5	66.1	52.9	38.5	29.3	15.5	3.7	0.9
WA3	74	100.0	100.0	79.1	59.0	49.0	39.4	28.1	14.7	3.4	0.8
WA4	74	100.0	87.8	61.6	47.6	31.7	20.7	15.9	14.0	6.1	2.4
WA5	74	100.0	78.7	46.9	29.1	19.4	11.4	5.7	2.8	1.9	0.9
WA6	74	100.0	96.2	73.8	54.1	38.5	29.8	22.7	16.1	9.0	2.8
WA1	75	100.0	93.3	58.7	40.6	29.3	16.3	12.6	11.1	8.5	1.6
WA2	75	100.0	93.3	58.7	40.6	29.3	16.3	12.6	11.1	8.5	1.6
WA5	75	100.0	92.4	56.0	40.3	28.4	17.2	9.7	6.8	5.1	1.2
WA7	75	100.0	100.0	70.6	53.0	41.2	27.7	17.7	12.3	6.9	1.4
WA1	78	100.0	100.0	74.6	50.4	34.4	26.0	22.1	18.7	10.0	4.7
WA5	78	100.0	100.0	86.9	76.9	56.4	37.5	30.3	27.7	21.3	8.7
WA1	83	100.0	89.0	66.0	39.2	22.8	15.6	12.3	10.2	6.5	3.4
WA2	83	100.0	92.6	69.9	48.8	30.4	19.4	15.6	12.0	7.1	4.0
WA3	83	100.0	70.1	59.2	40.9	28.6	20.1	13.8	9.6	6.1	3.5
WA4	83	81.5	81.5	55.8	30.0	20.6	14.2	8.4	5.8	4.0	2.2
WA5	83	100.0	78.8	74.5	56.5	36.5	25.1	18.0	13.6	9.0	5.1
WA1	84	100.0	84.3	53.4	31.5	18.8	12.9	8.9	6.1	3.4	1.8
WA5	84	100.0	97.3	86.2	69.4	53.0	43.6	37.2	32.3	26.1	17.0
WA10	84	91.7	81.8	59.3	38.2	24.1	15.9	9.0	6.1	4.0	2.1
WA14	84	82.7	71.6	46.6	28.2	15.9	10.3	7.5	5.5	3.3	1.5
WA15	84	100.0	94.9	65.2	37.7	18.9	14.2	10.9	9.1	6.9	3.2
WA3	85	100.0	100.0	80.3	58.1	42.4	28.1	18.3	14.0	10.0	3.8
WA4	85	97.9	97.9	62.3	47.8	36.2	24.7	15.5	11.7	8.4	3.1
WA5	85	100.0	85.5	55.5	36.1	26.1	19.0	13.6	10.7	7.8	3.3
WA8	85	100.0	89.9	88.7	63.3	41.3	31.7	26.5	20.9	13.4	3.7
WA9	85	100.0	83.5	58.2	38.1	26.0	17.0	10.4	7.2	5.3	2.3
WB1	75	100.0	100.0	72.8	51.1	35.5	24.1	17.8	7.4	4.8	0.4
WB3	75	100.0	96.7	59.3	30.1	17.3	11.7	7.8	6.3	2.0	0.8
WB4	75	100.0	96.7	59.3	30.1	17.3	11.7	7.8	6.3	2.0	0.8
WB5	75	100.0	85.9	52.4	34.8	27.3	18.4	14.0	11.6	6.5	2.1
WB6	75	100.0	100.0	71.2	47.3	30.1	20.5	14.4	8.3	4.0	1.8

Appendix III. Continued.

		Sieve mesh size (mm)									
		76.2	50.8	25.4	12.7	6.35	3.36	1.68	0.84	0.42	0.21
Ss	'Yr	Percent Passing									
WB4	78	100.0	100.0	72.2	46.8	27.7	19.0	14.8	12.7	9.8	5.2
WB6	78	100.0	100.0	85.3	67.5	47.8	34.4	28.9	21.5	12.5	5.1
WB1	83	100.0	100.0	91.1	58.4	27.4	17.6	15.5	15.2	14.4	8.1
WB2	83	100.0	100.0	81.3	55.3	34.4	23.1	16.6	13.5	11.2	7.0
WB3	83	95.6	95.6	81.4	61.6	43.0	30.5	21.8	15.6	8.4	5.0
WB4	83	100.0	100.0	91.1	74.0	49.2	31.3	21.0	14.8	8.0	4.7
WB5	83	100.0	100.0	76.8	54.5	36.7	27.3	19.7	14.2	8.3	5.3
WB2	84	88.7	76.0	59.6	45.1	33.0	22.2	14.3	9.3	5.8	3.2
WB4	84	100.0	100.0	71.3	54.8	36.8	25.0	16.0	10.8	6.2	3.3
WB10	84	94.8	87.1	57.3	41.4	24.2	14.8	9.6	6.9	4.2	2.3
WB13	84	83.6	74.8	63.8	46.1	23.4	11.4	7.2	5.8	4.3	2.3
WB15	84	91.8	79.6	51.6	36.7	24.1	16.1	11.2	8.1	5.3	2.3
WB1	85	100.0	100.0	82.2	50.8	31.0	20.4	14.9	11.6	8.2	4.0
WB4	85	100.0	100.0	87.3	65.7	46.9	31.9	21.7	16.8	11.9	5.0
WB6	85	100.0	100.0	93.4	62.3	38.8	23.5	15.6	12.8	10.9	5.9
WB7	85	100.0	100.0	71.8	58.6	49.7	39.2	33.4	28.3	24.3	11.0
WB8	85	100.0	85.6	70.5	54.2	39.5	30.3	24.7	17.7	8.9	3.4
WC2	75	72.6	72.6	67.7	57.7	44.2	29.4	21.5	9.5	4.1	2.6
WC4	75	100.0	100.0	84.1	64.3	46.3	29.7	19.9	14.8	8.2	2.4
WC6	75	100.0	100.0	74.5	49.6	34.0	24.1	15.4	10.0	6.4	4.2
WC8	75	100.0	100.0	80.5	55.3	41.5	26.7	17.7	9.2	2.8	1.6
WC1	76	100.0	100.0	69.3	45.1	29.8	20.9	13.3	8.0	3.2	1.2
WC3	76	100.0	100.0	69.5	49.7	39.2	22.8	14.4	8.4	4.8	1.8
WC5	76	100.0	79.4	49.4	33.2	19.0	9.7	4.9	3.2	2.8	1.2
WC6	76	100.0	100.0	68.5	45.3	27.2	17.1	8.7	4.4	3.4	0.7
WC8	76	100.0	95.9	74.4	57.2	40.6	31.3	20.9	12.2	5.9	0.9
WC3	77	77.2	63.7	52.3	44.3	33.8	23.5	17.6	13.0	7.8	1.8
WC4	77	100.0	96.9	81.2	60.3	42.0	26.7	14.0	8.9	4.3	1.0
WC1	78	100.0	92.2	62.9	48.0	33.1	22.8	18.4	16.1	13.0	7.2
WC2	78	100.0	91.5	60.2	37.9	24.5	17.5	12.9	9.4	6.4	3.2
WC6	78	100.0	95.9	83.6	65.5	46.8	34.8	26.4	17.7	9.3	4.5
WC8	78	100.0	82.2	67.4	52.1	37.8	27.1	20.5	16.4	11.8	6.2
WC9	78	100.0	90.8	74.3	47.7	26.4	15.3	10.0	6.9	4.6	2.4
WC3	84	100.0	94.4	69.6	52.3	35.9	23.6	15.2	10.3	7.0	4.5
WC5	84	92.7	79.7	62.8	47.4	32.9	23.7	14.8	8.7	5.7	4.0
WC7	84	100.0	95.9	70.6	50.1	31.4	19.6	10.6	6.5	4.7	3.4

Appendix III. Continued.

		Sieve mesh size (mm)									
		76.2	50.8	25.4	12.7	6.35	3.36	1.68	0.84	0.42	0.21
Ss	’Yr	Percent Passing									
WC9	84	75.5	67.5	50.6	37.6	25.8	17.8	12.1	7.7	5.0	3.5
WC11	84	93.2	93.2	66.8	49.9	33.0	22.0	13.9	10.0	7.2	4.9
WC1	85	100.0	100.0	78.9	64.9	42.7	28.0	17.9	14.5	10.9	6.4
WC2	85	100.0	100.0	79.0	54.5	36.5	25.5	17.7	14.0	10.1	5.8
WC4	85	100.0	96.2	64.4	46.6	30.3	20.1	14.4	11.9	9.1	5.8
WC5	85	100.0	100.0	74.1	58.3	40.8	26.9	17.7	12.9	8.6	5.1
WC6	85	100.0	83.8	72.3	56.2	40.8	27.1	15.4	10.2	6.2	3.8
WC8	85	100.0	100.0	73.0	54.4	40.5	27.4	18.2	11.5	5.6	3.8
WD1	73	78.6	78.6	67.6	49.4	32.8	24.2	15.5	9.3	4.5	0.8
WD2	73	100.0	96.3	86.1	68.3	44.3	28.2	19.1	11.0	5.4	0.6
WD2	74	100.0	100.0	68.8	61.5	50.5	41.3	24.8	13.8	8.3	2.8
WD4	74	100.0	100.0	82.1	53.1	32.1	22.3	17.9	9.8	2.2	0.4
WD19	74	100.0	100.0	83.3	63.2	45.3	34.9	26.4	20.2	9.3	2.3
WD20	74	100.0	100.0	83.3	63.2	45.3	34.9	26.4	20.2	9.3	2.3
WD32	74	100.0	100.0	84.6	73.6	48.4	24.2	10.4	7.7	4.9	2.7
WD1	75	100.0	100.0	75.7	52.4	37.5	19.8	15.6	11.8	7.2	2.2
WD6	75	100.0	100.0	94.5	67.8	43.7	33.0	25.4	18.9	4.3	1.6
WD8	75	100.0	100.0	100.0	95.1	54.6	25.8	13.1	10.0	6.7	3.1
WD10	75	100.0	100.0	100.0	64.6	34.9	22.3	13.9	8.9	5.4	2.1
WD1	76	100.0	100.0	100.0	85.0	62.9	40.4	20.6	11.6	4.9	0.7
WD4	76	100.0	64.2	42.9	29.6	20.1	13.9	9.9	5.9	3.1	0.3
WD7	76	100.0	100.0	89.8	70.1	45.9	25.5	12.7	6.4	5.1	2.5
WD8	76	100.0	77.3	67.4	46.8	31.3	21.0	12.9	9.0	5.2	2.1
WD11	76	100.0	79.4	76.5	55.5	39.7	28.3	18.4	12.1	4.4	1.5
WD1	78	100.0	100.0	68.7	30.7	13.3	6.7	4.7	4.4	4.1	3.9
WD3	78	100.0	100.0	55.5	39.5	27.8	16.9	13.5	9.7	6.8	4.7
WD6	78	100.0	94.9	82.5	45.5	26.6	18.7	13.2	10.4	7.7	4.9
WD8	78	100.0	100.0	97.1	71.7	39.9	27.0	19.9	17.0	12.8	8.1
WD10	78	100.0	100.0	83.3	57.8	36.5	26.7	22.1	19.3	15.6	8.2
WD1	83	100.0	92.0	72.2	57.7	41.0	27.1	16.2	11.4	8.1	5.5
WD2	83	100.0	89.9	79.7	61.3	43.8	30.2	17.2	11.9	8.4	5.8
WD3	83	100.0	90.7	71.2	53.6	34.8	21.8	12.6	9.5	7.4	5.2
WD4	83	100.0	100.0	84.3	66.1	38.8	21.6	12.4	10.4	9.0	5.8
WD5	83	100.0	100.0	90.9	75.8	55.4	36.6	21.2	12.6	9.0	6.3
WE5	73	100.0	92.2	85.3	70.2	46.4	29.9	20.3	15.5	5.8	1.4
WE7	73	90.9	71.2	40.9	27.6	16.2	9.2	6.5	5.7	3.5	1.0

Appendix III. Continued.

		Sieve mesh size (mm)									
		76.2	50.8	25.4	12.7	6.35	3.36	1.68	0.84	0.42	0.21
Ss	'Yr	Percent Passing									
WE9	73	83.7	63.2	51.2	33.4	15.9	10.5	7.1	3.8	1.4	0.6
WE10	73	100.0	90.0	73.7	52.4	36.3	26.3	18.9	13.2	4.2	0.8
WE11	73	89.5	85.3	74.2	57.7	44.5	33.7	25.4	15.8	4.1	2.0
WE13	73	100.0	94.1	84.5	71.0	51.5	36.9	25.9	13.8	3.6	1.0
WE15	73	100.0	100.0	78.0	59.7	41.8	31.9	22.2	13.6	2.5	0.6
WE16	73	100.0	89.1	69.3	49.1	34.2	23.7	16.8	10.9	5.6	0.8
WE17	73	100.0	98.9	84.7	61.2	40.7	28.3	19.4	14.5	6.0	1.2
WE18	73	100.0	100.0	79.6	58.3	42.2	29.4	21.6	15.4	5.6	1.6
WE20	73	86.2	75.4	58.0	46.6	33.7	22.7	16.2	10.3	4.1	1.4
WE7	74	100.0	100.0	72.6	53.8	35.8	21.2	13.7	9.4	2.4	0.9
WE8	74	100.0	95.3	89.5	71.2	53.2	39.2	26.5	17.2	6.1	1.2
WE10	74	100.0	100.0	88.2	69.7	44.5	30.3	14.7	8.1	4.3	0.9
WE12	74	100.0	100.0	81.3	63.9	52.3	41.1	31.1	18.7	6.6	2.5
WE25	74	100.0	93.8	80.9	59.6	41.3	32.0	20.4	13.8	5.8	1.3
WE28	74	100.0	92.5	72.9	48.5	32.3	19.5	11.3	7.1	4.1	1.5
WE34	74	100.0	100.0	94.5	63.6	31.4	21.4	17.3	14.5	7.3	2.3
WE2	75	100.0	100.0	79.3	64.7	47.8	36.3	26.3	20.1	9.4	1.9
WE3	75	100.0	100.0	95.1	71.6	48.1	33.5	23.2	15.1	4.1	1.2
WE5	75	100.0	100.0	63.2	44.8	23.1	12.3	9.4	7.0	4.8	0.9
WE7	75	100.0	92.2	70.9	53.7	37.7	26.4	17.4	9.8	4.8	1.1
WE9	75	100.0	100.0	60.6	27.7	15.2	10.6	5.9	1.6	0.9	0.4
WE3	76	100.0	100.0	94.9	71.3	47.0	31.1	19.3	11.5	4.7	0.7
WE5	76	100.0	89.4	76.4	58.1	34.5	20.8	13.7	9.5	7.0	1.4
WE7	76	100.0	100.0	84.2	64.4	43.3	29.9	19.0	9.9	5.6	1.8
WE11	76	100.0	94.4	70.2	46.5	26.8	16.2	11.6	9.6	6.1	2.0
WE2	78	100.0	100.0	59.4	42.1	28.9	18.8	15.7	15.2	9.6	5.6
WE3	78	100.0	100.0	84.7	70.8	47.5	32.7	26.4	21.9	14.7	8.0
WE7	78	100.0	100.0	55.4	36.1	24.8	19.3	15.8	14.4	10.9	6.9
WE9	78	100.0	100.0	57.6	40.1	27.4	20.1	13.3	10.8	5.5	5.0
WE1	83	100.0	100.0	64.0	46.3	34.8	25.7	18.4	15.7	7.0	4.6
WE2	83	100.0	100.0	76.0	57.1	41.6	31.1	18.4	12.6	8.4	5.5
WE3	83	100.0	94.6	65.2	48.8	37.6	29.1	19.2	11.7	7.3	4.6
WE4	83	100.0	100.0	75.9	56.5	40.5	28.7	19.2	12.5	8.4	5.5
WE5	83	100.0	100.0	52.6	33.6	23.5	17.4	13.2	10.8	8.7	6.0
WE2	84	100.0	100.0	75.6	50.8	31.3	20.6	11.8	8.8	7.2	4.9
WE4	84	100.0	84.8	52.5	39.6	27.7	19.1	12.7	9.5	6.9	4.4
WE9	84	100.0	86.8	67.3	47.8	28.8	16.6	9.3	6.8	5.5	4.2
WE11	84	100.0	100.0	75.2	45.3	24.8	14.1	10.0	7.7	5.7	4.1

Appendix III. Continued.

		Sieve mesh size (mm)									
		76.2	50.8	25.4	12.7	6.35	3.36	1.68	0.84	0.42	0.21
Ss	'Yr	Percent Passing									
WE12	84	100.0	80.3	54.7	40.2	28.2	20.6	14.3	8.9	6.3	4.3
WE2	85	100.0	98.8	65.2	49.4	33.7	24.4	17.6	13.4	9.5	5.0
WE14	85	100.0	92.4	69.8	49.8	32.1	21.3	15.8	13.3	10.4	7.8
WF1	83	100.0	100.0	94.3	72.5	45.5	29.2	19.4	13.0	9.2	5.5
WF2	83	100.0	100.0	77.6	54.4	36.7	24.9	16.0	10.0	6.2	4.0
WF3	83	100.0	94.5	77.1	56.0	34.7	20.6	13.7	10.1	7.3	4.8
WF4	83	100.0	100.0	94.9	52.3	30.1	22.3	17.0	14.4	11.1	7.0
WF5	83	100.0	91.9	80.4	58.4	38.4	24.8	14.9	10.9	8.9	5.6
WF1	84	100.0	93.4	81.2	65.5	43.4	25.5	14.6	9.6	6.4	3.6
WF2	84	100.0	100.0	76.6	44.5	28.2	20.4	16.1	13.3	9.7	5.6
WF3	84	100.0	100.0	82.4	58.4	34.6	20.0	11.8	8.6	6.7	4.7
WF4	84	100.0	91.6	77.5	58.6	37.6	24.9	15.1	11.4	8.8	5.5
WF5	84	100.0	88.1	80.3	63.6	43.0	29.9	21.2	14.7	8.7	4.8
WG1	75	100.0	100.0	64.9	50.9	42.3	33.3	23.7	11.5	5.1	1.6
WG5	75	100.0	100.0	73.9	62.5	46.5	35.0	27.5	15.9	3.2	1.4
WG7	75	100.0	93.3	86.3	70.0	49.7	37.6	27.6	22.0	8.5	1.3
WG9	75	100.0	100.0	78.7	54.2	35.5	24.6	14.3	8.3	4.8	1.5
WG1	76	100.0	90.1	67.8	40.1	24.3	17.1	11.8	8.6	5.9	1.3
WG4	76	100.0	100.0	85.2	62.1	42.3	29.2	19.5	13.8	6.7	2.7
WG5	76	100.0	94.5	84.7	65.6	44.8	26.2	19.1	12.6	8.7	4.9
WG6	76	100.0	86.8	61.8	40.3	26.4	16.0	8.0	6.3	4.2	0.7
WG10	76	100.0	80.0	49.0	34.1	21.6	13.7	9.0	4.7	2.7	0.4
WG1	78	100.0	100.0	70.9	49.3	31.0	23.2	16.3	13.8	11.2	4.7
WG4	78	100.0	89.3	55.7	32.7	20.4	11.3	7.6	6.9	6.4	4.2
WG6	78	100.0	86.8	71.2	49.0	35.9	23.9	16.3	12.0	8.4	5.0
WG10	78	100.0	90.4	79.2	56.0	36.0	25.6	19.6	13.8	9.0	5.0
WG1	83	100.0	100.0	67.0	51.2	40.9	30.7	18.0	10.8	6.6	4.2
WG2	83	100.0	89.8	71.1	58.3	46.5	34.9	24.7	16.7	11.3	7.6
WG3	83	100.0	78.5	62.3	45.5	28.0	18.4	14.2	12.2	8.0	5.0
WG4	83	100.0	100.0	77.3	57.5	39.8	28.9	21.8	17.5	11.5	7.6
WG5	83	100.0	77.9	60.7	48.4	33.0	22.7	17.7	15.1	10.8	7.0
WG1	84	88.1	71.9	53.8	40.4	28.4	20.0	14.3	10.8	6.7	3.4
WG2	84	100.0	90.1	59.7	41.3	26.4	16.5	11.8	9.1	7.7	5.3
WG3	84	100.0	100.0	86.8	59.2	37.6	24.0	16.6	13.1	10.1	7.2
WG4	84	100.0	95.6	69.8	49.5	32.9	22.9	16.2	12.1	7.9	4.6
WG5	84	100.0	95.3	87.7	67.5	41.8	25.5	16.3	11.4	7.7	4.6

Appendix III. Continued.

		Sieve mesh size (mm)									
		76.2	50.8	25.4	12.7	6.35	3.36	1.68	0.84	0.42	0.21
Ss	'Yr	Percent Passing									
WG2	85	100.0	100.0	61.4	46.5	36.6	29.4	24.2	21.7	13.6	8.9
WG4	85	100.0	96.1	85.3	68.7	48.2	33.1	24.2	20.2	16.9	10.7
WG5	85	100.0	80.9	60.9	42.3	30.1	22.8	17.8	14.9	12.5	6.3
WG6	85	100.0	87.1	60.0	37.0	18.4	12.6	9.9	7.8	5.1	3.2
DA1	73	100.0	89.0	73.5	58.1	44.0	35.6	23.2	13.4	5.7	1.2
DA2	73	95.1	88.7	68.4	56.0	43.0	32.5	23.0	16.2	4.7	2.3
DA3	73	100.0	96.4	91.0	75.9	57.0	39.2	26.9	16.9	8.1	2.7
DA4	73	85.4	83.2	71.5	56.2	43.1	31.5	22.9	16.9	8.8	4.5
DA1	74	100.0	100.0	78.7	57.1	42.1	31.2	20.1	11.6	1.9	0.5
DA2	74	100.0	91.4	78.4	63.7	48.5	37.7	28.4	19.6	8.8	2.0
DA1	76	100.0	94.8	70.2	48.0	29.4	15.7	8.1	4.0	2.8	1.2
DA4	76	100.0	100.0	89.5	75.1	54.5	34.2	19.1	9.7	3.9	0.4
DA12	76	100.0	93.7	74.1	45.2	29.7	18.4	10.9	6.3	2.5	0.8
DA15	76	100.0	90.2	86.8	76.5	54.4	36.3	21.6	15.7	8.3	2.5
DA1	78	100.0	100.0	88.5	69.4	50.0	38.9	31.7	21.6	19.5	11.2
DA2	78	100.0	100.0	62.0	37.4	18.0	10.6	6.9	6.1	5.4	4.6
DA5	78	100.0	100.0	73.9	56.6	42.1	34.4	30.5	26.6	18.9	9.3
DA6	78	100.0	100.0	90.7	74.3	61.1	36.5	28.3	23.7	18.2	11.2
DA10	78	100.0	100.0	86.3	70.1	41.2	30.1	25.0	20.0	15.4	9.8
DA1	83	100.0	100.0	45.4	29.6	20.3	14.4	11.7	10.3	8.3	5.7
DA2	83	78.4	78.4	55.9	36.7	23.6	18.0	13.6	10.5	7.9	5.5
DA3	83	100.0	100.0	79.8	49.5	25.9	15.4	12.6	11.6	9.7	6.2
DA4	83	100.0	88.3	59.2	37.1	24.9	18.2	14.8	12.9	9.9	7.0
DA5	83	100.0	100.0	73.0	51.9	33.7	22.9	15.9	11.2	6.9	4.5
DA1	84	100.0	89.8	60.2	36.0	22.1	13.0	8.1	6.1	4.5	2.9
DA2	84	100.0	94.1	60.8	26.0	13.0	9.6	8.2	7.4	6.6	5.2
DA3	84	100.0	91.1	73.5	50.5	29.6	18.6	12.2	9.1	6.5	4.0
DA4	84	100.0	69.1	45.5	27.5	17.6	12.0	8.2	6.1	4.4	2.7
DA5	84	100.0	89.1	65.4	43.9	27.2	17.0	10.5	7.1	4.8	3.3
DA1	85	100.0	100.0	84.3	57.7	35.1	23.5	17.6	14.1	10.3	4.1
DA5	85	100.0	100.0	69.4	52.8	37.5	25.9	17.9	12.9	9.3	5.4
DA7	85	100.0	100.0	72.5	54.2	42.3	34.6	28.9	15.3	11.6	7.1
DA11	85	100.0	100.0	78.4	57.3	38.0	25.5	17.6	13.2	9.3	4.9
DA12	85	100.0	100.0	70.0	47.9	27.5	16.4	12.6	10.9	9.0	5.0
DB4	76	100.0	76.1	47.3	24.7	11.1	4.9	2.5	2.1	0.8	0.4
DB7	76	100.0	100.0	72.7	54.9	40.5	28.4	17.4	11.7	7.6	1.9

Appendix III. Continued.

		Sieve mesh size (mm)									
		76.2	50.8	25.4	12.7	6.35	3.36	1.68	0.84	0.42	0.21
Ss	'Yr	Percent Passing									
DB10	76	100.0	90.2	85.7	71.4	56.7	41.1	30.8	23.7	13.4	4.0
DB11	76	100.0	96.1	84.8	65.0	44.7	30.9	21.8	16.0	7.0	0.8
DB14	76	100.0	100.0	100.0	79.4	52.3	36.2	22.5	15.1	6.4	0.9
DB15	76	100.0	92.2	68.3	45.4	27.8	16.6	8.8	5.4	3.9	1.5
DB2	78	100.0	100.0	95.7	81.5	64.2	49.3	40.3	27.6	17.8	8.0
DB3	78	100.0	100.0	86.8	55.9	39.1	29.5	23.6	20.0	14.1	8.2
DB4	78	100.0	100.0	70.3	56.1	36.3	24.7	15.7	12.2	7.9	5.3
DB5	78	100.0	100.0	100.0	94.7	71.9	55.1	42.0	23.0	14.7	8.5
DB7	78	100.0	100.0	50.6	30.2	20.0	16.2	13.5	13.0	12.5	8.2
DB1	83	100.0	100.0	74.9	56.3	37.7	22.6	15.6	13.1	9.3	6.2
DB2	83	100.0	85.0	60.8	43.7	31.3	21.2	14.2	10.3	7.1	4.6
DB3	83	100.0	93.8	77.7	58.5	38.5	25.2	16.2	12.1	8.0	5.1
DB4	83	100.0	100.0	61.8	46.7	32.0	19.3	11.3	8.0	5.6	3.5
DB5	83	100.0	92.7	78.5	58.2	40.2	26.1	15.4	11.7	8.4	7.5
DC1	83	100.0	100.0	69.8	40.1	24.1	18.2	15.5	13.9	7.9	5.2
DC2	83	100.0	100.0	74.9	36.8	19.7	14.3	12.6	11.7	8.1	5.2
DC3	83	100.0	90.5	60.9	45.9	28.1	17.6	12.8	10.4	7.0	4.6
DC4	83	82.5	82.5	55.4	39.2	26.7	17.7	12.2	9.4	5.8	3.7
DC5	83	100.0	100.0	70.2	44.5	21.4	11.4	7.9	6.6	5.2	3.4
DC1	84	100.0	94.5	68.8	38.1	22.3	15.0	12.2	10.6	6.5	3.3
DC2	84	100.0	84.5	63.5	37.2	19.4	11.2	7.7	6.3	4.7	2.9
DC3	84	100.0	100.0	67.3	38.3	20.0	13.0	10.4	9.1	6.5	3.5
DC1	85	100.0	95.3	75.3	49.3	30.9	21.2	17.5	15.6	5.8	3.8
DC3	85	100.0	100.0	69.7	46.8	29.3	20.5	16.2	14.0	9.7	4.8
DC4	85	100.0	100.0	75.8	45.0	29.8	21.6	17.9	16.0	12.8	5.4

Ss - Study section and sample site.
'Yr - Year of sample.

VIII. APPENDIX IV.

Appendix IV. Estimated water yield (dam^3) above critical stream discharge ($0.731\ m^3\ s^1$) and spawning discharge, and estimated fry production for Wampus creek in the Tri-Creeks Experimental Watershed.

		Water yield during incubation cycle (dam^3)	
Year	Fry production (no.'s/0.10 ha)	Above spawning discharge	Above critical discharge ($0.731\ m^3\ s^1$)
1969	52	3961.5	3402.4
1974	934	50.9	0.0
1975	780	287.2	12.9
1976	319	611.4	57.7
1977	680	834.5	229.2
1979	869	250.2	30.4
1980	125	826.0	1848.0
1984	783	640.4	158.3
1985	635	555.5	182.1

IX. APPENDIX V.

Appendix V. Size of streambed material that various velocities of water can transport.

Material (Lehansky's Terms)	Diameter (mm)	Mean velocity (cm/s)
Silt.............	0.005	15
Fine sand........	0.25	30
Medium sand......	0.01	30
Coarse sand......	1.0	55
Fine gravel......	2.5	65
Medium gravel....	5.0	80
Coarse gravel....	10.0	100
Fine pebbles.....	15.0	120
Medium pebbles...	25.0	120
Coarse pebbles...	40.0	180
Large pebbles....	75.0	240
Large pebbles....	100.0	270
Large pebbles....	150.0	330
Boulders.........	200.0	390

(From White and Bayaillian 1967)

X. APPENDIX VI.

Appendix VI. Physical characteristics of artificial substrates prior to placement in spawning riffles in Wampus Creek, 1979.

	Measured		Determined		
Sample No.	Bulk Volume Vb (ml)	Displaced Volume Vs (ml)	Void Volume Vb-Vs (ml)	Void Ratio Vv/Vs	Porosity (e) Vv/Vb
1	900	525	375	0.714	0.417
2	1200	715	485	0.678	0.404
3	1250	740	510	0.689	0.408
4	800	430	370	0.860	0.463
5	1050	600	450	0.750	0.429
6	1900	1085	815	0.751	0.429
7	1900	1160	740	0.638	0.389
8	700	370	330	0.892	0.471
9	1000	580	420	0.724	0.420
10	2500	1535	965	0.629	0.386
11	3450	1950	1500	0.769	0.435
12	2500	1485	1015	0.684	0.406
13	1950	1160	790	0.681	0.405
14	1900	1070	830	0.776	0.437
15	1450	845	605	0.716	0.417
16	1450	790	660	0.835	0.455
17	1550	925	625	0.676	0.403
18	1750	1030	720	0.699	0.411
19	1800	1035	765	0.739	0.425
20	1500	890	610	0.685	0.407
21	2200	1300	900	0.692	0.409
22	2400	1335	1065	0.798	0.444
23	2300	1355	945	0.697	0.411
24	2700	1520	1180	0.776	0.437
25	2900	1730	1170	0.676	0.403
26	3000	1755	1245	0.709	0.415
27	3100	1770	1330	0.751	0.429
28	2600	1580	1020	0.646	0.392
29	600	375	225	0.600	0.375
30	1850	1080	770	0.713	0.416
n	30	30	30	30	30
mean	1872	1091	781	0.722	0.418
SD	750	439	315	0.065	0.022
VAR	562947	192973	98916	0.004	0.000
Sx	136.99	80.20	57.42	0.012	0.004
t	2.045	2.045	2.045	2.045	2.045
CI	280	164	117	0.024	0.008

XI. APPENDIX VII.

Appendix VII.1. Analysis of artificial spawning substrates sampled at mid-incubation in Wampus Creek, 1979

Site	>6.35 Vs (ml)	e (%Vv)	Tot. Sed. Wt. (g)	Percent by Weight			Percent by Void Volume			f	dg
				Grav	Sand	S/C	Grav	Sand	S/C		
WA 2	1250	0.417	3180	0.11	1.12	1.39	0.3	2.7	3.3	5.89	12.0
WA 6	1122	0.417	3292	3.77	5.25	3.47	9.0	12.6	8.3	4.77	10.2
WA 7	1400	0.416	3832	1.10	2.11	1.44	2.6	5.1	3.5	6.06	12.4
WA 8	1119	0.417	2921	0.14	0.83	0.81	0.3	2.0	1.9	6.74	13.5
WA 9	1690	0.416	4435	0.05	0.18	1.00	0.1	0.4	2.4	7.78	14.9
WB 2	1295	0.417	2476	0.85	2.32	2.33	2.0	5.6	5.6	5.64	11.6
WB 3	1763	0.415	4734	0.08	2.93	2.29	0.2	7.0	5.5	6.32	12.5
WB 4	2265	0.415	6096	0.20	3.07	1.61	0.5	7.4	3.9	6.33	12.7
WB 7	2159	0.415	5892	0.22	3.28	1.52	0.5	7.9	3.7	5.44	11.3
WB 9	1675	0.416	4435	0.20	1.01	1.20	0.5	2.4	2.9	6.37	12.9
WC 3	1930	0.415	5812	0.10	8.37	5.19	0.2	20.1	12.5	4.91	9.8
WC 4	1715	0.416	5130	1.79	6.92	4.56	4.3	16.7	11.0	4.02	8.9
WC 7	1890	0.415	4263	2.04	6.27	4.20	4.9	15.1	10.1	4.66	9.9
WD 3	1780	0.415	5141	1.63	4.27	4.22	3.9	10.3	10.2	4.10	8.8
WD 5	1648	0.416	4683	1.55	3.19	3.05	3.7	7.7	7.3	4.99	10.5
WD 6	1355	0.416	4061	1.63	6.74	6.14	3.9	16.2	14.7	4.21	8.9
WD 8	1970	0.415	5754	1.06	4.45	4.47	2.6	10.7	10.8	4.95	10.3
WD 10	2056	0.415	5848	3.23	4.78	4.22	7.8	11.5	10.2	4.28	9.4
WF 1	1535	0.416	4169	0.74	1.82	1.41	1.8	4.4	3.4	5.69	11.7
WF 3	1887	0.415	5366	2.11	4.04	2.31	5.1	9.7	5.6	5.32	11.1
WF 4	1945	0.415	5348	0.60	3.29	2.32	1.4	7.9	5.6	5.57	11.5
WF 8	1751	0.416	3821	1.78	2.86	1.75	4.3	6.9	4.2	5.90	12.1
WF 10	908	0.418	4157	15.20	16.30	10.38	36.4	39.0	24.8	0.96	3.5
WG 2	1675	0.416	4599	0.39	2.57	3.02	0.9	6.2	7.3	5.81	11.8
WG 3	1780	0.415	4905	0.53	2.52	1.80	1.3	6.1	4.3	5.23	10.8
WG 5	1480	0.416	3999	0.30	3.29	2.61	0.7	7.9	6.3	5.53	11.4
WG 6	1510	0.416	4319	1.13	5.12	4.05	2.7	12.3	9.7	5.31	10.8
WG 10	1850	0.415	5353	0.67	3.43	3.26	1.6	8.3	7.8	5.66	11.5

Vs - displaced volume of substrate particles >6.35 mm.
e - porosity as % void volume.
grav - sediment particles 2.00 - 6.35 mm diameter.
sand - sediment particles 0.062 - 2.00 mm diameter.
s/c - sediment particles <0.062 mm diameter.

Appendix VII.2. Analysis of artificial substrates sampled at fry escapement in Wampus Creek, 1979.

				Percent by Weight			Percent by Void Volume				
Site	>6.35 Vs (ml)	e (%Vv)	Tot. Sed. Wt. (g)	Grav	Sand	S/C	Grav	Sand	S/C	f	dg
WA 2	1175	0.417	3267	0.25	2.49	2.27	0.59	5.98	5.43	5.76	11.80
WA 6	669	0.420	1896	0.36	2.58	1.49	0.85	6.14	3.54	5.96	12.20
WA 7	1070	0.417	2923	1.04	2.27	1.63	2.50	5.45	3.91	6.87	13.40
WA 8	960	0.418	2682	4.08	4.42	1.67	9.75	10.57	3.99	5.45	11.50
WA 9	1700	0.416	4087	0.11	0.79	1.40	0.27	1.89	3.37	6.53	13.10
WB 2	1485	0.416	4238	0.40	4.18	2.67	0.96	10.06	6.43	5.18	10.80
WB 3	2080	0.415	5492	0.11	2.67	1.12	0.27	6.43	2.71	6.91	13.60
WB 4	1470	0.416	5594	0.14	3.21	1.54	0.34	7.73	3.70	5.35	11.20
WB 7	1565	0.416	4530	0.36	6.88	2.39	0.87	16.54	5.75	5.06	10.70
WB 9	1535	0.416	4163	0.19	2.57	2.14	0.45	6.19	5.14	6.01	12.20
WC 3	2000	0.415	5581	1.30	5.10	2.75	3.13	12.30	6.62	4.38	9.32
WC 4	1665	0.416	4828	2.10	7.11	3.41	5.06	17.11	8.20	4.36	9.52
WC 7	1800	0.415	5068	0.54	5.68	3.23	1.31	13.68	7.77	4.74	10.09
WD 3	1435	0.416	4305	3.00	7.39	4.16	7.21	17.77	10.00	3.87	8.70
WD 5	2045	0.415	5780	1.24	4.30	3.24	2.98	10.35	7.81	4.50	9.60
WD 6	2020	0.415	5657	2.30	4.72	2.75	5.54	11.38	6.63	5.07	10.70
WD 8	2160	0.415	6336	1.84	6.42	4.57	4.44	15.47	11.02	3.78	8.40
WD 10	1880	0.415	5561	2.77	9.10	4.94	6.68	21.91	11.90	3.79	8.40
WE 1	2340	0.415	6243	0.25	1.04	1.39	0.59	2.50	3.34	7.04	13.80
WE 7	2360	0.415	6249	0.84	1.89	1.89	2.03	4.56	4.56	6.33	12.70
WE 8	1760	0.415	4649	0.75	3.89	4.49	1.81	9.36	10.82	4.32	9.20
WE 9	2140	0.415	6100	0.95	6.87	3.51	2.29	16.55	8.45	4.75	10.10
WE 10	1320	0.416	4123	1.24	10.54	6.85	2.97	25.30	16.45	3.52	7.70
WF 1	1840	0.415	4992	1.41	3.98	2.26	3.39	9.59	5.44	6.03	12.00
WF 3	1740	0.416	4935	1.24	5.85	3.84	2.99	14.08	9.24	4.31	9.30
WF 4	1440	0.416	4066	2.34	5.77	2.50	5.61	13.87	6.00	4.44	9.60
WF 8	1810	0.415	4694	0.68	1.91	1.11	1.63	4.59	2.68	7.20	14.00
WF 10	1340	0.416	3830	3.16	6.09	2.73	7.59	14.61	6.56	4.52	9.90
WG 2	1930	0.415	5216	0.74	3.39	3.32	1.77	8.17	7.98	4.99	10.50
WG 3	1460	0.416	4002	1.07	4.26	2.61	2.57	10.24	6.28	4.78	10.20
WG 5	1580	0.416	4643	6.88	3.21	3.68	16.54	7.73	8.86	3.92	8.70
WG 6	1170	0.417	3322	0.72	4.24	3.79	1.72	10.17	9.09	4.49	9.60
WG 10	1680	0.416	4697	0.34	5.42	3.16	0.81	13.05	7.59	4.95	10.40