Effects on Arctic Grayling *(Thymallus arcticus)* of Prolonged Exposure to Yukon Placer Mining Sediment: A Laboratory Study

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Yukon River Basin Study
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EFFECTS ON ARCTIC GRAYLING (*Thymallus arcticus*) OF PROLONGED EXPOSURE TO YUKON PLACER MINING SEDIMENT: A LABORATORY STUDY

by

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PREFACE

This study, along with other work on short-term exposures of Arctic grayling, including studies of fish food habits and distribution, was carried out to provide some initial information on the effects of placer mining sediments on this species of fish. While this work indicates the nature of certain physiological and behavioural responses of Arctic grayling to suspended sediment, it is recognized that a longer term programme of more comprehensive studies on the effects of sediments on various stages in the life cycle of grayling and their habitat are desirable.

Although we would urge caution in the interpretation and application of this first stage of research, it is hoped that the present findings together with those from our previous investigations with Arctic grayling, will provide information necessary for the sensitive and well-informed management of aquatic resources.

The Yukon River Basin Study (a joint study by Canada, Yukon, and British Columbia of the waters and related resources of the Yukon Basin) and the Department of Fisheries and Oceans Canada (Field Services Branch and Fisheries Research Branch) funded this project. Statements made are those of the authors and not necessarily those of the Yukon River Basin Committee nor Parties to the Basin Agreement. The work was a co-operative undertaking by D. McLeay & Associates Ltd. and staff of the Department of Fisheries and Oceans.

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ABSTRACT

McLeay, D. J., G. L. Ennis, I. K. Birtwell, and G. F. Hartman. 1984. Effects on Arctic grayling (Thymallus arcticus) of prolonged exposure to Yukon placer mining sediment: a laboratory study. Can. Tech. Rep. Fish. Aquat. Sci. 1241: 96 p.

The effects on underyearling Arctic grayling (Thymallus arcticus) of a 6-week exposure to differing strengths of suspended placer mining sediment was examined under controlled laboratory conditions during the summer of 1983. Groups of sixty grayling captured from a Yukon River tributary stream were transferred to eight test streams and acclimated to laboratory feed and water quality conditions. Thereafter, sediment collected from the downstream end of a Yukon placer mine settling pond was introduced continuously to six streams at a controlled rate in order to expose fish to suspended sediment concentrations of 100, 300 or 1000 $mg \cdot L^{-1}$ (two streams per treatment). Two control streams continued to receive clear (nonfiltrable residue $< 5 mg \cdot L^{-1}$) freshwater. Fish in each stream were fed a measured ration (7% wt · day^{-1}) of Biodiet, 4-5 times daily, together with supplemental feeding of live zooplankton (Daphnia pulex). Water quality conditions for each stream, including temperature ($15 \pm 1^{o}C$), pH (6.6 ± 0.1), conductivity (30 ± 5 $umho \cdot cm^{-1}$), dissolved oxygen (9.4 ± 0.2 $mg \cdot L^{-1}$), nonfiltrable residue and turbidity, were monitored daily.

The survival of fish in each stream throughout the 6-week test period was high (87 - 95%) and unaffected by the sediment suspensions. Fish growth, as monitored by weekly weighings of individual fish, was decreased slightly (6 - 10% relative to control fish) but significantly by 100 and 300 $mg \cdot L^{-1}$, and more markedly impaired (33% relative to controls) by 1000 $mg \cdot L^{-1}$. The linear distribution of grayling in each stream was unaffected by the lowest (100 $mg \cdot L^{-1}$) suspended sediment strength examined; however, the majority of fish held in each stream containing 300 or 1000 $mg \cdot L^{-1}$ sediment were displaced downstream throughout the test period.

Feeding response trials were conducted in each stream using live surface drift (adult fruit flies; Drosophila melanogaster), sub-surface drift (brine shrimp; Artemia salina) and benthic invertebrates (tubificid worms). Times to detect and consume surface drift for naive fish (previously unexposed to sediment) or those held in test streams for 5 weeks increased progressively with increasing sediment strengths. All suspended sediment strengths examined increased the response times relative to those for control fish. For each respective concentration, naive fish were slower to respond to surface drift. The majority of naive fish held in 1000 $mg \cdot L^{-1}$ sediment failed to accept the surface or sub-surface food types offered. Feeding trials conducted with grayling offered brine shrimp or tubifex worms in each test stream after 5 or 6 weeks' sediment exposure indicated that the feeding activity of fish in 1000 $mg \cdot L^{-1}$ suspended sediment was impaired, whereas those reared in 100 or 300 $mg \cdot L^{-1}$ sediment responded to these sub-surface food types as quickly as control fish in clear water.

The colouration of fish exposed to 300 or 1000 $mg \cdot L^{-1}$ suspended sediment was paler than that of controls or those held in 100 $mg \cdot L^{-1}$ sediment for 6 weeks. Otherwise, the appearance of all sediment exposed fish (including gross observations of fish gills) was indistinguishable from that of controls. Biological characteristics determined for fish groups sampled from each stream after 6 weeks' sediment exposure, including condition factor, body moisture content (%), blood hematocrit (%), blood leucocrit (%) and plasma glucose (mg%), were unchanged from control values for all sediment strengths examined.

The performance of fish groups sampled from each laboratory stream upon completion of the 6-week exposure was examined using standardized acute lethal tolerance tests with the reference toxicant pentachlorophenol, sealed jar bioassays (tolerance to hypoxia), and tests for upper lethal temperature tolerance. Both groups of fish chronically exposed to the two higher suspended sediment strengths examined (300 or 1000 $mg \cdot L^{-1}$) showed a decreased tolerance to this reference toxicant, and decreased times to death (increased oxygen uptake rates) in sealed jar bioassays. The ability of fish to withstand hypoxia or upper lethal temperature extremes was unaffected by the prolonged sediment exposures.

It was concluded that, whereas chronic exposure of Arctic grayling to suspended sediment concentrations ≤ 1000 $mg \cdot L^{-1}$ may not cause direct mortalities of fish or impair their respiratory capabilities, suspended sediment strengths above 100 $mg \cdot L^{-1}$ causes a number of serious sublethal effects including impaired feeding ability, reduced growth rates, downstream displacement, decreased scope for activity and decreased resistance to other environmental stressors. The environmental relevance of these findings is discussed.

RÉSUMÉ

McLeay, D. J., G. L. Ennis, I. K. Birtwell, and G. F. Hartman. 1984. Effects on Arctic grayling (Thymallus arcticus) of prolonged exposure to Yukon placer mining sediment: a laboratory study. Can. Tech. Rep. Fish. Aquat. Sci. 1241: 96 p.

Les auteurs ont étudié l'incidence de différentes concentrations de sédiments en suspension provenant d'une exploitation minière alluviale sur des ombres arctiques (Thymallus arcticus) de moins d'un an. L'exposition a duré six semaines sous des conditions contrôlées en laboratoire pendant l'été de 1983. Des groupes de 60 ombres capturés dans un tributaire du fleuve Yukon ont été transférés dans huit cours d'eau expérimentaux et acclimatés à la nourriture de laboratoire et à la qualité de l'eau. Des sédiments recueillis à la sortie d'un bassin de sédimentation d'une exploitation alluviale du Yukon ont été introduits continuellement dans six cours d'eau, à un taux contrôlé, de façon à exposer les poissons à des concentrations de sédiments en suspension de 100, 300 et 1000 mg.L^{-1} (deux cours d'eau par traitement). Les deux autres cours d'eau ont continué de recevoir de l'eau douce claire (résidu non filtrable 5 mg.L^{-1}). Tous les poissons ont été nourris de rations quantifiées (7% poids. jour $^{-1}$) de Biodiet quatre à cinq fois par jour, en plus de zooplancton (Daphnia pulex) vivant. Tous les jours, on a surveillé les facteurs qualitatifs de l'eau y compris la température (15 ± 1°C), le pH (6,6 ± 0,1), la conductivité (30 ± 5 umho.cm^{-1}), l'oxygène dissous (9,4 ± 0,2 mg.L^{-1}), les résidus non filtrables et la turbidité.

La survie des poissons dans tous les cours d'eau a été élevée (87-95%) pendant toute la période de six semaines et n'a pas souffert des sédiments en suspension. La croissance, contrôlée par la pesée hebdomadaire de chaque poisson, a baissé un peu (de 6 à 10% par rapport aux poissons témoins) mais de façon significative, aux concentrations 100 et 300 mg.L^{-1}, et elle a nettement diminué (33% par rapport aux poissons témoins) à 1000 mg.L^{-1}. La répartition linéaire des ombres dans chaque cours d'eau n'a pas été altérée par la plus faible concentration de sédiments en suspension (100 mg.L^{-1}); toutefois, la plupart des poissons peuplant les cours d'eau contenant 300 et 1000 mg.L^{-1} de sédiments se sont dirigés vers l'aval pendant toute la période d'expérience.

Des essais sur la réaction à la présence d'aliments ont été menés dans chaque cours d'eau à l'aide d'organismes vivants flottant à la surface (drosophiles adultes, Drosophila melanogaster) et sous la surface (artémias, Artemia salina) ainsi que d'invertébrés benthiques (Tubificidés). Le temps de détection et de consommation des proies de surface par les poissons à l'état naïf (encore jamais exposés aux sédiments) et par ceux gardés dans les cours d'eau expérimentaux pendant cinq semaines a augmenté progressivement en fonction des concentrations de sédiments. Toutes les concentrations étudiées

ont entraîné une augmentation des temps de réaction par rapport à ceux des poissons témoins. À chaque concentration, les spécimens à l'état naïf étaient plus lents à réagir aux proies de surface. La plupart de ces poissons gardés à une concentration de 1000 $mg.L^{-1}$ n'ont pas mangé les proies flottant à la surface ou sous la surface. Les essais d'alimentation à l'aide d'artémias ou de tubifex, menés dans les cours d'eau expérimentaux après cinq ou six semaines d'exposition à des sédiments, portent à croire que l'alimentation des poissons gardés à une concentration de 1000 $mg.L^{-1}$ de sédiments en suspension était altérée tandis que ceux maintenues à des concentrations de 100 ou 300 $mg.L^{-1}$ réagissaient aux proies présentes sous la surface aussi vite que les poissons témoins gardés en eau claire.

Les poissons exposés à des concentrations de 100 et de 300 $mg.L^{-1}$ de sédiments en suspension étaient plus pâles que les témoins ou les poissons gardés à une concentration de 100 $mg.L^{-1}$ pendant six semaines. Pour le reste, toutefois, l'apparence de tous les poissons exposés à des sédiments (y compris l'observation superficielle des branchies) n'était pas différente de celle des témoins. Les caractères biologiques (facteur de condition, teneur en eau (%), hématocrite sanguin (%), leucocrite sanguin (%) et glucose plasmatique (mg%)) déterminés chez des groupes de poisson échantillonnés dans chaque cours d'eau après six semaines d'exposition à des sédiments étainent semblables aux valeurs témoins à toutes les concentrations de sédiments étudiées.

On a évalué la performance des groupes de poisson échantillonnés dans chaque cours d'eau expérimental après une exposition de six semaines, à l'aide de tests de la tolérance létale aigüe avec le toxique étalon pentachlorophénol, de dosages biologiques en milieu fermé (tolérance à l'hypoxie) et de tests de tolérance de la température létale supérieure. Les deux groupes de poisson exposés chroniquement aux deux plus hautes concentrations de sédiments en suspension (300 et 1000 $mg.L^{-1}$) ont accusé une tolérance moindre à ce toxique étalon et des temps inférieurs de mortalité (absorption accrue de l'oxygène) au cours des tests en milieu fermé. La capacité de résistance des poissons à l'hypoxie ou aux extrêmes de températures létales supérieures n'était pas affectée par l'exposition prolongée à des sédiments.

Selon les auteurs, même si l'exposition chronique de l'ombre arctique à des concentrations de sédiments en suspension inférieures ou égales à 1000 $mg.L^{-1}$ ne cause pas la mortalité directe des poissons ou n'amoindrit pas leurs capacités respiratoires, des concentrations supérieures à 100 $mg.L^{-1}$ entraînent certains effets sublétaux importants y compris une capacité d'alimentation réduite, des taux de croissance inférieurs, un déplacement en aval, une capacité diminuée d'activité et une résistance moindre aux stress environnementaux. Les auteurs parlent aussi de l'importance environnementale de ces découvertes.

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INTRODUCTION

Recent field and laboratory studies conducted with underyearling Arctic grayling (Thymallus arcticus) demonstrated that brief (≤ 4 days) exposure to elevated levels of suspended placer mining sediment, while not lethal, caused a number of sublethal effects including acute stress responses (McLeay et al. 1983). Additionally, reports from a number of field surveys within Yukon documented a reduction in numbers of Arctic grayling and other fish species for receiving waters downstream of placer mining activities (Mathers et al. 1981; Ennis et al. 1983; Birtwell et al. 1984). These findings suggest an impact of placer mining sediment suspensions on the fisheries resource; however the nature and extent of effects of sediment strength and duration of exposure are not clearly understood at this time.

The present investigation was undertaken to gain some understanding concerning the effects on Arctic grayling caused by prolonged exposure to Yukon placer mining sediment. Although information is limited, reduced survival or impaired growth of salmonid fish species have been reported caused by their extended exposure to suspended sediment fines as low as 300 $mg \cdot L^{-1}$ (Herbert and Merkens 1961; Sigler 1981). The effects of prolonged sediment exposure on fish performance, biochemical indices of fish condition, or behavioural responses have not been reported. However, the need for further knowledge regarding these and other possible effects caused by chronic exposure of fish to elevated levels of suspended sediment has been recently delineated (Noggle 1978; Anon. 1983).

The strengths of suspended placer mining sediment selected for the present laboratory study (0, 100, 300 and 1000 $mg \cdot L^{-1}$ nonfiltrable residue) were chosen based on a number of considerations. Since the level of suspended sediment in certain placer-mined Yukon streams frequently remains elevated during summer months to values ≥ 1000 $mg \cdot L^{-1}$ (Mathers et al. 1981), the impact of this elevation on the wellbeing of resident grayling fry or fingerlings rearing in these waters is of concern. Although the adverse effects towards grayling caused by chronic exposure to suspended sediment are unknown, suspended sediment strengths ≥ 300 $mg \cdot L^{-1}$ have been reported to cause significant mortalities of salmonid fish if exposures are prolonged (Herbert and Merkens 1961), and strengths ≥ 100 $mg \cdot L^{-1}$ can cause reduced feeding activity and lower fish condition factors (Noggle 1978; Scullion and Edwards 1980). Following a review of (then) current literature, the European Inland Fisheries Advisory Commission (Anon. 1965) concluded "waters normally containing from 80 to 400 ppm ($mg \cdot L^{-1}$) suspended solids are unlikely to support good freshwater fisheries", and "at best, only poor fisheries are likely to be found in waters which normally contain more than 400 $mg \cdot L^{-1}$ suspended solids." Discharge standards of 100 or 1000 $mg \cdot L^{-1}$ (depending on stream classification) have been recently proposed for Yukon placer mining operations (Anon. 1983).

The study described in this report was designed to determine the effects of three replicate strengths of suspended placer mining sediment on the feeding behaviour, growth, biological condition and performance capabilities of underyearling Arctic grayling held in artificial streams under controlled environmental conditions. Variables measured to assess fish condition and performance were based on those shown to be useful in previous assessments of fish exposed to suspended sediment or other environmental stressors (Noggle 1978; Wedemeyer and McLeay 1981; McLeay et al. 1983; Wedemeyer et al. 1983).

MATERIALS AND METHODS

TEST FISH

Fish collection

A population of approximately 3000 young-of-the-year Arctic grayling were collected by pole seine from a Yukon River tributary stream (Nares Creek; near Carcross, Yukon Territory) during June 1983. These fish, captured by pole seining, measured 2 - 4 cm fork length. Creekwater temperature at the time of collection varied from 15 to 21°C.

Upon capture, fish were placed in plastic "laundry" baskets lined with fibreglass mesh screen, covered with plastic sheeting and held in Nares Creek for up to 48 h until sufficient numbers were collected for shipment. At this time, groups of 200 - 250 individuals were placed in separate plastic bags (creekwater with an oxygen atmosphere), packed with ice and shipped by air to Vancouver in twelve "Coleman" coolers.

Fish rearing

Grayling were transferred to the fish-culturing facilities at B.C. Research (Vancouver) upon receipt, and placed in an outdoor fibreglass hatchery trough. Water supply to this rearing trough was Vancouver City dechlorinated tap water. The water exchange rate was ≥ 5 $L \cdot g^{-1}$ fish per day and fish-loading density did not exceed 1.5 $g \cdot L^{-1}$ (Sprague 1973) throughout the period that grayling were reared in this trough.

Fish were fed an excess ration of Biodiet No.1 (≤ 0.6 mm crumble size; Bioproducts Inc., Warrenton, Oregon) 8 - 10 times daily, according to accepted hatchery practice (Leitritz and Lewis 1976). This diet was supplemented with daily feedings of live daphnia (Daphnia pulex) and weekly feedings of live brineshrimp (Artemia salina).

Daphnia were reared outdoors in two shallow (15 cm) circular (100 cm dia) plastic pools. Water supply for culturing daphnia was local mountain creekwater, transported in 20-L plastic jerricans. The initial brood stock of daphnia was obtained from the B.C. Ministry of Environment water quality laboratory. Daphnia were fed twice-weekly rations of finely homogenized fresh spinach. Water was aerated continuously and was renewed infrequently. The brineshrimp used for rearing fish and for feeding behavioural trials with test fish was purchased as required from a local distributor.

The fish trough was siphoned daily to remove excess food and faeces. Dead or injured fish were removed upon observation. All fish selected for prolonged exposure to sediment were acclimated to these conditions for 3 weeks prior to their transfer to the test streams.

TEST SEDIMENT

Sediment collection

A 275-kg sample of dry sediment was collected by Indian and Northern Affairs Canada personnel from a Yukon (Highet Creek) placer mine settling pond in June 1983. This sample was taken from a surficial 5-cm layer of sediment within the downstream end of a dewatered settling pond. Preliminary screening of pond sediment with a 50 um mesh screen was undertaken to select the section of the pond containing the largest percentage of fines.

The sediment was placed in ten (new) 25-L plastic pails with snap-on lids. This sample was shipped to Vancouver, whereupon it was mixed throughly and returned to the pails for storage (18 - 20°C) until required for testing.

Sediment preparation and analyses

Preliminary examination of the sample of settling pond sediment re-dispersed in freshwater indicated rapid re-settling of sediment particles. Initial trials with this sample stirred in water within the test apparatus used for the present study confirmed that sample suspensions with nonfiltrable residue (NFR) values of 100 - 1000 $mg{\cdot}L^{-1}$ could not be achieved without reduction of particle size. Accordingly, all portions of the sediment sample used in the bioassays were pulverized prior to fish exposure. Quantities of sediment required daily for the 6-week exposure study were oven-dried (50°C) to constant weight, and measured amounts (200 ml $\simeq$250 g) ring-pulverized according to a procedure used previously for acute exposure studies with grayling and inorganic placer mining sediment (McLeay et al. 1983).

A 250-g portion of untreated sediment and two 250-g portions of prepared (pulverized) sediment taken from separate plastic pails were analysed for particle size distribution. Each sample was wet-sieved, oven-dried (50°C) and mechanically agitated for 10 min through a standard series of Tyler sieves. The percentage weight of sediment retained on each sieve was calculated (Anon. 1972).

Two sub-samples of prepared sediment were analysed for each of the following characteristics: oxygen uptake rate, % volatile residue, % fixed residue, and concentration of inorganic constituents. The oxygen uptake rate of this sediment at 15°C was determined according to a procedure used previously with placer mining sediment (McLeay et al. 1983). Percentage volatile and fixed residue were determined according to Standard Methods (Anon. 1979, 1980). Major and trace inorganic constituents of the sediment were determined by plasma spectrographic analysis following sample digestion (Anon. 1979).

EXPERIMENTAL

Test apparatus

The experimental set-up used for this study is illustrated in Figure 1. Basic apparatus consisted of eight test streams, situated side-by-side and constructed of 6-mm plexiglass sheeting. Each stream measured 210 X 13 X 20 cm and was fitted with a removable screen partition at the mid- and down-stream positions (at 100 and 200 cm from the head end), a vertical overflow stand-pipe at the downstream end and horizontal inflow/outflow plastic pipes at each end. The water (or test suspension of sediment) in each stream was pumped (Cole-Parmer impeller driven pumps) at 10 $L \cdot min^{-1}$ through 2-cm ID plastic tubing. This flow rate maintained an upstream riffle of fast moving water within the first third of the test stream, and a downstream pool of slower-moving water within the latter stream portion. Oil-free compressed air was introduced continuously to the head- and mid-stream positions of each stream at a controlled rate. An emergency oxygen supply (compressed O_2 cylinder and regulator with normally closed solenoid valve) was plumbed into the air supply line to ensure against the event of a power failure.

Four 220-L capacity rigid polyethylene barrels were used as reservoirs for the sediment suspensions. The sediment strength prepared daily (using clear freshwater) in each of three barrels was stirred constantly (Greey Lightnin motor at 1700 rpm with a stainless steel shaft and 8-cm dia impeller). One barrel contained clear freshwater only (water for control streams). Throughout the 6-week period of sediment exposure, the contents of each barrel were pumped continuously (Cole-Parmer Masterflex peristaltic pumps) to each of two streams at a controlled rate of 70 $ml \cdot min^{-1} \cdot stream^{-1}$. This rate provided a 95% molecular exchange of each test suspension (and of control water) within each stream every 24 h (Sprague 1973).

All barrels, pumps, and streams were housed within a temperature-controlled room, regulated to provide a test temperature within each stream of 15 ± 1°C. Each stream was covered with fibreglass mesh screening to prevent fish escapements. The test apparatus was designed and positioned within the room to permit easy access to both ends of each stream for feeding, cleaning, and fish feeding behavioural trials.

Lighting to each test stream was provided by four 40-W broad-spectrum "Vitalite" fluorescent tubes, equally spaced across the streams. These lights were regulated by timer to maintain a day/night sequence of 18-h L: 6-h D. Additionally, overhead incandescent 40-W bulbs, regulated by timer and 30-min automated rheostat control, were synchronized with the fluorescent lights in order to provide a 30-min period of variable light intensity at each dawn and dusk. The intensity of light at the surface of each test stream during daylight hours was 100 ± 5 foot-candles (1076 ± 54 lux).

Treatment of fish

Following a 3-week period for the acclimation of grayling to laboratory conditions of water and feed, 480 fish selected from the rearing trough for similar size (mean weight for individuals, 0.4 g) were placed by random selection into the eight test streams, 60 per stream. Wet weight of each fish was recorded. Each stream contained clear (nonfiltrable residue <5 $mg \cdot L^{-1}$) freshwater only. This water (Vancouver City dechlorinated tap water at 15 ± 1°C) was renewed continuously by the inflow of fresh water to each stream at a rate $\geq$230 $ml \cdot min^{-1}$ (Appendix 1), providing a 95% exchange every 9 h or less (Sprague 1973).

Fish in each stream were fed a pre-weighed ration of Biodiet 4 - 5 times daily during an initial 7-day acclimation period in freshwater and throughout the 6-week sediment exposure period thereafter. The (excess) ration provided was approximately 7% wet body weight per day (based on the mean weight of fish in each test stream as derived from weekly weighings of individual fish), according to the dry food ration recommended for young salmonid fingerlings (Leitritz and Lewis 1976). This ration was initially Biodiet No. 1 ($<$0.6 mm crumble size) only, but was changed to a 50:50 mixture of Biodiet Nos. 1 and 2 (0.6 - 0.8 mm) after 3 weeks and to Biodiet No. 2 only after 6 weeks. Additionally, fish were fed live daphnia twice daily. The daphnia were concentrated in glass beakers and (approximately) equal quantities dispensed to each stream by pipeting. This supplemental ration of live food comprised less than 10% (dry weight basis) of the total daily food offerings. All food offered (commercial and live) was dispersed evenly along the length of the stream.

Excess food and faeces in each stream were removed daily by siphoning, and screens cleaned. Any dead fish noted at this time were removed, weighed, and examined.

Following a 7-day period for fish to acclimate to these streams, the freshwater supply to each stream was discontinued and individual fish were re-weighed. Pre-determined strengths of sediment suspensions were then metered continuously from the reservoirs into the test streams throughout the subsequent 6-week test period. The nominal strength of suspended placer mining sediment in each stream to which grayling were exposed, as assigned by random choice, was as follows:

Stream nos. 4 and 8:	0 $mg \cdot L^{-1}$ NFR (control streams);
Stream nos. 2 and 5:	100 $mg \cdot L^{-1}$ NFR;
Stream nos. 3 and 6:	300 $mg \cdot L^{-1}$ NFR; and
Stream nos. 1 and 7:	1000 $mg \cdot L^{-1}$ NFR

Test strengths of sediment

Prior to transferring fish to the test streams, a preliminary study was conducted using the test apparatus to ascertain the strengths of sediment required for addition to each barrel in order to achieve the desired suspended sediment strengths (0, 100, 300, or 1000 $mg \cdot L^{-1}$ NFR) within each stream. Pre-weighed strengths of pulverized placer mining sediment ranging from 300 to 5000 $mg \cdot L^{-1}$ were made up in each barrel (220-L volumes) using clear (NFR <5 $mg \cdot L^{-1}$) Vancouver City dechlorinated tap water at 15°C. Each suspension was pumped into a separate test stream at the desired flow rate (70 $ml \cdot min^{-1}$), and samples taken from the head- (upstream) and mid-stream positions of the stream for nonfiltrable residue (NFR) analyses after 22 h of dispensing.

Based on the results of this study, it was calculated that quantities of sediment required daily for preparing each 220-L volume were 120 g (100 $mg \cdot L^{-1}$ NFR in streams 2 and 5), 350 g (300 $mg \cdot L^{-1}$ NFR in streams 3 and 6), and 1140 g (1000 $mg \cdot L^{-1}$ NFR in streams 1 and 7). These quantities were used initially during the definitive study. However, based on nonfiltrable residue values determined for stream samples collected daily during the test period, sediment quantities added to each barrel were increased by 20% after 2 weeks' exposure. This quantity was again modified slightly at 4 weeks (10% reduction). Vancouver City dechlorinated tap water at 15$\pm$ 1°C was used daily for preparing each test suspension (and as control water).

Water quality monitoring

The freshwater supply used for rearing grayling and as the diluent/control water was analysed weekly throughout the duration of the study. Water quality characteristics determined (Anon. 1980) for each sample were as follows: pH, temperature (°C), dissolved oxygen (mg $O_2 \cdot L^{-1}$), conductance (umho$\cdot cm^{-1}$), alkalinity (mg $CaCO_3 \cdot L^{-1}$), EDTA hardness (mg $CaCO_3 \cdot L^{-1}$), and nonfiltrable residue (mg$\cdot L^{-1}$).

The water quality in each test stream was monitored daily throughout the 7-day acclimation period and the subsequent 6-week exposure period. The following variables were measured mid-stream (mid-depth, mid-length): temperature (°C), dissolved oxygen (mg $O_2 \cdot L^{-1}$), pH, conductance (umho$\cdot cm^{-1}$), nonfiltrable residue (mg$\cdot L^{-1}$) and turbidity (formazin turbidity units; FTU). Temperature was measured by thermometer to the nearest 0.1°C. Dissolved oxygen was determined using a portable oxygen meter (Delta Scientific Model No. 1010). Stream pH was measured using a portable pH meter (Metrohm Herisan Model No. E488). Water samples were collected daily from each stream by siphoning from the mid-stream position into clean plastic bottles. These samples were analysed subsequently for conductance, nonfiltrable residue and turbidity, using standardized methodologies (Anon. 1979, 1980). Samples with low turbidity values (< 25 FTU) were analysed for turbidity using a Hach Model 2100A turbidity meter; whereas those with higher values were determined using a Jackson Turbidimeter (APHA, U.S. Geological Survey).

The rate of inflow of each test suspension (or control water) to each stream was measured (stopwatch, graduate cylinder) and recorded daily. Minor adjustments to pumping rates were made as required.

On one occasion (13/08/83), water samples were taken concurrently from three positions (upstream, mid- and downstream) within each test stream. Each sample, collected by siphoning at mid-depth, was analysed for nonfiltrable residue content in order to ascertain the consistency of suspended sediment strengths along the length of each stream.

Fish growth

The growth of grayling in each test stream was monitored weekly throughout the study. At 7-day intervals following their transfer to streams, all fish in each stream were netted and placed in separate 44-L clean glass aquaria. Each aquarium contained the water or sediment suspension strength to which fish were exposed in test streams. The dissolved oxygen content of each aquarium water supply was maintained at >9 mg $O_2 \cdot L^{-1}$ by continuous aeration. Individual fish in the aquarium were netted and placed on a top-pan balance (Oertling Model No. HC22) into a beaker of test water (weight tared to zero). The weight of each fish was recorded to the nearest 0.01 g. Care was taken during each weighing to prevent excess carry-over of water.

Each group of fish from each stream was weighed and returned to the stream within a 60-min period. During this time, each stream was cleaned thoroughly and refilled with the test suspension/control water. Any dead or missing (based on the previous week's count) fish were noted for each group, and weekly mortalities recorded.

After 3 weeks' sediment exposure, ten fish were sampled randomly from each stream for assessment of their tolerance to the reference toxicant pentachlorophenol. The wet weight (g) and fork length (cm) of each of these fish were measured upon termination of the bioassay. Lengths and weights of each grayling surviving exposure to differing strengths of placer mining sediment for 6 weeks were also determined following the completion at this time of each evaluation of fish condition/performance.

Fish behaviour

Due to the opacity of sediment suspensions, observations of fish in test streams were restricted to fish movements (surfacing, response time) discerned during routine feeding. The position of fish in each stream could also be observed at this time.

On two occasions (after 4 and 5 weeks' sediment exposure), each stream was partitioned with screens into four equal lengths, just prior to the removal of fish for weight determinations. The number of fish occupying each stream portion was determined in order to gain some information concerning their distribution.

The effect of suspended sediment strength on feeding response times to live food organisms for grayling held in each test stream for 5 or 6 weeks was ascertained. Separate feeding response trials were conducted using surface drift food organisms (fruit flies; Drosophila melanogaster), sub-surface drift (brine shrimp; Artemia salina), or benthic food organisms (tubificid worms).

Live adult fruit flies were obtained from the Department of Zoology (Genetics Laboratory), University of British Columbia for the feeding response trials with surface drift. For each trial, all fish in each test stream were moved to the upstream half, and a screen partition inserted to prevent their downstream movement. Three fish in each stream were netted randomly and placed in the downstream half. Following a 60-min period for these fish to adjust to this transfer, the three fish were herded slowly to the most downstream 10-cm section of the stream using a second soft-mesh screen. A fruit fly was placed on the stream surface at a point 60 cm upstream of these fish, and the second screen removed (time 0). Time (seconds) for fish to consume the fly was measured (stopwatch) and recorded. Each test was terminated at 360 seconds (6 min) if flies were uneaten.

This procedure was replicated 5 - 9 times (depending on trial) using each group of three fish. Three separate trials with surface drift were conducted, using different groups of three fish selected from and tested in each stream for each trial.

Following these feeding response trials with grayling exposed to suspended sediment for 5 weeks, two trials (5 - 7 replicates per trial) were undertaken in each test stream using naive grayling (those previously unexposed to suspended placer mining sediment). All test fish in each stream were moved to the upstream half, and retained by screen partition. Naive fish were netted from the outdoor rearing trough and placed in the downstream half of each test stream, three fish per stream. Fish were given a 60-min period to adjust to this transfer. Thereafter, these fish were moved slowly to the most downstream 10-cm portion of the stream, and their feeding response to live fruit flies determined as before.

Feeding response trials with grayling and live sub-surface drift (brine shrimp) or benthic invertebrates (tubifex worms) were performed in test streams using submersible baskets. Each basket, measuring 60 X 15 X 15 cm, was constructed of white soft-mesh nylon cloth supported by a rigid framework (4 mm stainless steel wire). Baskets were designed to permit observation of the number of sub-surface food organisms consumed in test streams at fixed time intervals.

The tubifex worms used in feeding trials were obtained locally from a retail store. For each trial, all fish in each test stream were moved to the upstream half and screen partitions inserted. Ten worms were distributed randomly along the length of the bottom of a basket, and the basket submersed in the downstream portion of a test stream. Three grayling, selected randomly from the group held upstream, were netted and placed in the basket. The bottom of each basket was raised to just below the stream's surface at fixed time intervals of 1, 3, 5, 10, 15, 30, 45, and 60 min and the number of uneaten worms counted. Each observation was performed quickly (5 - 7 sec) and care was taken to ensure that fish were not struggling out of water at these times. For each test stream, three feeding trials with worms were conducted in this manner, using different groups of three fish for each trial. Additionally, one feeding trial with tubifex worms was carried out in each stream using naive fish selected from the outdoor rearing tank. These fish were transferred to the downstream half of each stream (3 fish per stream) and held for 1 h prior to placing them in baskets. The procedure for testing the feeding response of naive grayling with tubifex worms was identical to that used for fish held in the test streams for 5 weeks.

Three feeding response trials with live brine shrimp and stream grayling were conducted in each stream after 6 weeks' exposure of test fish to sediment suspensions. For each test, ten brine shrimp were placed randomly in each stream basket, and three fish introduced. Test procedures for conducting these trials were identical to those described for the tests with worms. The feeding response of naive grayling in test streams was not examined using brine shrimp.

Fish condition

Following 6 weeks' exposure to sediment suspensions, ten grayling were sampled from each test stream for assessment of fish condition. Individual fish were netted, damp-dried, and measured for length (cm) and wet weight (g). The caudal peduncle was severed and blood collected in a narrow-bore (0.5 mm ID) heparinized microhematocrit tube (Sherwood Industries Ltd., St. Louis). Fish carcasses were weighed (wet weight) and transferred to a 105°C oven until dried to constant weight. Body moisture content was determined thereafter. Autopsies of each group of ten fish were completed within 30 min.

All blood samples were centrifuged (12500 rpm; 3 min) upon collection. Hematocrit and leucocrit values were measured according to procedures described previously (McLeay and Gordon 1977; McLeay et al. 1983). Plasma portions remaining following centrifugation were stored (-20°C) until analysed for glucose content (Beckman Glucose Analyser 2).

The condition factor of each fish was calculated (based on fish fork length and wet weight). Fish condition factors were also determined for all fish sampled from test streams for assessments of fish performance after 3 and 6 weeks' exposure to placer mining sediment.

Fish performance

The acute lethal tolerance of test fish to the reference toxicant pentachlorophenol (Davis and Hoos 1975; McLeay et al. 1983) was determined following their exposure to sediment suspensions for 3 or 6 weeks. These bioassays were conducted using eight 50-L capacity plexiglass aquaria. At the time of each bioassay, identical volumes (25 L at 3 weeks, 40 L at 6 weeks) of a 150 $ug \cdot L^{-1}$ solution of pentachlorophenol dissolved in clear freshwater (15°C dechlorinated tap water; NFR < 5 $mg \cdot L^{-1}$) were prepared (Alderdice 1963; McLeay et al. 1983) and added to each aquarium. Ten fish, selected randomly from each test stream, were placed in each aquarium. The time to death of each fish was measured and recorded. Upon death, each fish was removed from the aquarium and its length and weight determined.

The effect of exposure of grayling to sediment suspensions for 6 weeks on fish respiration was assessed by sealed jar bioassay. Test procedures (McLeay 1976; Gordon and McLeay 1977) were those used for evaluating the respiratory responses of naive (previously unexposed) grayling to placer mining sediment (McLeay et al. 1983). Following the 6-week exposure period, 6-L volumes of test suspensions (or control water) from each of the eight test streams were heated to 20°C (test temperature) and aerated vigorously for 30 min to ensure oxygen saturation. Dissolved oxygen values were measured and each suspension transferred to ten 140-ml clean glass jars. Ten test fish, selected from each stream for similar size ($\sim$1.3 g) were placed in these jars, one fish per jar. Each jar was then filled with the appropriate test suspension and sealed (plastic lid) to exclude air. Upon the death of each fish, time to death, water temperature, and fish length and weight were recorded. The residual dissolved oxygen level in each suspension was measured using a portable oxygen meter (Delta Scientific Model 1010) with mechanical agitator.

The effect of prolonged (6-week) exposure of grayling to suspended sediment on their upper lethal temperature tolerance was evaluated by critical thermal maxima bioassays (McLeay and Howard 1977; McLeay and Gordon 1980). The apparatus and procedures used for these bioassays were identical to those employed previously with naive grayling and differing strengths of suspended inorganic sediment (McLeay et al. 1983). A 50-L volume of each test suspension or control water was collected (as 4 sub-samples of 13 L each) from each test stream and placed in each of eight rectangular plexiglass tanks. Each suspension (or control water) was recycled from the conical bottom of the tank at 10 $L \cdot min^{-1}$ (McLeay et al. 1983). Each tank was lined with a soft-mesh nylon basket.

All remaining grayling (8 - 17) in each test stream were transferred to the appropriate recycle tank. Water temperature in each tank was initially 15 $\pm$ 0.1^oC. This temperature was increased progressively at a controlled rate of 1$^oC \cdot h^{-1}$ (thermostatically-controlled immersion heaters) until all fish in each tank were dead. Baskets were raised at frequent intervals to permit observation of dying/dead fish. The temperature ($\pm$ 0.1^oC) of each test suspension was recorded at the time of death of each fish. Upon death, each fish was removed for length and weight determinations.

Statistical analyses

The condition factor (K) of test fish after 3 and 6 weeks' exposure to differing sediment strengths was determined as follows: $K = cW \cdot L^{-3}$ where c is a constant (100), W is wet weight (g) and L represents fork length in cm (Carlander 1969). Mean and standard deviation (SD) values for fish length, weight, and condition factor were calculated for each fish group. Mean $\pm$ SD wet weights for all fish in each test stream, as determined weekly throughout the study, were also calculated. Additionally, mean $\pm$ SD values for all other variables determined for groups of grayling during the feeding trials and tests for assessment of fish condition and performance were determined. Mean $\pm$ SD values for each water quality characteristic monitored daily for each stream throughout the 6-week test period were also calculated.

For certain values shown graphically, the 95% confidence interval (CI) for each mean was determined. Mean weekly fish weights for each of the four sediment treatments were calculated together with their 95% confidence intervals after 6 weeks' sediment exposure.

Lethal times to death of 50% (LT50 values) of each group of ten grayling exposed to the reference toxicant pentachlorophenol or examined for performance in sealed jar bioassays were calculated, together with their 95% confidence intervals, by log-probit analyses (Litchfield 1949). Provided that the median reaction times for replicate treatments did not differ significantly (Litchfield 1949), LT50 values for each treatment (n=20) were determined and examined for significance of difference from corresponding values for control fish, according to Litchfield (1949).

Fish weights determined weekly for each test stream were compared at each time interval using a 1-way analysis of variance (ANOVA). Values derived for identical treatments were pooled. For all comparisons where a significant difference in ANOVA was found ($P < 0.05$), Dunnett's test (Zar 1974) was employed to test for significance of each treatment versus the control group. Values derived for residual oxygen levels at death (sealed jar bioassays) and upper lethal temperatures at death (temperature tolerance tests) following a 6-week exposure of grayling to differing sediment strengths were also compared in this manner.

RESULTS

SEDIMENT CHARACTERISTICS AND DISPERSAL

Particle size distributions for the samples of untreated or prepared (pulverized) settling pond sediment analysed for this study are presented in Table 1. Analysis of the untreated test sediment (as sampled from the settling pond) indicated that the majority (62%) of material present was fine to very fine sand (> 45 um), and only 23% of the sample was comprised of silt- or clay-sized sediment fines (<38 um). Unlike this sample, each of the samples of prepared (test) sediment analysed was comprised of 70 - 71% silt or clay material (<38 um) (Table 1). Particle sizes for all but 2 - 3% of each of these samples were <75 um.

Volatile/fixed residue content and oxygen uptake rate (in freshwater at 15°C) for replicate samples of the test sediment are given in Table 2. The values derived for oxygen uptake rate are identical to those found previously for inorganic placer mining sediment (McLeay et al. 1983), and are indicative of an inert sediment with little, if any, oxygen demand. The residue analyses (Table 2) support this observation, inasmuch as only 4 - 5% of the test sediment was comprised of volatile (organic) material.

Results from the plasma scan analysis of two samples of the test sediment for metal content are given in Table 3. As with the other sediment characteristics examined, the concentrations of specific metal constituents in each sample were very similar (i.e. the characteristics analysed for different portions of the test sediment were homogeneous). These values are presented for purposes of sample "fingerprinting" only. Strengths of specific metals dissolved in freshwater suspensions of the test sediment (and conceivably biologically available) were not analysed in this study.

The relationship of sediment strengths in the barrel reservoirs to those mantained in suspension within the test streams is illustrated in Figure 2. This relationship was linear with respect to concentration; i.e. for all concentrations examined the sediment strengths made up in the barrel reservoirs were approximately five times the nonfiltrable residue values measured in the test streams.

Results in Figure 2 and those in Table 4 indicate that stream position (horizontal distribution) did not affect the suspended sediment strength. Non-filtrable residue values for water samples taken concurrently from upstream, mid- or downstream positions did not differ appreciably for any of the test strengths examined. The vertical or cross-stream distribution of suspended sediment strengths within the test streams were not examined.

WATER QUALITY

Mean $\pm$ SD values for the freshwater supply, as determined from grab samples taken weekly following the receipt of test fish, were as follows: temperature 15 $\pm$ 0.5^{o}C, pH 6.6 $\pm$ 0.1, dissolved oxygen 9.3 $\pm$ 0.2 mg$\cdot$L^{-1}, conductance 26 $\pm$ 4 umho$\cdot$cm^{-1}, alkalinity 1.8 $\pm$ 0.6 mg$\cdot$L^{-1}, EDTA hardness 4.1 $\pm$ 0.2 mg$\cdot$L^{-1}, and nonfiltrable residue $<$ 5 mg$\cdot$L^{-1}.

Water quality characteristics determined daily for each test stream throughout the 7-day acclimation period and the subsequent 6-week exposure period are given in Appendix 1 and summarized in Table 5. Daily fluctuations in stream NFR and turbidity values are illustrated in Figures 3 and 4, respectively.

The rate of inflow of fresh suspensions of sediment or control water to each test stream was nearly constant throughout the exposure period (Appendix 1), and did not differ appreciably between streams (Table 5). Mean water temperatures for streams 1 - 7 were similar and did not vary greatly during the study. However, the temperature for stream 8 (control stream) water was consistently less than that for all other streams (mean value 0.9 - 1.6^{o}C lower; Table 5). Dissolved oxygen values for all stream samples were $\geq$90% air saturation ($\geq$ 8.8 mg $O_2\cdot$L^{-1}), and were unaffected by sediment treatment. Mean pH values for each stream were similar (6.5 - 6.7). The conductivity (ionic strength) of streamwater was increased slightly but consistently due to the higher sediment strengths (300 and 1000 mg$\cdot$L^{-1}), with mean daily values of 30 or 36 umho$\cdot$cm^{-1} respectively (control water 25 umho$\cdot$cm $^{-1}$) (Table 5).

Nonfiltrable residue values for the control water (streams 4 and 8) were consistently below the limit of detection (< 5 mg$\cdot$L^{-1}). Mean NFR values for streams 2 and 5 (nominal strength, 100 mg$\cdot$L^{-1}) were 86 and 93 mg$\cdot$L^{-1} respectively, with mean values of 286 or 273 mg$\cdot$L^{-1} (streams 3 and 6) and 988 or 955 mg$\cdot$L^{-1} (streams 1 and 7) for nominal suspended sediment strengths of 300 or 1000 mg$\cdot$L^{-1}. The NFR values measured daily for each of these test streams varied somewhat, with slightly higher values for each respective stream evident during the third and fourth weeks of exposure (Fig. 3, Appendix 1). However, no overlaps of any NFR values occurred between the differing sediment treatments employed (100, 300 or 1000 mg$\cdot$L^{-1}).

As with stream NFR, daily and mean turbidity values for identical treatments were similar (Fig. 4, Table 5). Turbidity values for all samples of clear (control) freshwater analysed were ≤ 3 FTU. The pattern of daily fluctuations in turbidity values for grayling exposed to 100, 300 or 1000 mg$\cdot$L^{-1} suspended sediment was similar to that noted previously for NFR values (see Fig. 3 and 4).

FISH SURVIVAL AND GROWTH

All of the sixty fish placed in each of the eight test streams survived the initial 7-day acclimation period following their transfer. Thereafter, dead fish were found occasionally in each stream during the subsequent 6-week test period. These deaths occurred randomly and were unrelated to sediment treatment (Table 6). The majority (68%) of dead fish were found during the initial 2-week test period. Overall, 8% of the test fish died or were unaccounted for (presumed to be dead) during the 6-week test period (Table 6).

Examination of the dead fish indicated that 77% (20 of 26) had lacerations to the abdominal region or to the dorsal body region immediately posterior to the opercula. The six remaining dead fish appeared normal or were sufficiently decomposed to prevent the detection of these injuries. The gross examination of gill tissue for each dead fish showed no signs of clubbing, accumulation of sediment particles, or excessive mucous production. All moribund fish observed in clear water (controls) showed evidence of physical injury (nips or tears), and aggressive fish interactions resulting in deaths of otherwise healthy fish were noted on two occasions. Similarly, a high percentage of fish deaths found for the stock population of grayling reared in the outdoor trough were caused by excessive fish aggression.

The initial mean weights (and standard deviations) for each group of sixty grayling transferred to the test streams were nearly identical (Table 7). Weight gains during the initial 7-day period of acclimation to each stream (clear freshwater only) were also similar and were substantial (increases of approximately 25%). Differences in fish weights due to treatment were not apparent after 1 or 2 weeks' exposure to any sediment strength. However, for each of the subsequent exposure periods examined, the mean weights of each group of control fish were greater than those for any sediment treatment (Table 7). Reduced growth due to sediment exposure was concentration-dependent.

The average percentage weight gain experienced for each treatment during the test period was as follows (based on differences in mean weights of fish at 0 vs. 6 weeks' exposure; Table 7):

0	$mg \cdot L^{-1}$	:	241 % increase
100	$mg \cdot L^{-1}$	:	227 % increase
300	$mg \cdot L^{-1}$	:	217 % increase
1000	$mg \cdot L^{-1}$	:	161 % increase

Relative to the control values, there was a 33, 10, and 6% reduction in growth of fish exposed to 1000, 300 and 100 $mg \cdot L^{-1}$ suspended sediment, respectively.

The analysis of variance of weekly fish weights showed that the differences in variances due to sediment treatment were significant ($P < 0.05$) at 2 weeks; and highly significant ($P < 0.01$) after 3, 4, 5, and 6 weeks' sediment exposure. Dunnett's test for significance (Zar 1974) indicated that weights for fish exposed to the highest sediment strength examined (1000 $mg \cdot L^{-1}$) were decreased significantly from respective values for control fish at 2, 3, 4, 5, and 6 weeks. Corresponding weights for fish exposed to 100 and 300 $mg \cdot L^{-1}$ sediment were depressed significantly from control values after 3, 4, and 5 weeks' sediment exposure. Differences between values for these lower sediment strengths and controls did not differ statistically following 6 weeks' exposure.

FISH BEHAVIOUR

Distribution in streams

Routine daily observations of fish surfacing to feed in each test stream indicated that those held in the higher sediment strengths (300 and 1000 $mg \cdot L^{-1}$) were usually distributed in the downstream half. Unlike these observations, grayling held in clear freshwater or in 100 $mg \cdot L^{-1}$ sediment were distributed along the length of the stream, feeding actively in the upstream half as well as the downstream portion. This pattern of fish distribution was evident within 1 hour of the initial introduction of sediment to test streams and, thereafter, throughout the 6-week exposure period. With the exception of these periods of feeding, surfacing of fish in the test streams was not observed. Other observations of fish behavioural responses (i.e. coughing, threats, nips, swimming activity) could not be made due to the opacity of all test suspensions examined.

The percentage distribution of grayling in each quarter of each test stream, after 4 and 5 weeks' exposure to placer mining sediment, is shown in Table 8. Fish distributions during these periods of observation were unaffected by feeding activity since no food was offered on each day prior to the determinations of fish distribution (and weight).

For the control streams and those containing 100 $mg \cdot L^{-1}$ sediment, the distribution of fish in each stream quarter appeared to be somewhat random and unaffected by sediment treatment. The average distribution of fish in the upstream and downstream halves of these test streams was approximately equal although the majority of fish (62%) were found within the second and third quarters. Unlike this finding, the average percentage distribution of fish in the downstream half (third and four quarters) of each stream containing 300 or 1000 $mg \cdot L^{-1}$ suspended sediment was 80 - 91% (Table 8). These data, together with the subjective observations of fish distribution during routine feeding, indicate that the majority of test fish were displaced downstream by the higher strengths of suspended sediment (300 and 100 $mg \cdot L^{-1}$).

Feeding response trials

For each of the three feeding response trials conducted with grayling using live surface drift (Drosophila melanogaster), the rate of response to fruit flies for fish in each clearwater (control) stream was similar (mean values, 6 - 8 sec) (Table 9). Mean response times were increased consistently by all sediment strengths examined including 100 $mg \cdot L^{-1}$. Response times increased progressively with increasing suspended sediment strength (Table 9, Fig. 6). In all but three of the 45 separate tests conducted with the highest sediment strength (streams 1 and 7), the fruit fly was consumed within the 360-second test period (Table 9). Mis-strikes (failed feeding attempts) were noted frequently for fish reared and tested in 300 and 1000 $mg \cdot L^{-1}$ sediment but were not observed for those held in clear water or 100 $mg \cdot L^{-1}$ sediment.

The increased response times to surface drift measured in these controlled feeding trials were consistent with observations made during the routine (daily) feedings with commercial ration (Biodiet). At these times, control fish in each stream surfaced and initiated feeding activity more rapidly than those held in 100 $mg \cdot L^{-1}$ or higher suspensions. Lag times prior to initiation of feeding were consistently longest for fish held in 1000 $mg \cdot L^{-1}$ sediment. Differences in response times for fish reared in 100 vs. 300 $mg \cdot L^{-1}$ could not be discerned.

The feeding response times to surface drift for naive grayling (those held in test streams for 1 h prior to testing) are given in Table 9 and illustrated in Figure 6. In these trials, the response of control fish was somewhat more variable than that noted previously for acclimated fish (Table 9), with mean values of 10 - 25 seconds. Mean response times were again increased due to increasing strength of suspended sediment (Fig. 6). For each respective sediment exposure, mean response times were similar but appreciably longer than those recorded previously for grayling reared in test steams for 5 weeks prior to evaluation. Failure to feed was noted for 18 of the 24 tests with naive fish held in 1000 $mg \cdot L^{-1}$ sediment, and for 3 or 6 (respectively) of the 24 tests with naive fish held in 100 or 300 $mg \cdot L^{-1}$ sediment (Table 10). Feeding mis-strikes were noted for fish held in the higher sediment strengths, but were less frequent than those observed in the previous feeding trials.

The feeding response of grayling to sub-surface drift (live brine shrimp) following 6 weeks' exposure to differing strengths of suspended sediment is given in Table 11 and summarized in Figure 7. For each of the three trials conducted, the response times for identical treatments were similar. No consistent differences in response to sub-surface drift were found for groups of fish reared and tested in 0, 100, or 300 $mg \cdot L^{-1}$ sediment (Table 11, Fig. 7) Mean times for consumption of all brine shrimp offered were 3 - 8 min. Unlike these findings, times to consumption of brine shrimp were increased due to 1000 $mg \cdot L^{-1}$ sediment. Test fish held in this sediment strength consistently failed to consume all of the brine shrimp offered within the 60-min test period (Table 11).

Suspended sediment strengths of 100 and 300 $mg \cdot L^{-1}$ did not affect the feeding response times for grayling held in test streams for 5 weeks or 1 hour and fed live tubificid worms (Table 12). Irrespective of the length of previous exposure, mean response times for consumption of all worms by control fish or those held in 100 or 300 $mg \cdot L^{-1}$ sediment were 3 - 10 min, and no consistent changes in response due to treatment were observed (Fig. 8). However, the highest sediment strength examined (1000 $mg \cdot L^{-1}$) inhibited the feeding response of naive or previously exposed fish to these benthic invertebrates, with 0 - 10% worms consumed in any test during the 60-min period.

CONDITION OF FISH

General

Inspection of grayling sampled from each test stream after 3 or 6 weeks in differing strengths of placer mining sediment revealed no overt signs of disease or damage attributable to these sediment exposures. A small but consistent incidence (<5%) of fish with spinal deformities (crinklebacks) became evident in each stream (including control streams) during the test period. However, no body lesions were evident. Fins and opercula of all fish appeared normal, and no internal or external hemorrhages were observed. Gross examination of the gills of each fish showed no signs of clubbing, discolouration, excess mucous production, or adhesion of sediment particles.

All fish sampled from the highest strength of sediment tested (1000 $mg \cdot L^{-1}$) were notably paler than control fish, and parr marks were indistinct. Those held in 300 $mg \cdot L^{-1}$ sediment were only slightly paler than fish reared in clear freshwater. No differences in appearance were discerned for fish reared in 100 $mg \cdot L^{-1}$ sediment vs. control water.

Fish length and condition factor

Mean condition factors (100 $W \cdot L^{-3}$) for all fish sampled from each stream after 3 or 6 weeks' sediment exposure differed randomly and were not affected by treatment (Table 13). Mean values varied from 0.81 to 0.96; standard deviations for each sample were similar (Table 13).

Mean lengths (and weights) determined for the group of ten fish sampled from each stream after 3 weeks' exposure to placer mining sediment were not considered to be representative of overall stream values due to the small sample size. Mean fork lengths for all groups of sediment-exposed fish sampled at 6 weeks ($n = 42-47$) were consistently smaller than this value for either group of control fish, with greatest differences noted between lengths for controls and those exposed to 1000 $mg \cdot L^{-1}$ sediment (Table 13).

Biological characteristics

The biological characteristics determined for each group of ten grayling sampled from each stream after 6 weeks' sediment exposure are given in Table 14. The mean percentage body moisture content for fish from each stream was similar (77 - 79%) and apparently unaffected by sediment treatment. Hematocrit and leucocrit values for fish were also unchanged by prolonged exposure to any sediment strength (Table 14). Mean plasma glucose values for each sample were consistently low (58 - 68 mg%) with no consistent changes in magnitude or sample variance caused by any of these sediment strengths.

PERFORMANCE OF FISH

Tolerance to reference toxicant

Data concerning the acute lethal tolerance of test fish to pentachlorophenol, following a 3-week exposure to differing strengths of suspended sediment, are given in Table 15 and illustrated in Figure 9. Based on these median time-to-death (LT50) values, grayling reared for 3 weeks in the lowest strength of sediment examined (100 $mg{\cdot}L^{-1}$) were more tolerant to this reference toxicant than the control fish or those held in the higher sediment strengths (300 and 1000 $mg{\cdot}L^{-1}$). Response times for identical treatments did not differ significantly for any comparison. However, times to death for all fish reared in 100 $mg{\cdot}L^{-1}$ sediment were significantly ($P < 0.05$) longer than those for control fish or grayling reared in 1000 $mg{\cdot}L^{-1}$ sediment.

After 6 weeks' exposure to sediment, the tolerance to pentachlorophenol for both control groups and fish reared in 100 $mg{\cdot}L^{-1}$ sediment was similarly high (Table 16, Fig. 10). Unlike these values, times to death in pentachlorophenol for fish reared in 300 or 1000 $mg{\cdot}L^{-1}$ sediment were consistently and appreciably shorter. Statistical analyses (Litchfield 1949) indicated that response times for streams receiving identical treatments did not differ ($P > 0.05$), whereas values for fish held in 300 or 1000 $mg{\cdot}L^{-1}$ were significantly lower than those for controls. These results indicate that the acute lethal tolerance of grayling to this reference toxicant was depressed by prolonged exposure to these higher strengths of suspended sediment.

Respiration

Findings from the sealed jar bioassays indicate that the short-term capacity of grayling to withstand hypoxic conditions was unaffected by their prolonged exposure to sediment. Mean residual dissolved oxygen values derived for fish from streams receiving identical treatments were somewhat variable and showed no consistent change with respect to sediment strength (Table 17, Fig. 11). Additionally, the 95% confidence intervals for differing treatments showed considerable overlap (Fig. 11).

Unlike these findings, times to death of fish exposed to 300 or 1000 $mg{\cdot}L^{-1}$ sediment in these sealed jar bioassays (and for 6 weeks in test streams) were decreased consistently relative to corresponding values for control fish or those held in 100 $mg{\cdot}L^{-1}$ sediment (Table 17, Fig. 12). These declines proved significant (Table 17), whereas values derived for fish from separate streams receiving identical treatment did not differ ($P > 0.05$) for any comparison.

Based on mean fish weights, times to death, and residual dissolved oxygen values at death of fish in sealed jars after 6 weeks' sediment exposure, oxygen uptake rates ($mg\ O_2{\cdot}g\ fish^{-1}{\cdot}h^{-1}$) were calculated for each group of ten fish from each test stream. Results obtained were as follows:

Sediment strength ($mg \cdot L^{-1}$)	Stream no.	Oxygen uptake rate ($mg\ O_2 \cdot g\ fish^{-1} \cdot h^{-1}$)
0	4	2.1
0	8	2.2
100	2	2.1
100	5	2.2
300	3	2.3
300	6	2.3
1000	1	2.5
1000	7	2.5

These results show an increase in oxygen consumption rates for each group of fish exposed to the two higher strengths of suspended sediment only.

Temperature tolerance

Upper lethal temperatures (mean ± SD) for test grayling held in differing suspended sediment strengths following their 6-week exposure are given in Table 18. Mean temperatures at death for fish from each stream, together with their 95% confidence intervals, are depicted in Figure 13.

The mean temperature at death for fish from one control stream (stream 4) was similar to values for all groups of fish exposed to placer mining sediment (27.7 - 28.0°C). The 95% confidence intervals for these groups were similarly small (Fig. 13). However, the mean temperature at death for the second control group (stream 8) was notably lower (27.0°C) and its 95% confidence interval expanded. Analysis of variance indicated that differences in lethal temperatures between treatments were significant ($P < 0.01$). Additionally, pooled values for each sediment treatment differed significantly from those from the pooled control value according to Dunnett's test (Zar 1974).

Mean temperatures of acclimation for fish from each stream during the 6-week period of sediment exposure are also presented in Table 18. The acclimation temperature for stream-4 fish (15.2°C) was consistent with those for fish held for 6 weeks in differing sediment strengths (14.9 - 15.6°C), whereas controls reared in stream 8 were acclimated to somewhat cooler (14.0°C) water.

DISCUSSION

SEDIMENT DISPERSAL/CONCENTRATION IN TEST STREAMS

Based on daily observations during cleaning/refilling of the sediment suspensions in each barrel reservoir, little if any settlement of sediment occurred within these barrels. Thus the 5-fold difference between sediment strengths in barrels and nonfiltrable residue values in test streams (Fig. 2) was due primarily to the settlement of larger-sized sediment particles on the stream bottom. This conclusion is consistent with the observation of a concentration - dependent buildup of packed sediment ≤ 2 cm in depth on the bottom of each stream during the weekly cleaning periods. A portion of the sediment suspended in test strengths may also have passed through the 0.45 um filter upon analysis (and therefore not have contributed to the NFR values derived). However, based on previous analyses of suspensions of similar inorganic sediment for both nonfiltrable and total residue content (McLeay et al. 1983), the contribution of test sediment to this filtrable portion of stream water would likely have been minimal.

Although the vertical or cross-stream gradients of suspended sediment within each test stream were not examined, it is thought that the relatively shallow depth and narrow width of each stream, together with the rapid rate of mixing and recycling of each test suspension, would have negated any marked stream gradients. The visual inspection of surface and sub-surface grab samples of water from a number of positions within each test stream supported this conclusion. Additionally, stream-length gradients of differing suspended sediment strength were not apparent (Table 4, Fig. 2).

The daily variations in nonfiltrable residue and turbidity values determined for each test stream (Figs. 3 and 4) are due to a number of variables including minor modifications to the amount of sediment added to the barrel reservoirs at 2 and 4 weeks, unknown experimental error, and errors in precision of the analytical techniques (Anon. 1979, 1980). Despite these inherent/experimental errors, suspended sediment strength and turbidity for each test stream were reasonably constant throughout the 6-week exposure period, and mean nonfiltrable residue values for streams to which test fish were exposed approximated (albeit values were 1 - 15% lower) the desired concentrations of 100, 300 or 1000 $mg \cdot L^{-1}$ (Table 5). Relative to daily (or hourly) changes in turbidity or suspended sediment strength for streams receiving discharges from placer mining activities (McLeay et al. 1983), the variations for these variables recorded in the present study are minor. Additionally, the control/diluent water remained clear (NFR <5 $mg \cdot L^{-1}$, turbidity <3 FTU) throughout the study period.

FISH SURVIVAL AND GROWTH

With the exception of the suspended sediment loadings, water quality within all test streams was compatible with fish survival and near optimum for growth of grayling. Freshwaters with dissolved oxygen values $\geq$90% saturation are not restrictive in terms of the condition and performance of cold-water fish species (Davis 1975), and stream pH values of 6.5 - 6.7 are considered within the range of normal values. Although the optimum temperature for growth of Arctic grayling has not been defined, the test temperature of 15°C approaches the physiological optimum determined for other juvenile salmonid fish species (Brett et al. 1969; Brett 1971). The minor increase in stream conductivity due to the highest sediment strength examined would not cause any osmotic stress to test fish; however, the impact of specific (unmeasured) ions leached from the sediment on fish growth and well-being cannot be ascertained from the present study. Water currents in test streams did not cause undue energy demands.

The present findings indicate that prolonged (6-week) exposure of underyearling Arctic grayling to strengths of suspended placer mining sediment $\leq$1000 $mg \cdot L^{-1}$, under otherwise optimal water quality conditions including the readily available excess food, does not affect fish survival. These findings are consistent with our previous (McLeay et al. 1983) observations for grayling held in suspended sediment strengths 50000 $mg \cdot L^{-1}$ for 2 weeks or less, and with earlier (Griffin 1938, Herbert and Richards 1963) reports of survival of rainbow trout (Salmo gairdneri) or Pacific salmon fingerlings exposed to suspended sediment strengths ranging from 200 to 750 $mg \cdot L^{-1}$ for several weeks or months. On the other hand, suspensions of natural sediments in the range of 1000 - 2500 $mg \cdot L^{-1}$ have been reported to cause deaths of young salmonid fish within 3 weeks or less (Campbell 1954; Noggle 1978). The European Inland Fisheries Advisory Commission (Anon. 1965) reviewed these and other findings of fish death or survival in sediment suspensions, and attributed the diverse results to differences in sediment particle size, angularity or hardness.

The significant reduction in the growth of grayling exposed to 100, 300 or 1000 $mg \cdot L^{-1}$ suspended placer mining sediment for periods of 3 to 6 weeks are consistent with previous findings for growth studies with sediment-exposed salmonid fish. Herbert and Richards (1963) reported growth impairment for rainbow trout reared for 33 - 40 weeks in suspensions of coal-washery waste or wood fibre as low as 50 $mg \cdot L^{-1}$. Similarly, Sigler (1981) found reduced growth for underyearling steelhead trout (S. gairdneri) or coho salmon (Oncorhynchus kisutch) held for 2 weeks in laboratory streams containing suspended clay solids with turbidity values of 40 - 60 NTU. Depending on the nature and availability of the food supply, settled sediment fines may also constrict the growth of stream-reared fish (Crouse et al. 1981).

Unlike the findings for grayling in test streams receiving 1000 $mg \cdot L^{-1}$ suspended sediment, those reared in 100 or 300 $mg \cdot L^{-1}$ sediment grew nearly as well as the control fish. However, these fish were presented with an abundant supply of food throughout the test period. Based on the findings from the feeding response trials with live food organisms, it is thought that these lower suspended sediment strengths, if present within natural streams for extended periods of time, could result in a greater impairment of fish growth than was observed here.

FISH DISTRIBUTION

Since the predominantly downstream distribution of grayling exposed to the higher suspended sediment strengths (300 and 1000 $mg \cdot L^{-1}$) was observed within one hour of the initial establishment of the sediment gradients, it is unlikely that this behavioural response was caused by movement downstream in search of food. Rather, these findings suggest an innate downstream movement of these fish in response to sediment exposure.

Sigler (1981) found downstream displacement of steelhead trout and coho salmon fry from artificial streams receiving clay suspensions with turbidity values of 40 - 50 NTU. Noggle (1978) reported avoidance responses for juvenile coho salmon exposed to suspended sediment strengths of 4000 - 8000 $mg \cdot L^{-1}$, whereas lower strengths (1000 - 4000 $mg \cdot L^{-1}$) caused preference responses (fish attraction). Other investigators have reported no response (Gradall and Swenson 1982), preference (cited in Noggle 1978) or avoidance reactions (Anon. 1965) for other species of salmonid fish exposed to low-to-medium (<1000 $mg \cdot L^{-1}$) strengths of suspended sediment under controlled conditions. Berg (1982) determined that short-term pulses of suspended sediment with turbidity values ≤ 60 NTU caused a breakdown of social organization for juvenile coho salmon in laboratory stream environments, resulting in increased activity and a loss of aggressive interactions. From the foregoing, it is apparent that the behavioural responses of stream fish to suspended sediment are, as yet, unclear; and that differences in fish species, age, and sediment strength and type (particle size and shape) may result in diverse behavioural reactions.

Fish distribution in natural stream environments can be markedly affected by suspended sediment loadings. Several instances of salmonid or other fish species avoiding muddy streamwater have been reported (Anon. 1965). Herbert et al. (1961) reported an absence of brown trout (*Salmo trutta*) fry from downstream sites for streams receiving china-clay wastes; whereas these fish were abundant at up-stream, clearwater sites. Similarly, Birtwell et al. (1984) recently found a consistent reduction in numbers of juvenile Arctic grayling within downstream water receiving suspensions of placer mining sediment, relative to numbers found in upstream creekwater or clear-water tributary streams. These findings provide evidence for a displacement of juvenile Arctic grayling or other salmonid fish species from stream environments caused by high suspended sediment loadings.

FEEDING BEHAVIOUR OF FISH

As with other salmonid fish species, the feeding habits of Arctic grayling vary depending on life stage. Underyearling grayling feed primarily on zooplankton or drift from benthic invertebrate larvae, whereas larger juveniles (>13 cm) or adult grayling tend to feed on benthic or emergent insects and larger terrestrial insect drift (O'Brien et al. 1979; Schmidt and O'Brien 1982; Birtwell et al. 1984). An examination of stomach contents for underyearling grayling captured during summer months from clearwater Yukon streams indicated that these fish were feeding principally on aquatic invertebrate drift (Chironomidae, Simuliidae) (Birtwell et al. 1984).

Schmidt and O'Brien (1982) determined that the reactive distance of Arctic grayling (i.e. distance within which a positive feeding response occurred) to a number of live zooplankton species was increased with increasing light intensity. Although several salmonid fish species appear to reach their maximum visual acuity at a light intensity of about 100 lux (Schmidt and O'Brien 1982), these investigators found that reactive distances for grayling increased up to a light intensity of 20000 lux. Based on these findings, these authors concluded "Because grayling, at least in the Arctic, may do much of their feeding under conditions of continuous daylight and very clear water, (genetic) selection for low light vision may be low." Our findings from feeding response trials with Arctic grayling and live food organisms support this previous evidence that grayling rely on visual cues to locate insects, and that decreased light intensity (due in this instance to suspended solids) will impair feeding responses for this fish species.

Present results indicate clearly that a 1000 $mg \cdot L^{-1}$ suspension of placer mining sediment markedly impairs the feeding performance of underyearling grayling offered surface drift, sub-surface drift or benthic invertebrates. This impaired response is evident for both naive fish and those exposed continuously to this suspended sediment stength for 5 or 6 weeks. Interpretation of the effects noted for fish held in the lower sediment strengths (100 or 300 $mg \cdot L^{-1}$) are less clear and confounded by modifications in the experimental approach used with differing food organisms. The increase in time to respond to surface drift for fish chronically exposed to 100 or 300 $mg \cdot L^{-1}$ sediment suggests that these sediment strengths (and 1000 $mg \cdot L^{-1}$) decreased the fishes' reactive distance (ability to detect surface prey). The relatively slower reponse to surface drift for naive grayling held only briefly in these sediment strengths prior to testing may indicate that those fish subjected to prolonged sediment exposure have improved their ability to discern surface food in turbid water. Alternatively, short-term exposure to these sediment strengths may have disrupted feeding activities to some extent. The similarly rapid feeding response times for naive controls versus long-term controls shows that the feeding activity of naive fish was not disrupted by transfer of fish from the stock tank to the test apparatus.

Unlike the findings with surface drift, suspended sediment strengths of 100 or 300 $mg \cdot L^{-1}$ did not impair feeding response times for grayling offered sub-surface drift (Artemia salina) or benthic invertebrates (tubificids). The ability of naive or chronically-exposed grayling to detect and consume tubifex worms or brine shrimp in these sediment strengths equally as well as control fish was likely due at least in part to the experimental design for this test. The white background provided by the submersed nylon-mesh baskets may have silhouetted these prey, making their detection easier. Additionally, holding fish within the confines of each basket may have decreased the distance between predator and prey sufficiently for these fish to readily detect (and consume) these organisms at these sediment strengths. Or perhaps the reactive distance for these sub-surface food organisms at each respective suspended sediment strength, whether related to visual or olfactory cues, is greater than that for surface drift.

Several investigators have reported a reduction in the feeding responses of salmonid fish due to the presence of suspended sediment. Noggle (1978) found that a suspended sediment strength of 100 $mg \cdot L^{-1}$ reduced feeding of coho salmon smolts toward caddisfly larvae by 45%, and that feeding ceased altogether above 300 $mg \cdot L^{-1}$. Although both juvenile cutthroat trout (Salmo clarki) and chinook salmon (Oncorhynchus tshawytscha) can continue to feed on surface drift in suspended sediment concentrations greater than 500 $mg \cdot L^{-1}$ (Griffin 1938), one study (Anon. 1965) reported that cutthroat trout subjected for two hours to 35 $mg \cdot L^{-1}$ suspended sediment within a river sought cover and stopped feeding. Berg (1982) determined that suspended sediment with a turbidity of 60 NTU had a marked effect on the visual ability of juvenile coho salmon. Delayed response times to surface drift, mis-strikes at food, and frequent collisions of fish with an obstacle within the test tank were evident. These findings are consistent with those for Arctic grayling (particularly naive fish) offered surface food in the presence of sediment suspensions $\geq$100 $mg \cdot L^{-1}$.

FISH CONDITION

With the exception of fish colour, all grayling reared for 6 weeks in placer mining sediment suspensions $\leq$1000 $mg \cdot L^{-1}$ were normal in appearance, showing no overt pathologies attributable to sediment exposure. The observation that fish exposed to 300 and 1000 $mg \cdot L^{-1}$ were paler in colour is consistent with other findings for salmonid fish exposed to elevated suspended sediment levels under field or laboratory conditions (Herbert and Merkens 1961, Herbert et al. 1961), and probably reflects a contraction of epithelial chromatophores in response to background colour.

Mean condition factors determined for groups of fish held for 3 or 6 weeks in control streams or those containing differing strengths of suspended placer mining sediment were typical of those values found for underyearling Arctic grayling captured from clearwater Yukon streams (Birtwell et al. 1984). As in the present study, Sigler (1981) found no change in condition factors for underyearling steelhead trout or coho salmon held for extended periods in laboratory streams containing sediment suspensions, whereas these fish grew less than the control fish in clear water. Fish were provided an excess food ration in both studies. Webb and Brett (1972, 1973) reported a similar growth impairment (without change in condition factors) for underyearling sockeye salmon (Oncorhynchus nerka) exposed to sublethal concentrations of kraft pulpmill effluent or pentachlorophenol, together with a reduced food conversion efficiency. As in the current investigation, the percentage moisture content of these contaminant-exposed salmon was unchanged. A reduction in food conversion efficiency could be caused by increasing maintenance energy costs, thus reducing the proportion of energy available for growth (Warren and Davis 1967); ie. reducing the "scope for growth" (Brett 1976). The reduced growth of grayling or other salmonid fish species caused by suspended sediment may also reflect a decreased food intake, although it is thought that this would be reflected in a reduction in fish condition factor. As with other increased metabolic demands, a sustained increase in swimming activity of fish due to suspended sediment (Berg 1982) would increase energy costs, resulting in less energy available for growth.

Since blood hematocrit values for salmonid fish generally increase due to hypoxia (caused by impaired gas exchange or oxygen-deficient waters) (Holeton and Randall 1967; Soivio et al. 1974 a,b), the absence of any change in hematocrit for grayling exposed to suspended sediment for 6 weeks suggests that these exposures did not lower blood oxygen tension. O'Connor et al. (1977) reported elevated hematocrits, red blood cell counts and hemoglobin values together with histological evidence of gill damage for certain species of estuarine fish exposed to suspended sediment, whereas for other species these blood values and gill histology were unchanged from controls. Hematocrit values and gill histology of underyearling Arctic grayling were shown previously to be unaffected by acute (≤ 4 days) exposure to suspensions of placer mining sediment under field or laboratory conditions (McLeay et al. 1983). A lack of change in hematocrit values does not necessarily imply no gill tissue damage, however, since fish have a large "reserve" surface area of gill tissue available for maintaining blood gas tensions at normal values (Randall 1970).

Exposure of Arctic grayling and other fish species to suspended sediment at strengths which can be found within natural streams has been shown to cause a number of typical stress responses, including short-term increases in plasma cortisol levels (Redding and Schreck 1980), depletion of liver glycogen energy reserves (Sherk et al. 1974, O'Connor et al. 1977), elevation of plasma glucose levels (Noggle 1978, McLeay et al. 1983) and depression of leucocrit values (McLeay et al. 1983). When the stress is prolonged, certain fish stress indices including plasma cortisol and glucose levels and numbers of circulating white blood cells (leucocrit) recover to basal or near-basal levels (McLeay and Brown 1974, McLeay 1977, McLeay and Gordon 1977, Redding and Schreck 1980). These recoveries typify the stage of resistance to stress (Selye 1950), and are only achieved at a metabolic cost. Thus the apparent absence of change in leucocrit or plasma glucose values for Arctic grayling following 6 weeks' exposure to suspensions of placer mining sediment is not unexpected, and does not imply that these fish were not stressed. A better understanding as to whether or not the grayling in this study were chronically stressed by suspended sediment, and the stage of this response after 6 weeks' exposure (ie. resistance or exhaustion stages; Selye 1950), would require a more detailed biochemical/histopathological examination of test fish. This was beyond the scope of the present investigation.

FISH PERFORMANCE

An examination of the performance of fish during or subsequent to their exposure to environmental stressors can provide meaningful information concerning their condition and adaptive capabilities (Wedemeyer and McLeay 1981; Wedemeyer et al. 1983). The present sealed jar bioassays, temperature tolerance tests and challenge tests with the reference toxicant pentachlorophenol enabled a better understanding of the sublethal effects caused by prolonged exposure of Arctic grayling to suspensions of placer mining sediment.

Results from the bioassays with pentachlorophenol showed that grayling exposed for 6 weeks to 300 or 1000 mg·L^{-1} suspended sediment were less able to withstand this reference toxicant than control fish or those held in 100 mg·L^{-1} sediment. Similarly, both groups of fish exposed to these higher sediment strengths for 6 weeks showed shorter times to death (increased oxygen uptake rates) in sealed jar bioassays. These results suggest that the adaptive capabilities of grayling were diminished by prolonged exposure to suspensions of placer mining sediment $\geq$300 mg·L^{-1}.

The increased oxygen uptake rate found for grayling held for 6 weeks in 100 or 300 mg·L^{-1} suspended sediment may reflect an increased basal metabolic rate or a sustained increase in physical activity for these fish. This response indicates a decreased scope for activity of the fish (Fry 1971). Measurements of scope for activity have been used previously to assess the impact of environmental stressors on fish (Brett 1958; Wedemeyer and McLeay 1981). Since the ability of grayling to withstand hypoxia was unaffected by chronic exposure to any sediment strength examined (residual dissolved oxygen values were unchanged), the decreased times to death found in sealed jar tests for fish exposed to 300 or 1000 mg·L^{-1} sediment probably reflect heightened energy demands for these fish rather than impaired blood gas exhange (D.J. Randall, pers. commun.). This conclusion is also consistent with the lack of change in hematocrit values for the sediment-exposed fish.

Findings for the current temperature tolerance tests indicate that the capacity of all fish groups to withstand high temperatures was unaffected by prolonged exposure to any strength of suspended sediment examined. This result is consistent with previous evidence that little if any change in the upper lethal temperature tolerance of salmonid fish is caused by aquatic contaminants which do not block oxygen exchange at the gills or otherwise impair tissue respiration (McLeay and Gordon 1980; McLeay et al. 1983). The reduced temperature tolerance found for one group of control fish (stream 8) simply reflects the slightly lower temperature to which this group of fish was acclimated (Brett 1952; Black 1953; McLeay et al. 1983).

GENERAL

Inasmuch as the sublethal effects of prolonged exposure of salmonid fish to suspended sediment have previously received little attention, the harmful effects caused by such exposures are not clearly understood. The present study indicates that, at least for the sediment type examined, direct fish mortalities are unlikely from exposure to suspended sediment strengths less than or equal to 1000 $mg \cdot L^{-1}$ under otherwise optimal environmental conditions. However, sublethal effects including a continued impairment of feeding activity, impaired growth, decreased scope for activity and decreased resistance to other environmental stressors can occur.

Present findings indicate that strengths of suspended placer mining sediment as low as 100 $mg \cdot L^{-1}$ can affect fish growth and feeding responses, and that strengths of 300 $mg \cdot L^{-1}$ or higher can increase oxygen consumption (metabolic rate), lower the tolerance of grayling to a reference toxicant, and cause fish to be distributed further downstream. These findings provide cause for concern if sediment concentrations above 100 $mg \cdot L^{-1}$ remain suspended in streams inhabited by juvenile Arctic grayling or other sensitive fish species for extended periods. Suspended sediment strengths as low as 100 $mg \cdot L^{-1}$ may also prove harmful to the long-term well-being of grayling in natural stream environments. Although the effects on growth and feeding response times for fish exposed to 100 $mg \cdot L^{-1}$ sediment for 6 weeks were minimal, the absence of a continuous supply of excess food in the natural environment together with the greater effort required for the detection and capture of available food, predator/prey interactions and simultaneous exposure to other less-than-optimal environmental conditions may increase the impact of prolonged exposure to this suspended sediment strength.

The displacement of salmonid fish from upstream waters shown in this study for suspended sediment strengths greater than 100 $mg \cdot L^{-1}$ and in a previous (Sigler 1981) laboratory investigation where stream turbidity was 40 - 50 NTU is of particular concern, as these findings indicate that short-term pulses of suspended sediment may cause downstream migration of otherwise resident fish. This downstream displacement and probable reduction in the amount and quality of living space are cause for concern. Clarification of the effects of suspended sediment on fish displacement and avoidance/preference responses under natural and controlled environmental conditions is desirable. A better understanding of the influence of sediment type (particle shape and size) and concentration on fish behaviour, stress responses and energetics should also be achieved.

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TABLE 1. Particle size distribution for test sediment collected from a placer mine settling pond.

Sieve size (mesh)	Particle size (um)	Untreated sediment[a]		Prepared sediment[b]			
				Sample no. 1		Sample no. 2	
		Weight (%)	Cumulative weight (%)	Weight (%)	Cumulative weight (%)	Weight (%)	Cumulative weight (%)
+35	>400	0.0	0.0	0.0	0.0	0.0	0.0
+48	>300	0.0	0.0	0.0	0.0	0.0	0.0
+65	>210	0.1	0.1	0.0	0.0	0.0	0.0
+100	>150	0.4	0.5	0.0	0.0	0.1	0.1
+150	>100	3.3	3.8	0.2	0.2	0.1	0.2
+200	> 75	17.1	20.9	2.3	2.5	1.6	1.8
+325	> 45	40.6	61.5	16.8	19.3	16.5	18.3
+400	> 38	15.7	77.2	10.0	29.3	11.9	30.2
-400	< 38	22.8	100.0	70.7	100.0	69.8	100.0

[a] Surficial sediment as collected from the downstream end of a de-watered settling pond.

[b] Oven-dried (50°C) and pulverized (vibratory ring pulverizer) for 2 min.

TABLE 2. Oxygen uptake rate, volatile and fixed residue for test sediment collected from a placer mine settling pond.

Characteristic	Sample no. 1	Sample no. 2
oxygen uptake rate at 15°C ($mg\ O_2 \cdot g^{-1}$ dry sediment$\cdot 24h^{-1}$)	0.01	0.01
oxygen uptake rate at 15°C ($mg\ O_2 \cdot ml^{-1}$ dry sediment$\cdot 24h^{-1}$)	0.01	0.01
volatile residue (%)	5.	4.
fixed residue (%)	95.	96.

TABLE 3. Metal content[a] for test sediment collected from a placer mine settling pond.

Component		Concentration ($ug \cdot g^{-1}$ dry weight)	
		Sample no. 1	sample no. 2
arsenic	As	653.	649.
barium	Ba	341.	344.
beryllium	Be	0.6	0.6
cadmium	Cd	0.3	0.3
cobalt	Co	12.2	12.0
chromium	Cr	56.1	41.8
copper	Cu	39.4	37.5
manganese	Mn	705.	705.
molybdenum	Mo	4.6	2.3
nickel	Ni	25.	25.
phosphorous	P	720.	726.
lead	Pb	13.	11.
tin	Sn	2.0	2.0
strontium	Sr	36.4	36.6
titanium	Ti	649.	632.
vanadium	V	45.	44.
zinc	Zn	81.6	82.0
aluminum	Al	20700.	20800.
iron	Fe	40300.	40100.
silicon	Si	4400.	5160.
calcium	Ca	3770.	3710.
magnesium	Mg	5510.	5540.
sodium	Na	420.	390.

[a]Based on analysis of sediment digest by inductively coupled argon plasma spectrograph (Anon. 1979).

TABLE 4. Effect of stream position on suspended sediment strength.

Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Stream position		
		Upstream	Midstream	Downstream
0	4	<5[a]	<5[a]	<5[a]
0	8	<5	<5	<5
100	2	95	97	91
100	5	111	98	110
300	3	308	305	316
300	6	318	308	310
1000	1	1030	1020	1030
1000	7	997	1010	1000

[a]Nonfiltrable residue values determined for grab samples collected concurrently at mid-depth.

TABLE 5. Summary of water quality characteristics in test streams during the 6-week period of exposure of underyearling Arctic grayling to differing strengths of suspended placer mining sediment.

		Nominal strength of suspended sediment ($mg \cdot L^{-1}$)							
		0 (control)		100		300		1000	
Variable	Statistic	Stream 4	Stream 8	Stream 2	Stream 5	Stream 3	Stream 6	Stream 1	Stream 7
temperature ($^{\circ}C$)	mean	15.2	14.0	15.1	15.6	15.4	15.1	14.9	14.9
	SD	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.6
dissolved oxygen ($mg \cdot L^{-1}$)	mean	9.4	9.7	9.4	9.3	9.3	9.4	9.5	9.4
	SD	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.3
pH	mean	6.5	6.5	6.6	6.6	6.7	6.6	6.7	6.7
	SD	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2
conductance ($umho \cdot cm^{-1}$)	mean	25	25	27	26	30	30	36	36
	SD	5	4	4	4	5	5	4	5
nonfiltrable residue ($mg \cdot L^{-1}$)	mean	<5	<5	86	93	286	273	988	955
	SD	0	0	25	26	48	51	130	127
turbidity (FTU)	mean	1.1	1.1	118	123	361	371	1661	1590
	SD	0.4	0.4	26	25	78	72	224	234
inflow rate ($ml \cdot min^{-1}$)	mean	73	73	72	73	70	69	71	71
	SD	3	2	3	2	2	3	2	3

TABLE 6. Weekly mortalities of underyearling Arctic grayling[a] in test streams during prolonged exposure to differing strengths of placer mining sediment.

Duration of exposure (weeks)	Nominal strength of suspended sediment ($mg \cdot L^{-1}$)															
	0 (control)				100				300				1000			
	Stream 4		Stream 8		Stream 2		Stream 5		Stream 3		Stream 6		Stream 1		Stream 7	
	M[b]	D[c]	M	D	M	D	M	D	M	D	M	D	M	D	M	D
0[d]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	2	0	1	3	0	0	1	1	1	1	0	0	0
2	0	3	0	5	0	1	1	1	0	0	0	2	2	0	2	0
3[e]	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0
4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	1	0	0	0	0	1	0	0	2	0	1
6	0	1	0	0	0	0	0	0	0	2	0	0	1	0	0	0
total[f]	5		8		3		5		3		6		7		3	

[a] Sixty fish added initially to each of eight test streams.
[b] Fish missing; presumed dead.
[c] Fish dead; examined for lesions.
[d] During the initial 7-day period for acclimation of fish to test streams.
[e] Ten fish removed from each stream for pentachlorophenol bioassays.
[f] Combined value for missing and/or dead fish in each stream throughout the test period.

TABLE 7. Weekly weights for groups[a] of underyearling Arctic grayling exposed for 6 weeks to differing strengths of suspended placer mining sediment.

Duration of exposure (weeks)	Nominal strength of suspended sediment ($mg \cdot L^{-1}$): 0 (control)		100		300		1000	
	Stream 4	Stream 8	Stream 2	Stream 5	Stream 3	Stream 6	Stream 1	Stream 7
0[b]	0.41[d] (0.09)	0.41 (0.08)	0.40 (0.08)	0.42 (0.09)	0.41 (0.08)	0.42 (0.09)	0.44 (0.09)	0.40 (0.09)
0[c]	0.55 (0.12)	0.53 (0.11)	0.53 (0.11)	0.54 (0.10)	0.52 (0.10)	0.52 (0.11)	0.53 (0.11)	0.56 (0.10)
1	0.64 (0.18)	0.64 (0.15)	0.62 (0.15)	0.67 (0.15)	0.62 (0.14)	0.63 (0.15)	0.59 (0.14)	0.66 (0.14)
2	0.80 (0.25)	0.77 (0.18)	0.75 (0.18)	0.80 (0.18)	0.74 (0.18)	0.77 (0.17)	0.68 (0.18)	0.75 (0.17)
3	0.97 (0.31)	0.96 (0.24)	0.86 (0.22)	0.94 (0.23)	0.85 (0.22)	0.91 (0.20)	0.74 (0.19)	0.83 (0.19)
4	1.11 (0.36)	1.13 (0.30)	0.98 (0.24)	1.10 (0.28)	0.99 (0.27)	1.08 (0.26)	0.84 (0.21)	0.96 (0.20)
5	1.28 (0.42)	1.31 (0.35)	1.13 (0.29)	1.22 (0.35)	1.13 (0.36)	1.24 (0.32)	0.94 (0.20)	1.05 (0.24)
6	1.40 (0.49)	1.39 (0.41)	1.30 (0.37)	1.38 (0.45)	1.30 (0.44)	1.33 (0.35)	1.01 (0.25)	1.18 (0.28)

[a] Sixty fish added initially to each of eight test streams.

[b] Upon addition of fish to test streams.

[c] Following a 7-day period for acclimation of fish to test streams.

[d] Mean weight (g), with standard deviation in parenthesis.

TABLE 8. Percentage distribution of underyearling Arctic grayling in four equal portions of each test stream following exposure of fish to suspended placer mining sediment for 4 or 5 weeks.

Duration of exposure (weeks)	Stream position (quarter)	Nominal strength of suspended sediment ($mg \cdot L^{-1}$)							
		0 (control)		100		300		1000	
		Stream 4	Stream 8	Stream 2	Stream 5	Stream 3	Stream 6	Stream 1	Stream 7
4	1	11[a]	48	6	6	2	2	0	2
	2	37	38	40	7	10	13	15	10
	3	15	12	27	40	53	40	15	48
	4	37	2	27	47	35	45	70	40
5	1	0	7	12	2	2	7	2	4
	2	59	38	34	18	4	18	14	15
	3	37	55	28	11	55	32	36	49
	4	4	0	26	69	39	43	48	32
4 + 5 (mean)	1	6	27	9	4	2	4	1	3
	2	48	38	37	13	7	16	15	13
	3	26	34	27	26	54	36	26	48
	4	20	1	27	57	37	44	58	36
4 + 5 (mean)	1 + 2[b]	54	66	46	17	9	20	16	16
	3 + 4[c]	46	34	54	83	91	80	84	84

[a]Percentage of fish occupying stream position indicated.
[b]Upstream half of test stream.
[c]Downstream half of test stream.

TABLE 9. Effect of differing strengths of suspended placer mining sediment on the feeding response to surface drift (<u>Drosophila melanogaster</u>) for underyearling Arctic grayling held in test streams for 5 weeks.

		Feeding response time (seconds)[c]							
		0 (control)		100 $mg \cdot L^{-1}$ Sediment		300 $mg \cdot L^{-1}$ Sediment		1000 $mg \cdot L^{-1}$ Sediment	
Trial no.[a]	Replicate no. [b]	Stream 4	Stream 8	Stream 2	Stream 5	Stream 3	Stream 6	Stream 1	Stream 7
1	1	10	6	45	26	40	143	166	> 360
	2	5	7	5	40	80	60	40	115
	3	7	7	21	25	30	47	150	46
	4	7	6	17	34	17	87	198	140
	5	7	5	10	19	17	75	48	296
mean		7	6	20	29	37	82	120	> 191
(SD)		2	1	15	8	26	37	72	(>131)
2	1	4	6	15	13	28	23	184	22
	2	5	5	15	39	20	13	115	32
	3	6	6	8	39	21	10	19	15
	4	6	6	20	18	30	10	92	43
	5	5	8	20	40	19	43	> 360	23
	6	9	5	20	21	45	20	> 360	21
	7	8	6	15	53	102	63	22	21
mean		6	6	16	32	38	26	> 165	25
(SD)		2	1	4	15	30	20	(>145)	9
3	1	9	13	31	49	26	45	88	22
	2	8	8	8	35	23	22	49	82
	3	10	6	15	26	82	12	145	45
	4	5	7	15	31	18	68	61	40
	5	6	8	10	14	20	12	60	24
	6	6	7	26	10	26	18	59	55
	7	5	7	7	18	21	10	22	21
	8	11	6	22	31	15	21	90	21
	9	16	8	6	28	23	9	44	238
mean		8	8	16	27	28	24	69	61
(SD)		4	2	9	12	20	20	35	69

[a] Each trial conducted with 3 fish selected randomly from the test stream.

[b] Test repeated using same 3 fish.

c Time for fish to consume a live fruit fly placed on stream surface 60 cm upstream from fish.

TABLE 10. Effect of differing strengths of suspended placer mining sediment on the feeding response to surface drift (*Drosophila melanogaster*) for underyearling Arctic grayling held in test streams for 1 hour prior to testing.

		Feeding response time (seconds)[c]							
		0 (control)		100 $mg \cdot L^{-1}$ Sediment		300 $mg \cdot L^{-1}$ Sediment		1000 $mg \cdot L^{-1}$ Sediment	
Trial no.[a]	Replicate no. [b]	Stream 4	Stream 8	Stream 2	Stream 5	Stream 3	Stream 6	Stream 1	Stream 7
1	1	19	7	>360	>360	>360	285	>360	45
	2	6	11	13	24	>360	175	>360	209
	3	4	19	74	11	>360	156	>360	288
	4	26	9	72	21	50	54	>360	>360
	5	4	6	14	14	>360	13	>360	160
mean		12	10	>107	>86	>298	137	>360	>213
(SD)		10	5	145	153	139	107	0	121
2	1	21	85	>360	260	>360	320	>360	360
	2	12	31	226	100	80	29	310	360
	3	10	27	17	206	>360	187	>360	342
	4	5	5	23	47	114	43	>360	360
	5	6	6	10	16	18	37	>360	360
	6	4	6	21	28	85	27	>360	360
	7	12	12	21	20	69	14	>360	360
mean		10	25	>97	97	>155	94	>353	>357
(SD)		6	29	140	98	143	116	19	7

[a] Each trial conducted with 3 fish selected randomly from the outside rearing tank.

[b] Test repeated using same 3 fish.

[c] Time for fish to consume a live fruit fly placed on stream surface 60 cm upstream from fish.

TABLE 11. Effect of differing strengths of suspended placer mining sediment on the feeding response to sub-surface drift (*Artemia salina*) for underyearling Arctic grayling held in test streams for 6 weeks.

Trial no.[a]	Observation time (min)[b]	Total no. of brine shrimp consumed (n=10)[c]							
		0 (control)		100 $mg \cdot L^{-1}$ Sediment		300 $mg \cdot L^{-1}$ Sediment		1000 $mg \cdot L^{-1}$ Sediment	
		Stream 4	Stream 8	Stream 2	Stream 5	Stream 3	Stream 6	Stream 1	Stream 7
1	1	8	7	8	5	4	5	0	1
	3	10	10	10	10	7	10	0	1
	5	-	-	-	-	9	-	0	2
	10	-	-	-	-	10	-	0	3
	15	-	-	-	-	-	-	0	3
	30	-	-	-	-	-	-	1	6
	45	-	-	-	-	-	-	7	6
	60	-	-	-	-	-	-	8	6
2	1	4	8	5	4	5	8	0	1
	3	8	10	10	8	7	9	0	1
	5	10	-	-	10	9	10	0	3
	10	-	-	-	-	10	-	0	4
	15	-	-	-	-	-	-	0	4
	30	-	-	-	-	-	-	0	5
	45	-	-	-	-	-	-	0	5
	60	-	-	-	-	-	-	0	7
3	1	6	7	6	10	7	5	0	1
	3	9	10	10	-	10	10	1	1
	5	10	-	-	-	-	-	1	1
	10	-	-	-	-	-	-	1	1
	15	-	-	-	-	-	-	2	1
	30	-	-	-	-	-	-	2	2
	45	-	-	-	-	-	-	3	2
	60	-	-	-	-	-	-	4	2
	Reponse time (min)[d]	4 (3-5)	3	3	3 (1-5)	8 (3-10)	4 (3-5)	60	60

[a] Each trial conducted with 3 fish selected randomly from the test stream.

[b] Baskets raised at fixed time intervals in order to count no. of brine shrimp uneaten.

[c] Ten live brine shrimp placed in a nylon-mesh basket submersed in the test stream, and fish introduced at time 0.

[d] Mean time to consumption of all brine shrimp (range in parentheses).

TABLE 12. Effect of differing strengths of suspended placer mining sediment on the feeding response to a benthic invertebrate (tubificid worms) for underyearling Arctic grayling held in test streams for 5 weeks vs. 1 hour prior to testing.

Duration of sediment exposure	Trial no.[a]	Observation time (min)[b]	Total no. of worms consumed (n=10)[c]							
			0 (control)		100 mg·L^{-1} Sediment		300 mg·L^{-1} Sediment		1000 mg·L^{-1} Sediment	
			Stream 4	Stream 8	Stream 2	Stream 5	Stream 3	Stream 6	Stream 1	Stream 7
5 weeks	1	1	6	6	6	7	5	8	0	0
		3	6	7	7	9	8	10	0	0
		5	7	8	8	10	9	-	0	0
		10	9	10	9	-	10	-	0	0
		15	10	-	10	-	-	-	0	0
		30	-	-	-	-	-	-	1	0
		45	-	-	-	-	-	-	1	0
		60	-	-	-	-	-	-	1	0
5 weeks	2	1	5	3	3	4	8	7	0	0
		3	7	6	3	10	10	8	0	0
		5	8	8	9	-	-	8	0	0
		10	10	9	10	-	-	10	0	0
		15	-	10	-	-	-	-	0	0
		30	-	-	-	-	-	-	0	0
		45	-	-	-	-	-	-	0	0
		60	-	-	-	-	-	-	0	0
5 weeks	3	1	6	8	8	9	0	7	0	0
		3	10	10	10	10	0	8	0	0
		5	-	-	-	-	4	10	0	0
		10	-	-	-	-	9	-	0	0
		15	-	-	-	-	10	-	0	0
		30	-	-	-	-	-	-	1	0
		45	-	-	-	-	-	-	1	0
		60	-	-	-	-	-	-	1	0
Response time (min)[d]			9 (3-15)	9 (3-15)	9 (3-15)	4 (3-5)	9 (3-15)	6 (3-10)	>60	>60
1 hour	1	1	8	7	4	1	5	8	0	0
		3	9	9	4	8	7	10	0	0
		5	10	10	6	10	10	-	0	0
		10	-	-	10	-	-	-	0	0
		15	-	-	-	-	-	-	0	0
		30	-	-	-	-	-	-	0	0
		45	-	-	-	-	-	-	0	0
		60	-	-	-	-	-	-	0	0
Response time (min)[d]			5	5	10	5	5	3	>60	>60

[a] Each trial conducted with 3 fish selected randomly from the test stream/outside tank.

[b] Baskets raised at fixed time intervals in order to count no. of worms uneaten.

[c] Ten live tubifex worms placed in a nylon-mesh basket submersed in the test stream, and fish introduced at time 0.

[d] Mean time to consumption of all worms (range in parentheses).

TABLE 13. Length, weight, and condition factor of underyearling Arctic grayling following exposure to differing strengths of suspended placer mining sediment for 3 or 6 weeks.

Duration of exposure (weeks)	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	No. of fish	Fish length (cm)		Fish weight (g)		Condition factor (K)	
				Mean	SD	Mean	SD	Mean	SD
3	0	4	10	4.8	0.5	0.99	0.28	0.86	0.07
	0	8	10	4.8	0.6	1.01	0.34	0.86	0.11
	100	2	10	4.8	0.3	0.93	0.23	0.83	0.05
	100	5	10	4.9	0.4	1.13	0.29	0.96	0.07
	300	3	10	4.9	0.2	1.00	0.20	0.85	0.07
	300	6	10	4.8	0.5	1.07	0.29	0.95	0.07
	1000	1	10	4.6	0.4	0.82	0.22	0.82	0.05
	1000	7	10	4.6	0.3	0.95	0.24	0.96	0.08
6	0	4	45	5.4	0.6	1.40	0.49	0.85	0.10
	0	8	42	5.5	0.5	1.39	0.41	0.81	0.11
	100	2	47	5.2	0.5	1.30	0.37	0.90	0.11
	100	5	45	5.3	0.5	1.38	0.45	0.89	0.09
	300	3	47	5.2	0.5	1.30	0.44	0.92	0.11
	300	6	44	5.3	0.5	1.33	0.35	0.88	0.09
	1000	1	43	4.9	0.4	1.01	0.25	0.83	0.11
	1000	7	47	5.1	0.4	1.18	0.28	0.88	0.08

TABLE 14. Biological characteristics determined for underyearling Arctic grayling[a] following exposure to different strengths of suspended placer mining sediment for 6 weeks.

Variable	Statistic	Nominal strength of suspended sediment ($mg \cdot L^{-1}$)							
		0 (control)		100		300		1000	
		Stream 4	Stream 8	Stream 2	Stream 5	Stream 3	Stream 6	Stream 1	Stream 7
length	mean	5.1	5.5	5.2	5.3	5.2	5.4	5.0	5.0
(cm)	SD	0.6	0.4	0.4	0.5	0.3	0.3	0.5	0.5
weight	mean	1.18	1.31	1.19	1.25	1.18	1.36	0.98	1.05
(g)	SD	0.41	0.27	0.25	0.35	0.24	0.29	0.26	0.34
condition	mean	0.84	0.78	0.85	0.82	0.82	0.85	0.78	0.80
factor (K)	SD	0.08	0.09	0.10	0.06	0.05	0.05	0.06	0.07
body	mean	77	78	78	77	77	77	79	78
moisture (%)	SD	1	1	1	1	2	2	1	1
hematocrit	mean	34	30	36	29	35	31	28	30
(%)	SD	7	3	5	5	6	4	4	5
leucocrit	mean	1.0	1.0	0.9	1.0	0.9	1.0	1.0	0.9
(%)	SD	0.4	0.2	0.2	0.2	0.1	0.2	0.2	0.2
plasma	mean	62	60	68	58	67	62	57	59
glucose (mg%)	SD	8	12	7	7	8	7	8	6

[a] Values determined for groups of 10 fish sampled randomly from each test stream.

TABLE 15. Acute lethal tolerance of underyearling Arctic grayling to the reference toxicant pentachlorophenol following exposure to differing strengths of suspended placer mining sediment for 3 weeks.

Suspended sediment strength (mg·L^{-1})	Stream no.	Fish weight (g)		Time to death (min) in 150 ug·L^{-1} pentachlorophenol[a]	
		Mean	SD	LT50[b]	95% CI[c]
0	4	0.99	0.28	280	247-316
0	8	1.01	0.34	255	224-291
100	2	0.93	0.23	320*	286-358
100	5	1.23	0.29	310*	277-347
300	3	1.00	0.20	290	266-316
300	6	1.07	0.29	290	257-328
1000	1	0.82	0.22	250	219-285
1000	7	0.95	0.24	275	248-305

[a]Determined by exposing groups of 10 fish to 30-L volumes of pentachlorophenol dissolved in clear (NFR < 5 mg·L^{-1}) freshwater.

[b]Lethal time to 50% mortality of test fish.

[c]95% confidence interval.

*Pooled value for treatment differs significantly ($P < 0.05$) from that for controls.

TABLE 16. Acute lethal tolerance of underyearling grayling to the reference toxicant pentachlorophenol following exposure to differing strengths of suspended placer mining sediment for 6 weeks.

Suspended sediment strength ($mg \cdot L^{-1}$)	Stream no.	Fish weight (g)		Time to death (min) in 150 $ug \cdot L^{-1}$ pentachlorophenol[a]	
		Mean	SD	LT50[b]	95% CI[c]
0	4	1.46	0.47	285	261-311
0	8	1.57	0.55	310	258-372
100	2	1.24	0.37	302	288-317
100	5	1.32	0.48	300	283-318
300	3	1.53	0.53	265*	234-299
300	6	1.42	0.49	235*	208-266
1000	1	0.91	0.22	260*	226-299
1000	7	1.11	0.20	265*	250-281

[a]Determined by exposing groups of 10 fish to 30-L volumes of pentachlorophenol dissolved in clear (NFR <5 $mg \cdot L^{-1}$) freshwater.

[b]Lethal time to 50% mortality of test fish.

[c]95% confidence interval.

*Pooled value for treatment differs significantly ($P < 0.05$) from that for controls.

TABLE 17. Response of underyearling Arctic grayling to hypoxia[a] following exposure to differing strengths of suspended placer mining sediment for 6 weeks.

Suspended sediment strength ($mg \cdot L^{-1}$)	Stream no.	Fish weight (g)		Time to death (min)		Residual oxygen at death ($mg\ O_2 \cdot L^{-1}$)		
		Mean	SD	LT50[b]	95% CI[c]	Mean	SD	Range
0	4	1.28	0.30	147	134 - 162	2.7	0.5	1.8 - 3.2
0	8	1.11	0.27	158	140 - 179	2.9	0.2	2.4 - 3.2
100	2	1.29	0.31	145	134 - 157	2.7	0.3	2.2 - 3.0
100	5	1.28	0.17	145	134 - 157	2.4	0.3	2.0 - 3.2
300	3	1.25	0.35	125*	113 - 139	3.1	0.5	2.3 - 3.9
300	6	1.45	0.24	115*	106 - 124	2.9	0.8	2.1 - 4.5
1000	1	1.15	0.20	125*	112 - 140	3.2	0.4	2.6 - 3.6
1000	7	1.29	0.34	125*	116 - 135	2.6	0.4	2.2 - 3.5

[a]Determined by sealed jar bioassays (n = 10) with test suspensions at 20 °C.
[b]Lethal time to 50% mortality of test fish.
[c]95% confidence interval.

*Pooled value for treatment differs significantly ($P < 0.05$) from that for controls.

TABLE 18. Upper lethal temperature tolerance of underyearling Arctic grayling following exposure to differing strengths of suspended placer mining sediment for 6 weeks.

Suspended sediment strength ($mg \cdot L^{-1}$)	Stream no.	Sample size (n)	Acclimation temperature[a] (°C)		Temperature at death[b] (°C)		
			Mean	SD	Mean	SD	Range
0	4	15	15.2	0.4	27.7	0.3	26.9 - 28.2
0	8	8	14.0	0.4	27.0	0.7	26.0 - 27.7
100	2	17	15.1	0.3	27.7	0.3	26.8 - 27.9
100	5	15	15.6	0.4	27.9	0.3	27.2 - 28.1
300	3	17	15.4	0.4	28.0	0.2	27.8 - 28.2
300	6	14	15.1	0.4	27.7	0.1	27.5 - 28.1
1000	1	9	14.9	0.4	27.7	0.1	27.6 - 27.8
1000	7	17	14.9	0.6	27.8	0.2	27.6 - 28.0

[a]Based on daily record of water temperature in each test stream.

[b]Determined by increasing the temperature of each suspension at $1^{\circ}C \cdot h^{-1}$ until all fish were dead.

Figure 1. Illustration of test streams showing reservoir barrels, barrel stirrers, peristaltic pumps for dispensing sediment suspensions, recycle pumps and air supply.

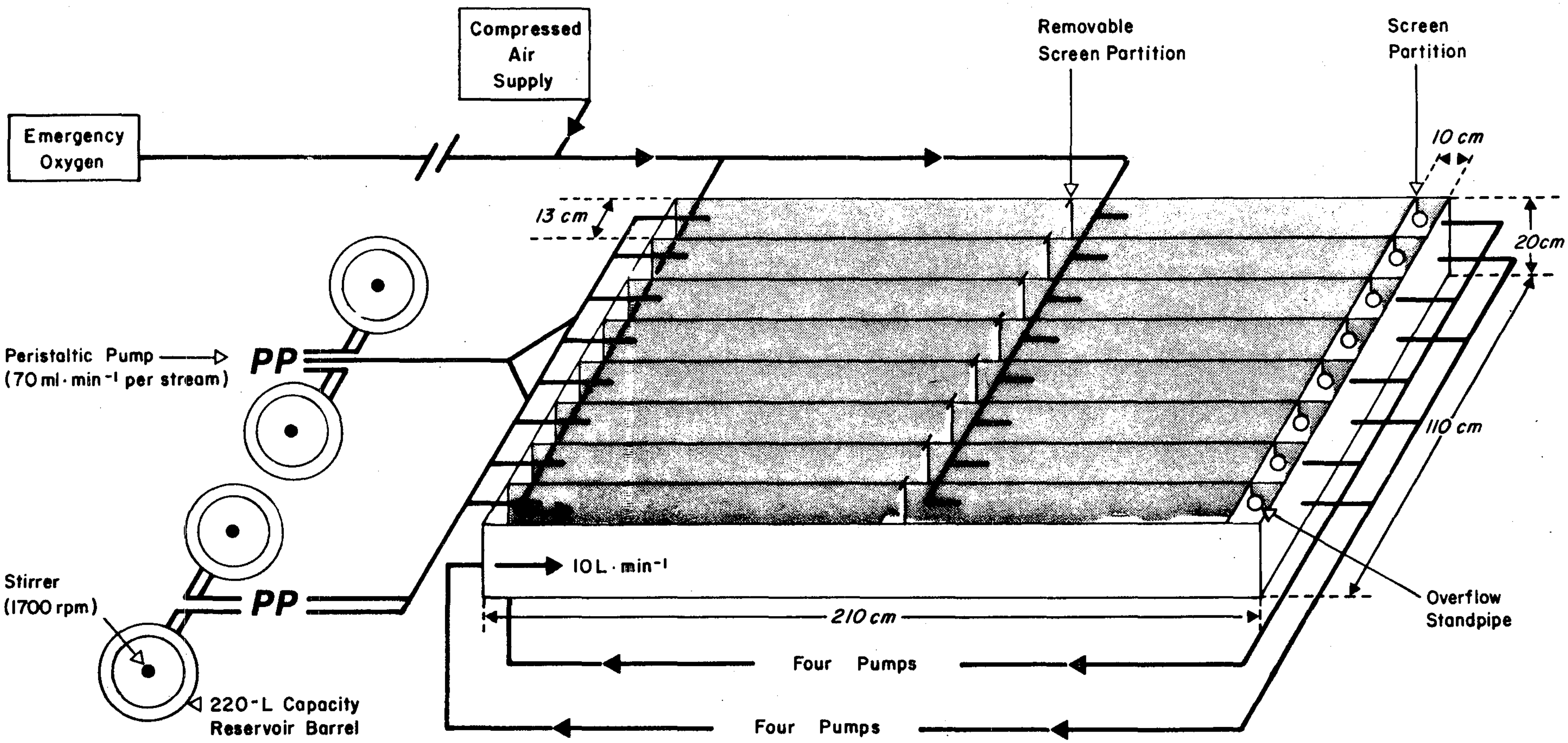

Compressed Air Supply
Emergency Oxygen
Removable Screen Partition
Screen Partition
10 cm
13 cm
20cm
Peristaltic Pump
(70 ml · min⁻¹ per stream)
PP
PP
110 cm
Stirrer
(1700 rpm)
10 L · min⁻¹
Overflow Standpipe
210 cm
220-L Capacity Reservoir Barrel
Four Pumps
Four Pumps

Figure 2. Relationship of nonfiltrable residue (NFR) concentration of placer mining sediment added to barrel vs. suspended sediment strength within test streams.

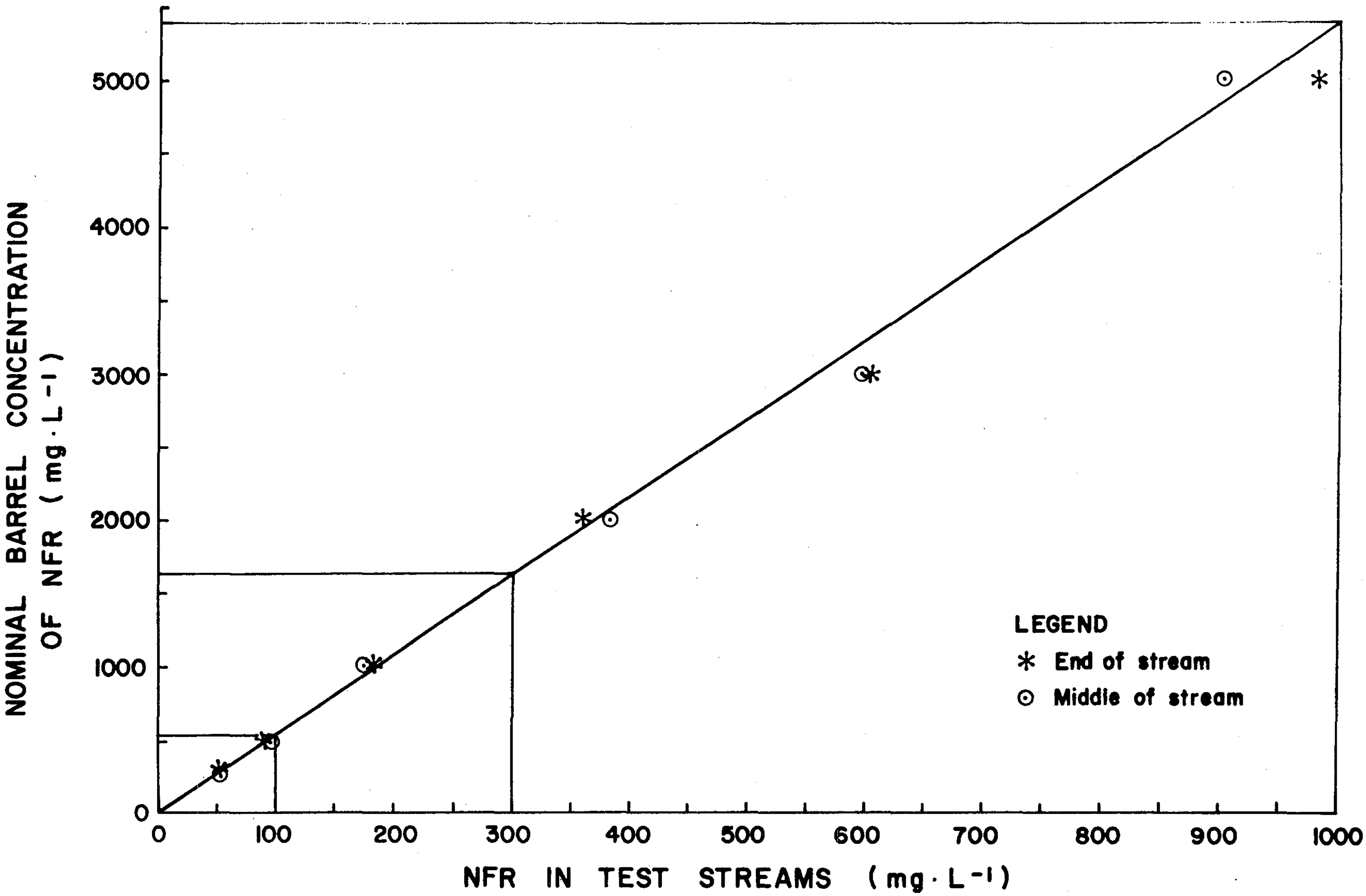

NOMINAL BARREL CONCENTRATION
OF NFR (mg · L⁻¹)
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
700
800
900
1000
NFR IN TEST STREAMS (mg · L⁻¹)
LEGEND
* End of stream
⊙ Middle of stream

Figure 3. Illustration of daily fluctuations in concentration of nonfiltrable residue within each test stream throughout the 6-week exposure period.

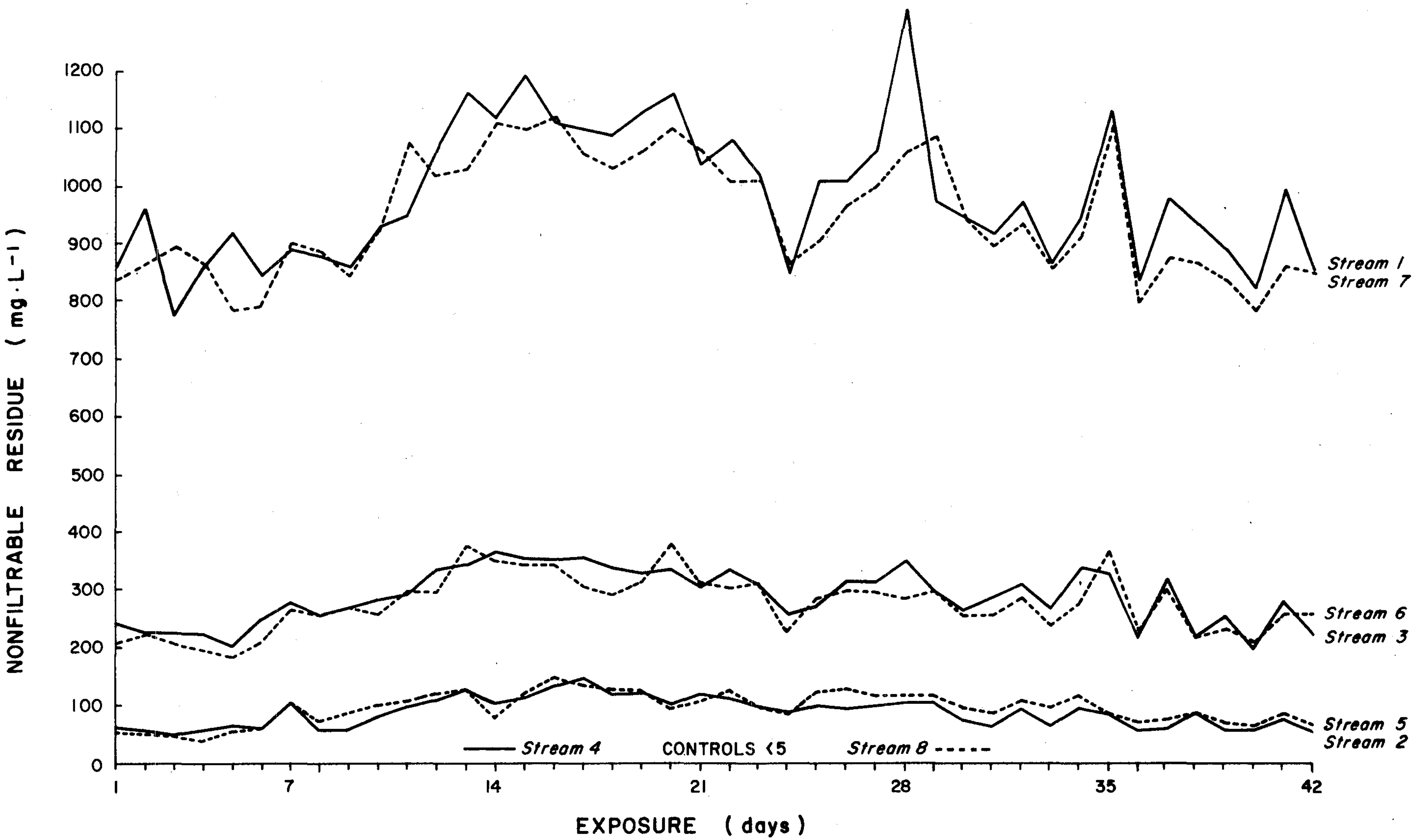
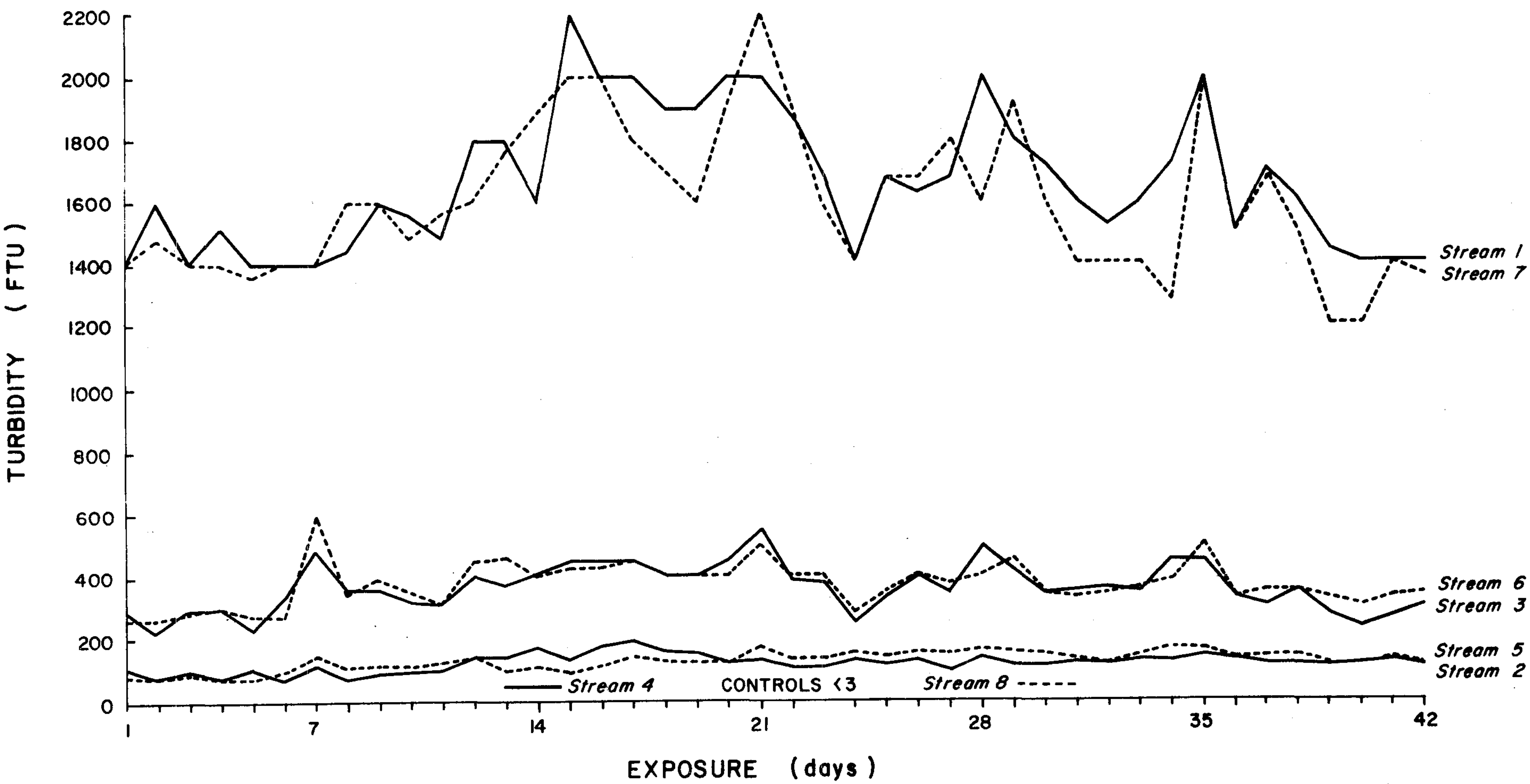

NONFILTRABLE RESIDUE (mg·L⁻¹)
EXPOSURE (days)
Stream 1
Stream 7
Stream 6
Stream 3
Stream 5
Stream 2
Stream 4
CONTROLS <5
Stream 8

Figure 4. Illustration of daily fluctuations in turbidity within each test stream throughout the 6-week exposure period.



TURBIDITY (FTU)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
7
14
21
28
35
42
EXPOSURE (days)
Stream 1
Stream 7
Stream 6
Stream 3
Stream 5
Stream 2
Stream 4
CONTROLS <3
Stream 8

Figure 5. Effect of suspended placer mining sediment on the growth (weekly wet weight gain) of underyearling Arctic grayling. Mean values for each treatment are shown, together with the 95% confidence intervals at 6 weeks only.

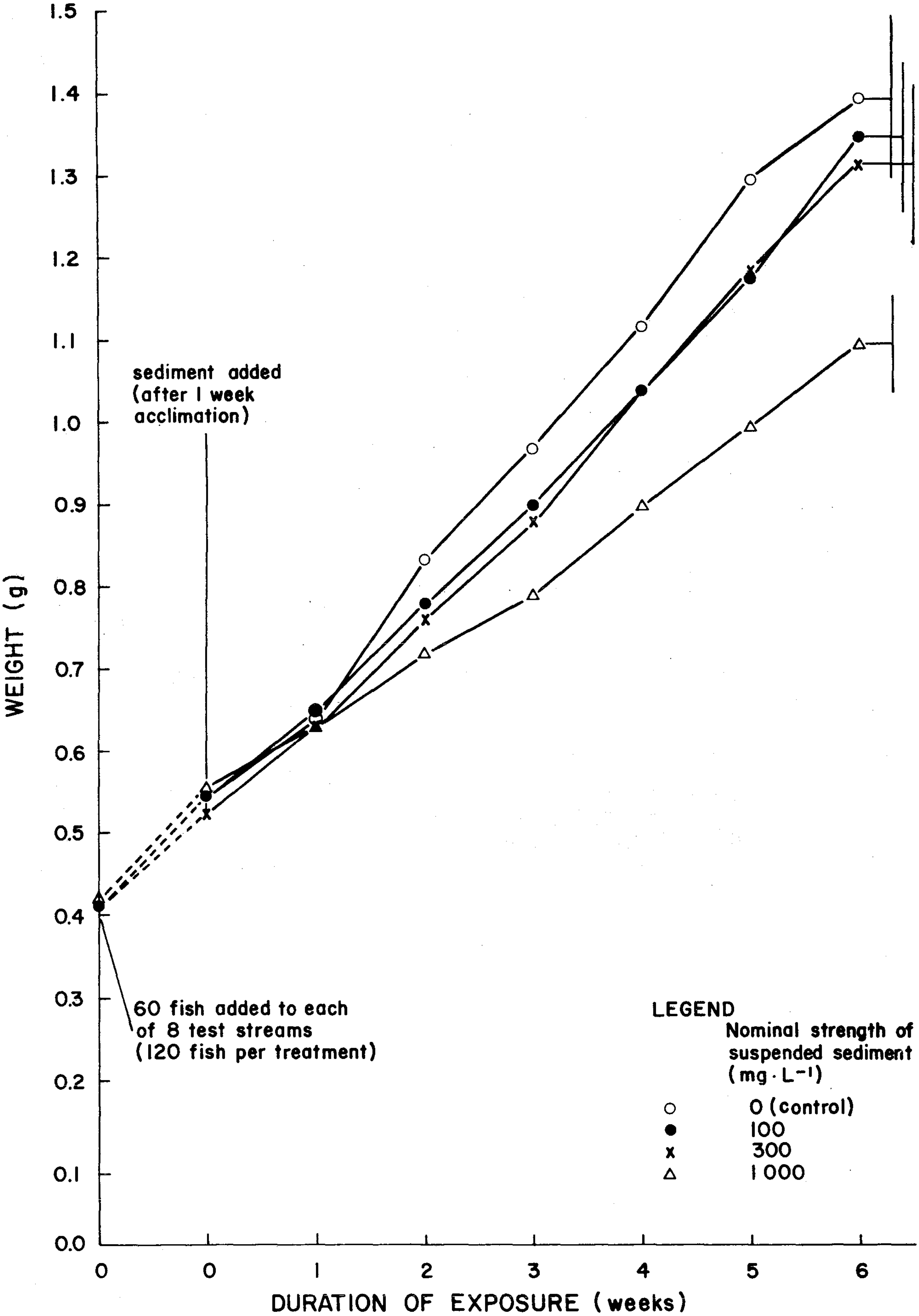
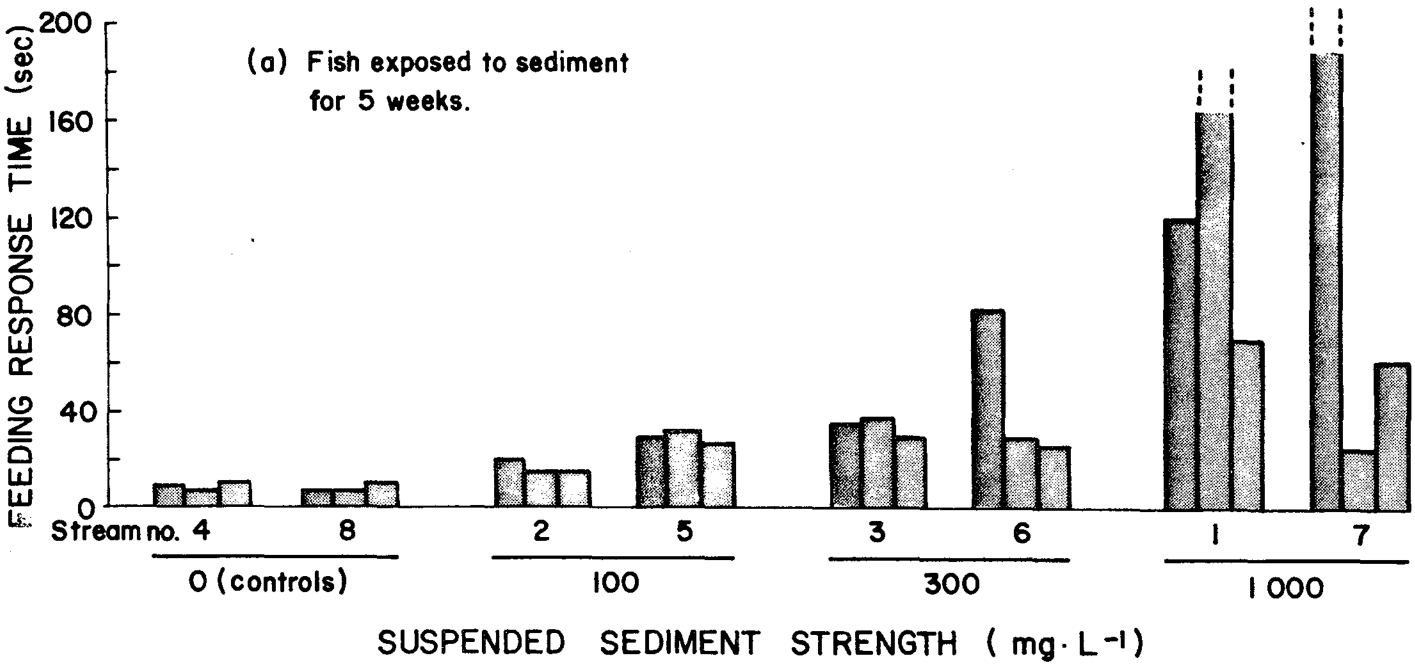

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
WEIGHT (g)
sediment added
(after 1 week
acclimation)
60 fish added to each
of 8 test streams
(120 fish per treatment)
LEGEND
Nominal strength of
suspended sediment
(mg · L⁻¹)
0 (control)
100
300
1 000
0
0
1
2
3
4
5
6
DURATION OF EXPOSURE (weeks)

Figure 6. Illustration of effect of differing strengths of suspended placer mining sediment on feeding response for underyearling Arctic grayling held in test streams for (a) 5 weeks or (b) 1 hour prior to testing. Bars represent mean values for separate trials, and broken extensions of bars represent "greater than" values.


(a) Fish exposed to sediment for 5 weeks.
FEEDING RESPONSE TIME (sec)
200
160
120
80
40
0
Stream no. 4
8
2
5
3
6
1
7
0 (controls)
100
300
1 000
SUSPENDED SEDIMENT STRENGTH (mg · L-1)

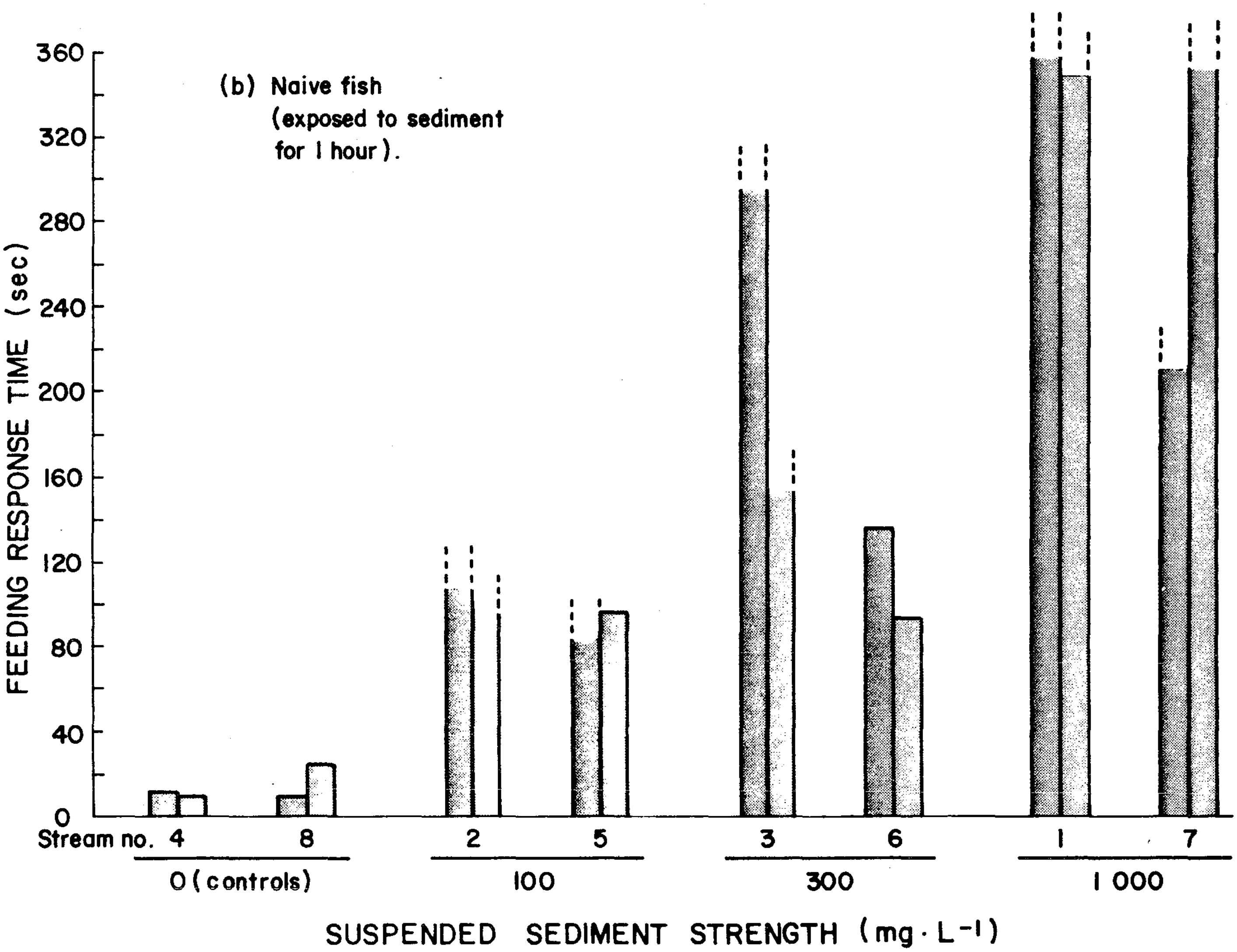
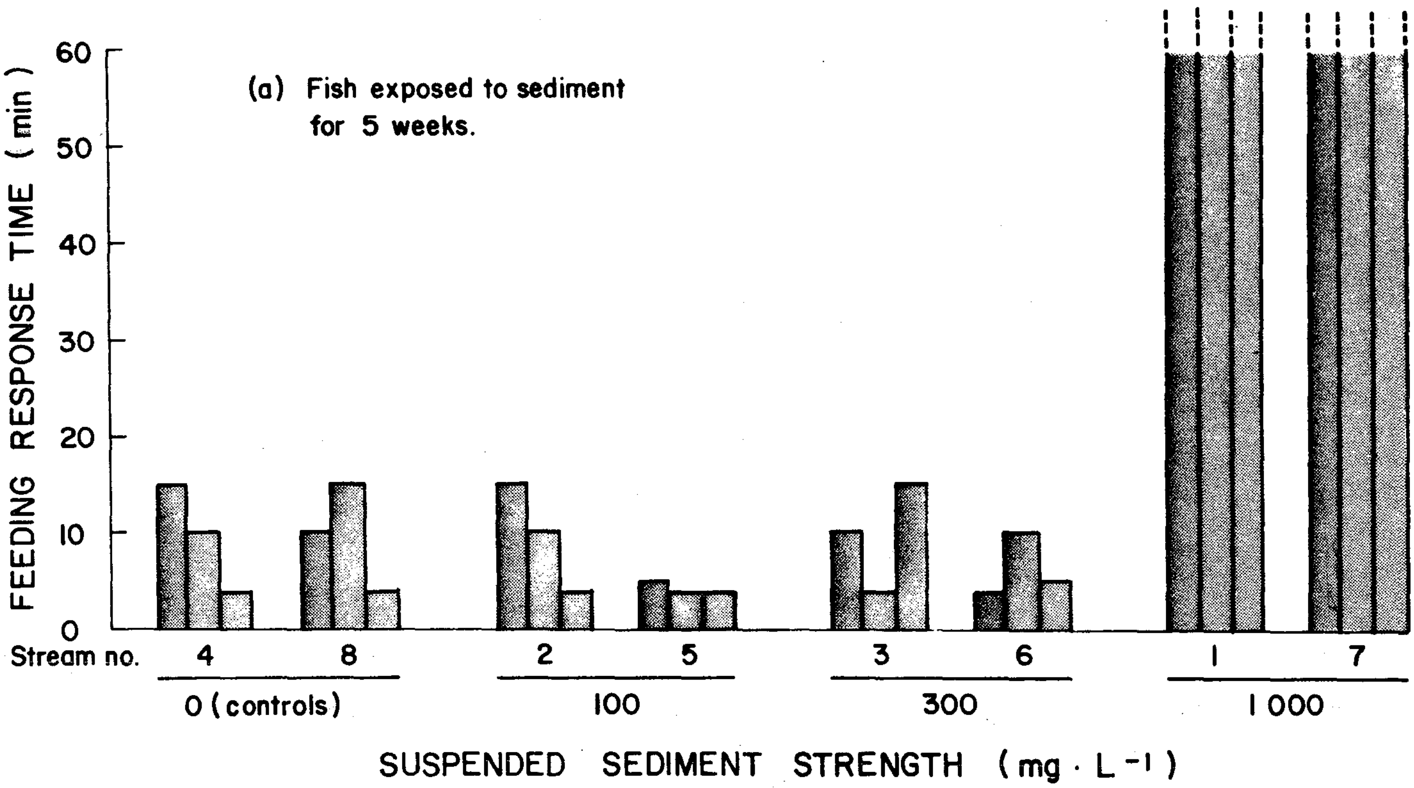
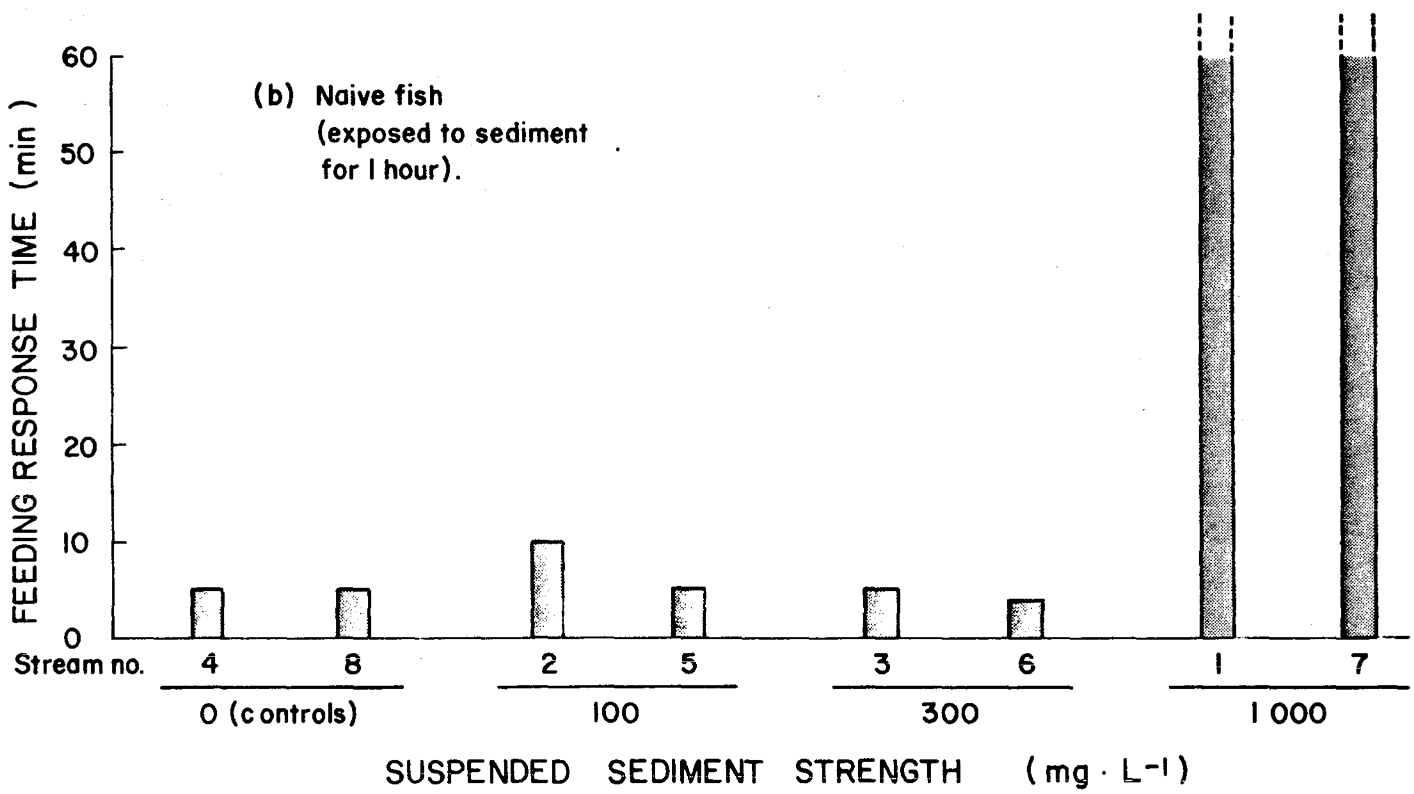

(b) Naive fish (exposed to sediment for 1 hour).
FEEDING RESPONSE TIME (sec)
360
320
280
240
200
160
120
80
40
0
Stream no. 4
8
2
5
3
6
1
7
0 (controls)
100
300
1 000
SUSPENDED SEDIMENT STRENGTH (mg · L-1)

Figure 7. Illustration of effect of differing strengths of suspended placer mining sediment on time to consume groups of 10 sub-surface drift organisms (*Artemia salina*) for underyearling Arctic grayling held in test streams for 6 weeks prior to testing. Bars represent values derived for each trial, and broken extensions of bars represent "greater than" values.



(a) Fish exposed to sediment for 5 weeks.
FEEDING RESPONSE TIME (min)
60
50
40
30
20
10
0
Stream no.
4
8
2
5
3
6
1
7
0 (controls)
100
300
1 000
SUSPENDED SEDIMENT STRENGTH (mg · L -1)



(b) Naive fish (exposed to sediment for 1 hour).
FEEDING RESPONSE TIME (min)
60
50
40
30
20
10
0
Stream no.
4
8
2
5
3
6
1
7
0 (controls)
100
300
1 000
SUSPENDED SEDIMENT STRENGTH (mg · L-1)

Figure 8. Illustration of effect of differing strengths of suspended placer mining sediment on time to consume groups of 10 benthic worms (tubificids) for underyearling Arctic grayling held in test streams for (a) 5 weeks or (b) 1 hour prior to testing. Bars represent values derived for each trial and broken extensions of bars represent "greater than" values.

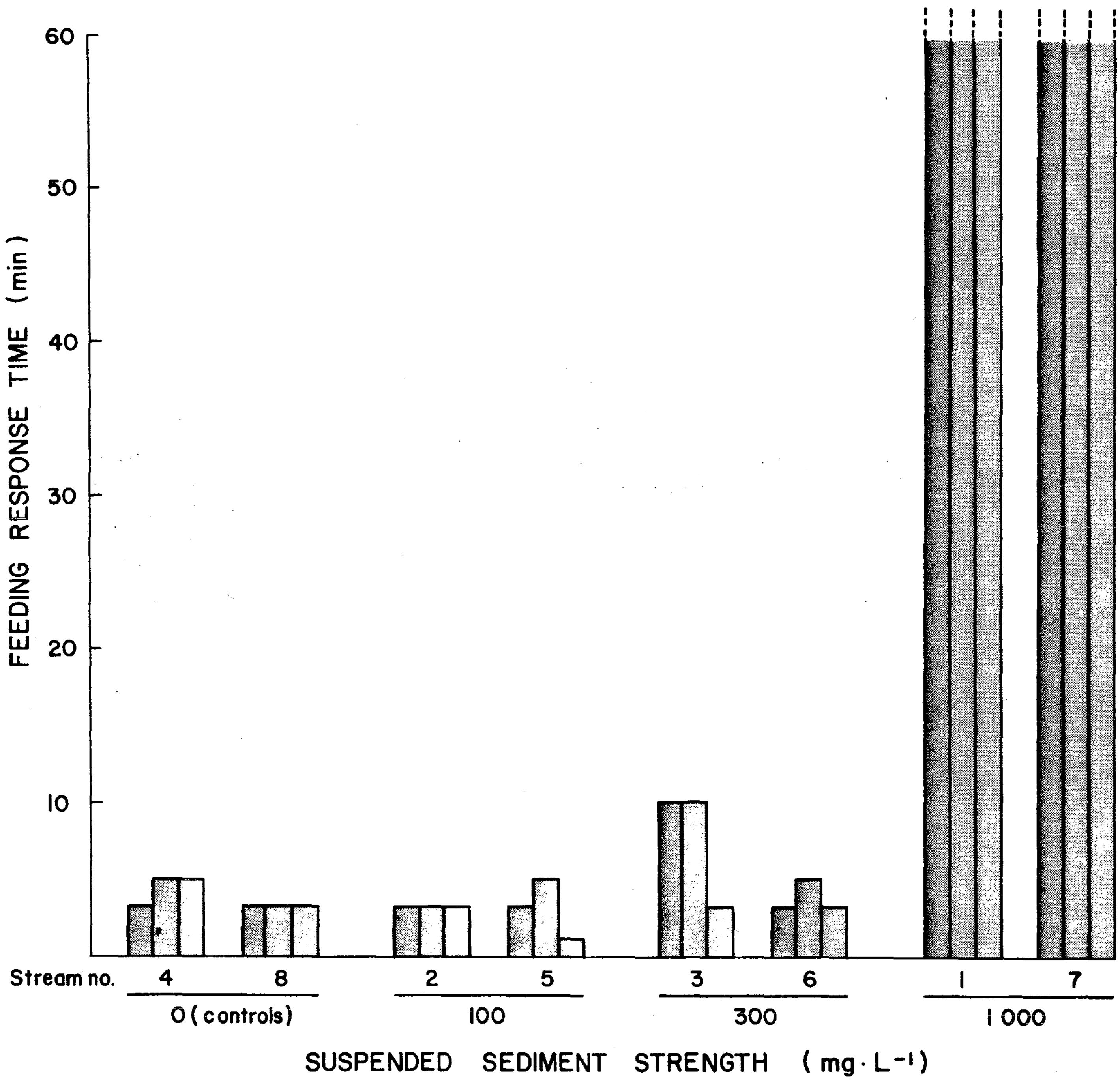

60
50
40
30
20
10
FEEDING RESPONSE TIME (min)
Stream no.
4
8
2
5
3
6
1
7
0 (controls)
100
300
1 000
SUSPENDED SEDIMENT STRENGTH (mg · L⁻¹)

Figure 9. Effect of 3-week exposure of underyearling Arctic grayling to suspended placer mining sediment on their acute lethal tolerance to the reference toxicant pentachlorophenol. Points represent lethal times to 50% mortality of fish (LT50), bars represent 95% confidence intervals.

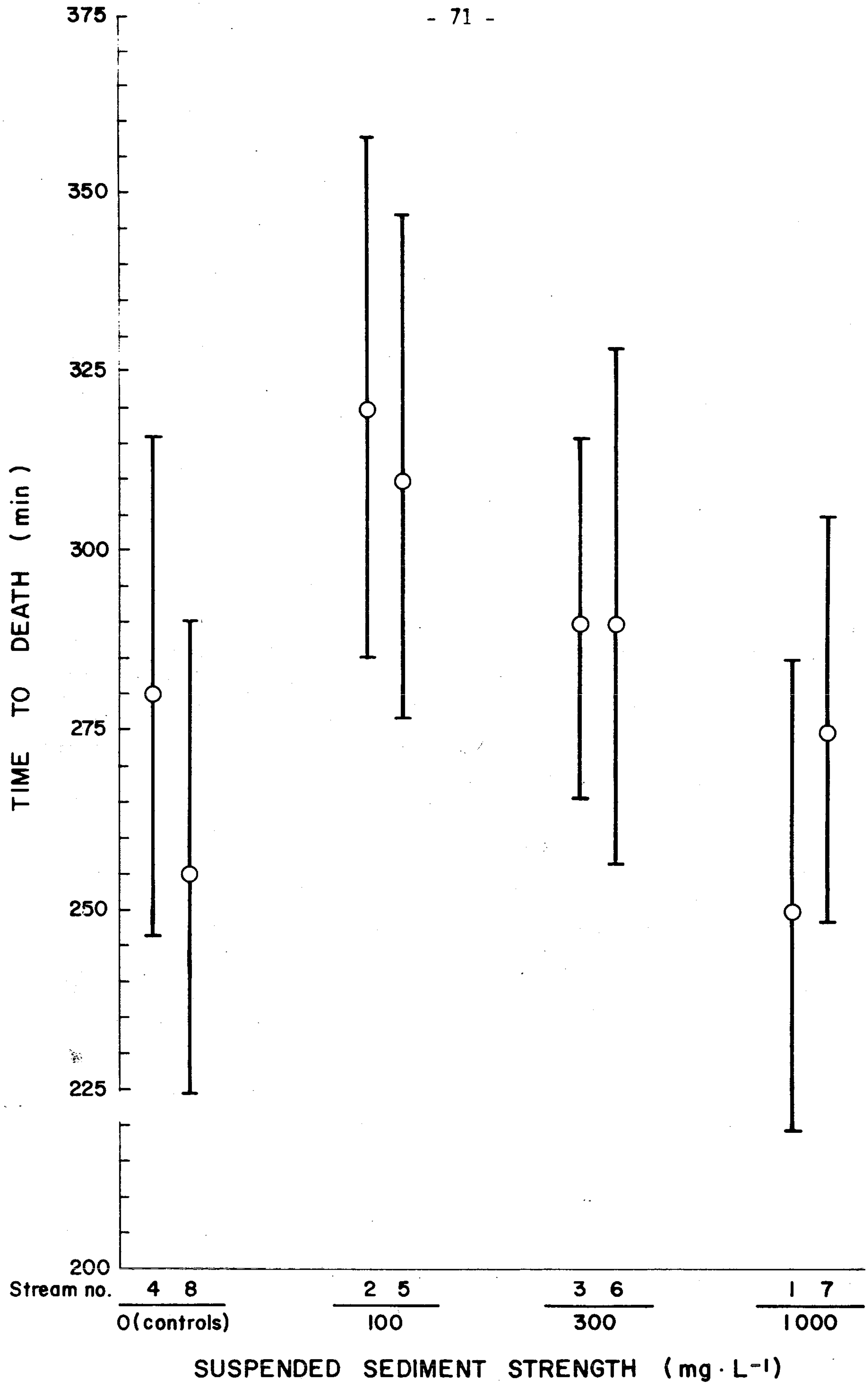

375
350
325
300
275
250
225
200
TIME TO DEATH (min)
Stream no.
4 8
0(controls)
2 5
100
3 6
300
1 7
1000
SUSPENDED SEDIMENT STRENGTH (mg · L-1)

Figure 10. Effect of prolonged (6-week) exposure of under-yearling Arctic grayling to suspended placer mining sediment on their acute lethal tolerance to the reference toxicant pentachlorophenol. Points represent lethal times to 50% mortality of fish (LT50), bars represent 95% confidence intervals.

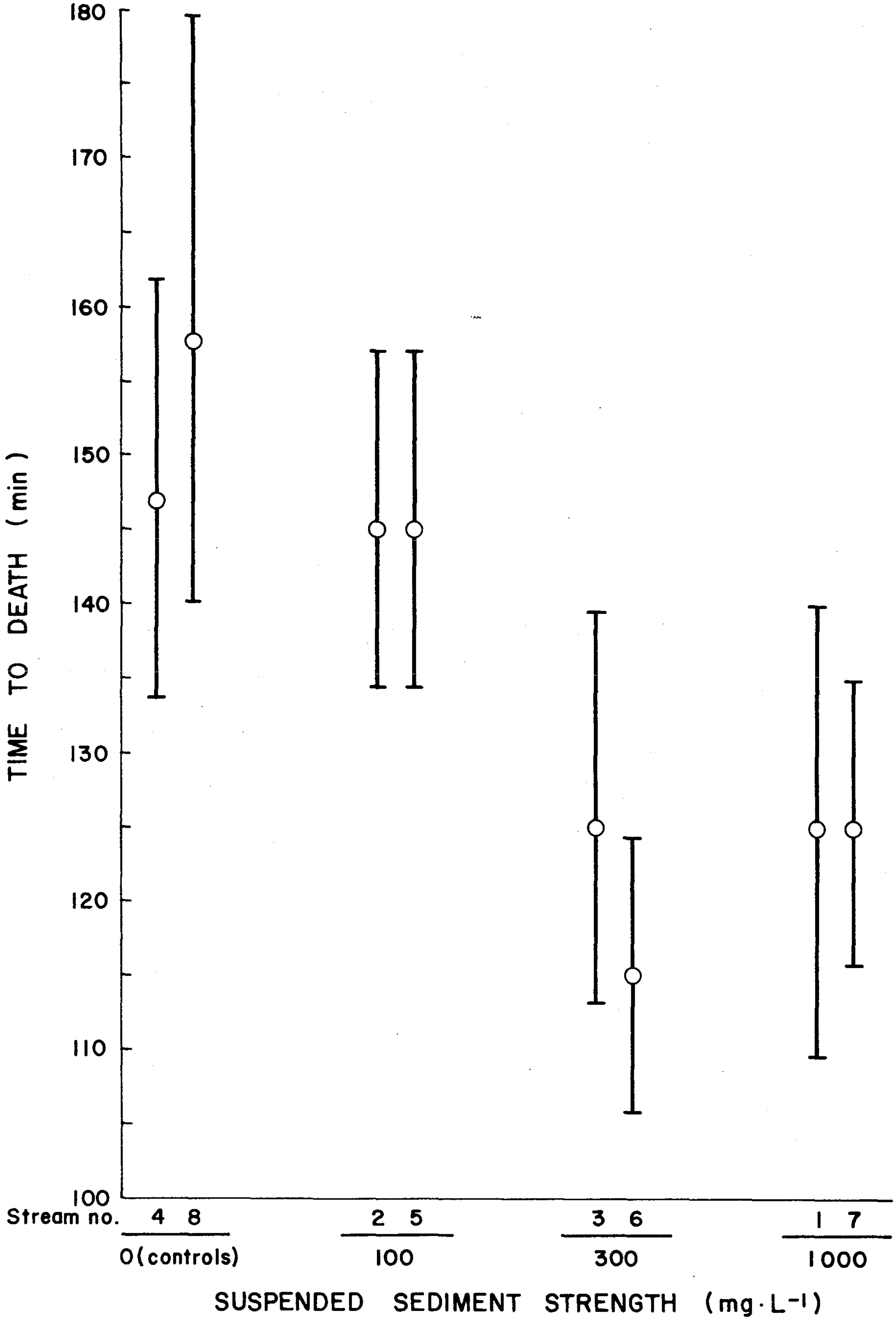

180
170
160
150
140
130
120
110
100
TIME TO DEATH (min)
Stream no.
4 8
0(controls)
2 5
100
3 6
300
1 7
1000
SUSPENDED SEDIMENT STRENGTH (mg·L⁻¹)

Figure 11. Effect of prolonged (6-week) exposure of under-yearling Arctic grayling to suspended placer mining sediment on their residual dissolved oxygen values at death in sealed jar bioassays. Points represent mean values, bars represent 95% confidence intervals.

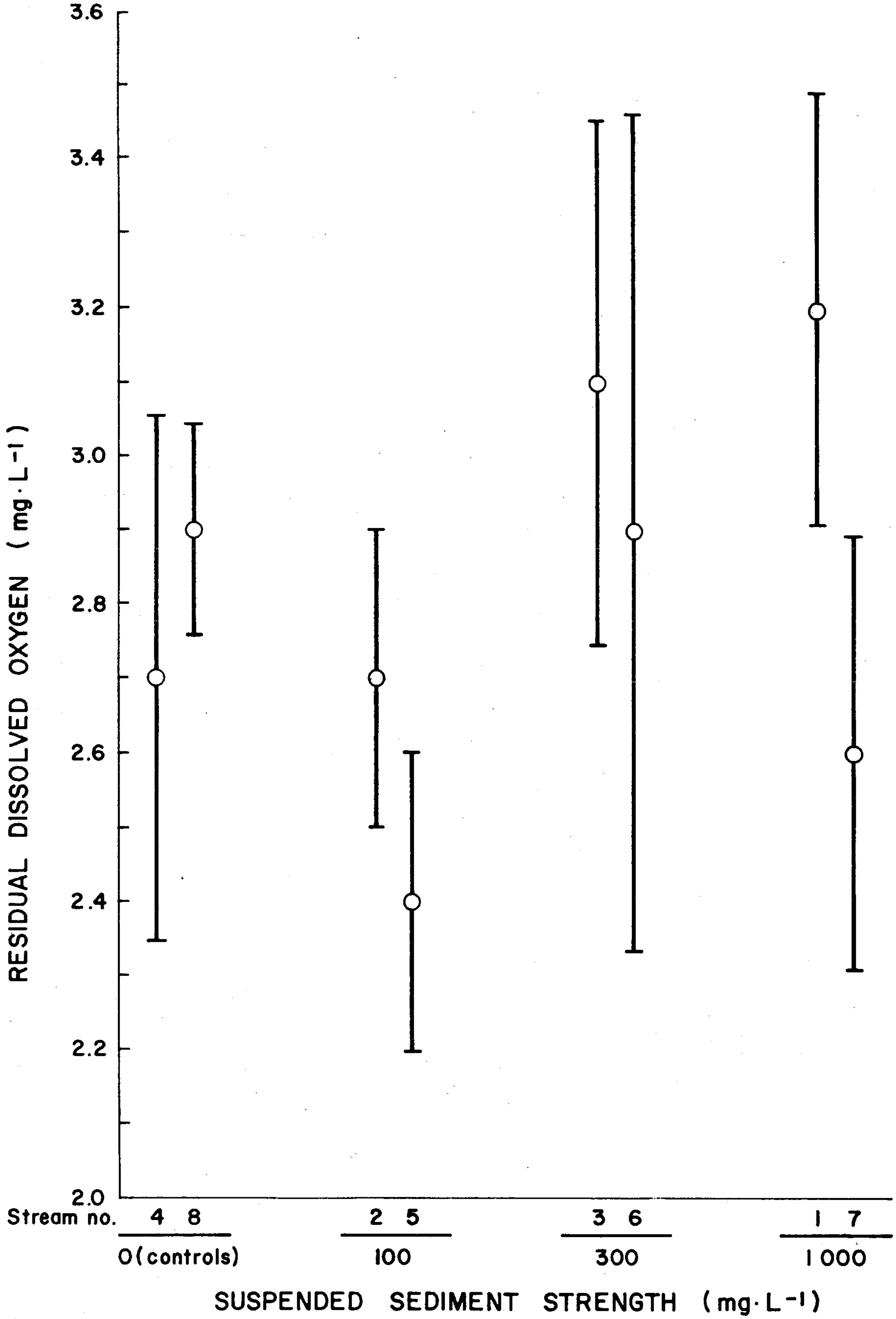

3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
RESIDUAL DISSOLVED OXYGEN (mg·L-1)
Stream no.
4 8
2 5
3 6
1 7
0(controls)
100
300
1000
SUSPENDED SEDIMENT STRENGTH (mg·L-1)

Figure 12. Effect of prolonged (6-week) exposure of under-yearling Arctic grayling to suspended placer mining sediment on their time to death in sealed jar bioassays. Points represent lethal times to 50% mortality of fish (LT50), bars represent 95% confidence intervals.

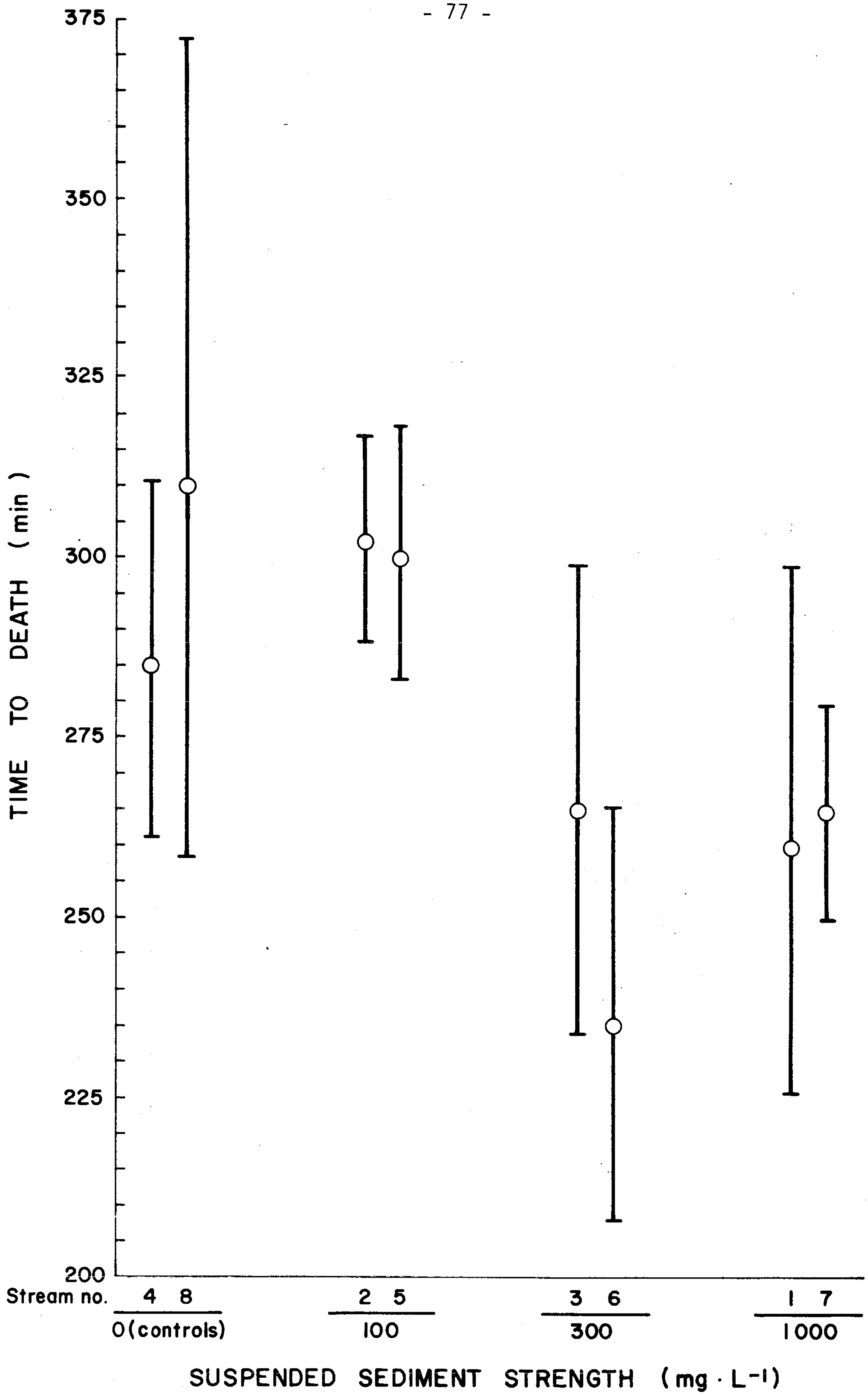
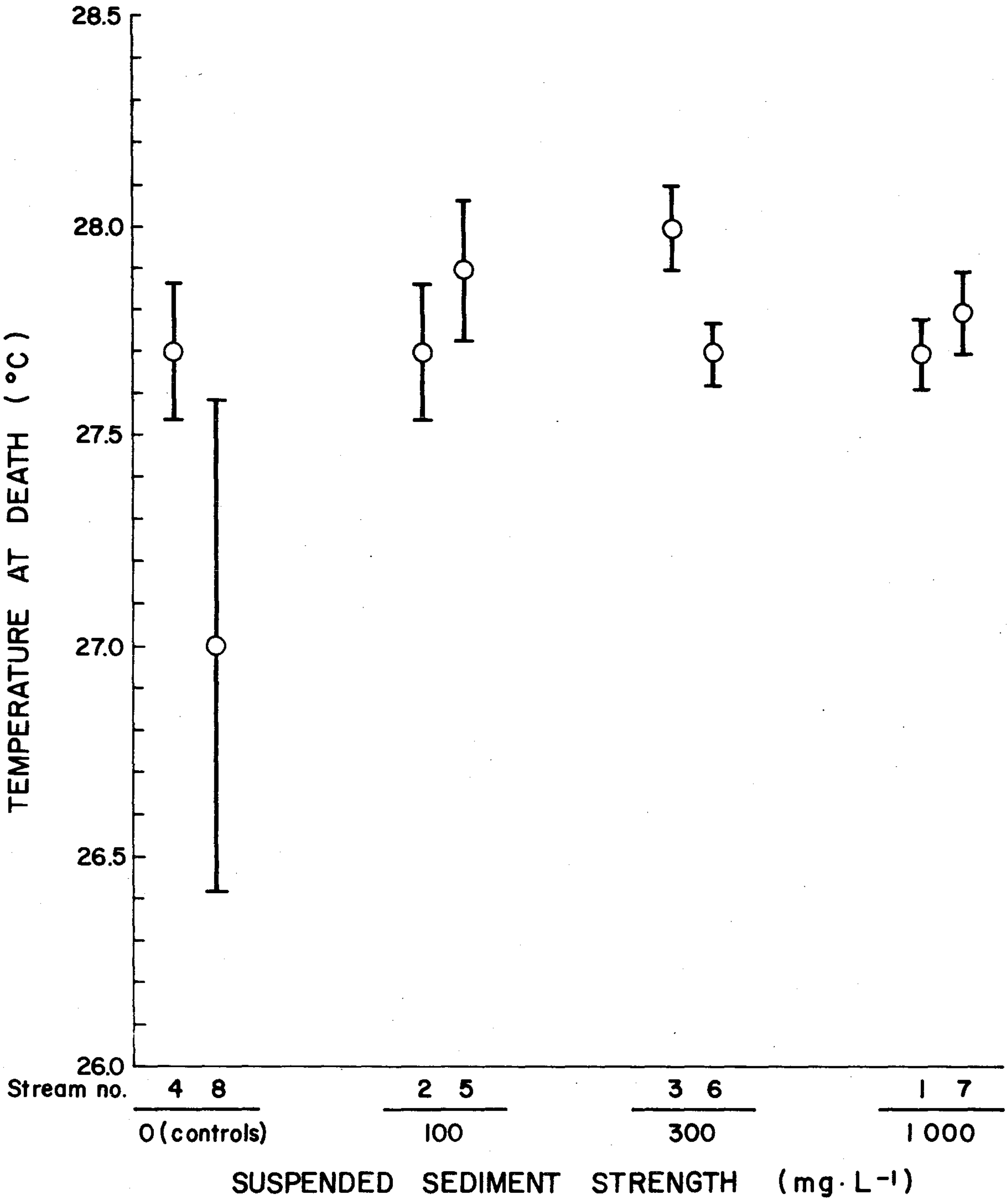

375
350
325
300
275
250
225
200
TIME TO DEATH (min)
Stream no.
4 8
0 (controls)
2 5
100
3 6
300
1 7
1000
SUSPENDED SEDIMENT STRENGTH (mg · L-1)

Figure 13. Effect of prolonged (6-week) exposure of under-yearling Arctic grayling to suspended placer mining sediment on their upper lethal temperature tolerance. Points represent mean temperatures at death, bars represent 95% confidence intervals.


28.5
28.0
27.5
27.0
26.5
26.0
TEMPERATURE AT DEATH (°C)
Stream no.
4 8
2 5
3 6
1 7
0 (controls)
100
300
1 000
SUSPENDED SEDIMENT STRENGTH (mg · L⁻¹)

APPENDIX 1. Daily water quality characteristics in test streams during prolonged exposure of underyearling Arctic grayling to differing strengths of suspended placer mining sediment.

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
14/07/83	0	4	14.5	9.6	6.4	14	<5	1	–[b]
	0	8	13.9	9.6	6.4	14	<5	1	–
	0	2	14.4	9.5	6.4	14	<5	1	–
	0	5	14.5	9.6	6.3	15	<5	1	–
	0	3	14.4	9.6	6.4	14	<5	1	–
	0	6	14.4	9.5	6.4	14	<5	1	–
	0	1	14.3	9.6	6.4	15	<5	1	–
	0	7	14.4	9.6	6.4	14	<5	1	–
15/07/83	0	4	14.4	9.5	6.3	15	<5	1	–
	0	8	13.8	9.5	6.4	14	<5	1	–
	0	2	14.3	9.5	6.3	15	<5	1	–
	0	5	14.6	9.7	6.3	15	<5	1	–
	0	3	14.5	9.5	6.2	15	<5	1	–
	0	6	14.2	9.5	6.3	14	<5	1	–
	0	1	14.3	9.5	6.3	14	<5	1	–
	0	7	14.3	9.5	6.3	15	<5	1	–
16/07/83	0	4	14.5	9.6	6.4	13	<5	1	270
	0	8	13.8	9.8	6.3	13	<5	1	250
	0	2	14.3	9.5	6.4	14	<5	1	590
	0	5	14.8	9.5	6.3	13	<5	1	490
	0	3	14.6	9.6	6.2	13	<5	1	430
	0	6	14.4	9.6	6.5	13	<5	1	330
	0	1	14.3	9.6	6.1	14	<5	1	700
	0	7	14.4	9.8	6.3	13	<5	1	490

[a]Sampled/determined mid-stream.

[b]Not determined.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
17/07/83	0	4	13.2	9.7	6.2	13	< 5	1	280
	0	8	12.6	9.6	6.3	13	< 5	1	270
	0	2	13.2	9.8	6.1	13	< 5	1	590
	0	5	13.6	9.4	6.2	13	< 5	1	500
	0	3	13.4	9.7	6.3	14	< 5	1	420
	0	6	13.2	9.4	6.3	12	< 5	1	340
	0	1	13.3	9.8	6.2	13	< 5	1	700
	0	7	13.4	9.2	6.3	12	< 5	1	490
18/07/83	0	4	14.0	9.7	6.5	18	< 5	1	260
	0	8	13.4	9.7	6.6	18	< 5	1	230
	0	2	14.0	10.0	6.6	16	< 5	1	550
	0	5	14.2	9.8	6.6	16	< 5	1	455
	0	3	14.2	10.0	6.5	17	< 5	1	395
	0	6	13.9	9.7	6.5	18	< 5	1	305
	0	1	14.0	10.1	6.6	18	< 5	1	650
	0	7	14.0	9.8	6.6	16	< 5	1	465
19/07/83	0	4	14.4	10.1	6.8	17	< 5	1	245
	0	8	13.6	10.5	6.9	17	< 5	1	230
	0	2	14.6	10.0	6.8	15	< 5	1	545
	0	5	14.8	10.1	6.8	17	< 5	1	455
	0	3	14.7	10.0	6.9	16	< 5	1	390
	0	6	14.5	10.1	6.8	16	< 5	1	305
	0	1	14.7	9.9	6.8	17	< 5	1	635
	0	7	14.6	10.1	6.8	17	< 5	1	460

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength (mg·L^{-1})	Stream no.	Temperature (°C)[a]	Dissolved oxygen (mg·L^{-1})[a]	pH[a]	Conductance (umho·cm^{-1})[a]	Nonfiltrable residue (mg·L^{-1})[a]	Turbidity (FTU)[a]	Inflow rate (ml·min^{-1})
20/07/83	0	4	14.6	10.1	6.6	14	< 5	1	270
	0	8	14.0	9.6	6.3	14	< 5	1	240
	0	2	14.3	10.0	6.8	14	< 5	1	600
	0	5	14.8	10.0	6.5	13	< 5	1	500
	0	3	14.7	10.1	6.7	13	< 5	1	440
	0	6	14.6	10.1	6.4	14	< 5	1	330
	0	1	14.4	9.9	6.6	14	< 5	1	690
	0	7	14.7	10.0	6.4	13	< 5	1	510
21/07/83	0	4	14.4	9.2	6.7	23	< 5	1	59
	0	8	13.1	9.9	6.7	22	< 5	1	66
	100	2	14.2	9.2	6.8	23	7	27	68
	100	5	14.6	9.2	6.6	23	< 5	27	65
	300	3	14.5	9.4	6.8	23	74	100	68
	300	6	14.1	9.8	6.7	23	88	98	69
	1000	1	14.0	9.6	6.8	27	264	320	68
	1000	7	13.9	9.6	6.7	23	313	340	70
22/07/83	0	4	15.3	9.9	7.2	22	< 5	1	68
	0	8	13.9	10.2	7.3	22	< 5	1	70
	100	2	15.0	9.7	7.0	23	60	105	66
	100	5	15.6	9.6	7.2	22	53	80	73
	300	3	15.4	9.7	7.0	27	240	285	68
	300	6	15.1	9.5	7.3	26	203	260	68
	1000	1	14.9	9.8	6.8	35	860	1400	68
	1000	7	14.9	9.6	7.2	35	833	1400	70

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
23/07/83	0	4	15.5	9.2	6.9	23	<5	2	72
	0	8	14.1	9.6	6.7	23	<5	2	74
	100	2	15.2	9.5	7.1	25	56	76	70
	100	5	15.8	9.1	6.8	25	50	74	76
	300	3	15.6	9.5	7.0	28	223	220	67
	300	6	15.2	9.3	6.9	28	220	260	63
	1000	1	14.9	9.3	7.2	36	963	1600	69
	1000	7	15.0	9.4	7.2	36	863	1480	70
24/07/83	0	4	15.2	9.6	6.9	23	<5	1	71
	0	8	13.8	9.8	6.9	23	<5	1	73
	100	2	15.1	9.6	7.0	24	47	96	69
	100	5	15.7	9.6	7.1	24	48	88	74
	300	3	15.5	9.5	7.0	27	223	290	66
	300	6	15.1	9.4	6.9	29	204	280	62
	1000	1	15.2	9.7	7.0	38	773	1400	67
	1000	7	14.8	9.8	7.0	33	893	1400	68
25/07/83	0	4	15.3	9.4	6.5	25	<5	1	71
	0	8	13.8	10.5	6.7	21	<5	1	72
	100	2	15.1	9.5	6.6	27	54	75	68
	100	5	15.7	9.4	6.5	26	40	75	75
	300	3	15.5	9.4	6.5	30	220	300	70
	300	6	15.1	9.4	6.6	30	193	300	65
	1000	1	14.9	9.3	6.8	37	855	1520	72
	1000	7	14.6	9.6	6.3	36	870	1400	72

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
26/07/83	0	4	15.2	9.4	6.4	27	<5	1	71
	0	8	13.9	9.6	6.4	25	<5	1	72
	100	2	15.0	9.5	6.5	27	64	102	69
	100	5	15.7	9.4	6.4	26	56	75	74
	300	3	15.4	9.4	6.5	31	200	230	70
	300	6	15.2	9.5	6.5	31	180	280	64
	1000	1	14.8	9.4	6.6	37	920	1400	70
	1000	7	15.0	9.3	6.6	37	780	1360	72
27/07/83	0	4	15.2	9.6	6.5	20	<5	2	70
	0	8	13.9	9.7	6.6	24	<5	2	72
	100	2	15.0	9.5	6.5	18	60	70	70
	100	5	15.7	9.5	6.6	21	61	95	74
	300	3	15.4	9.5	6.6	19	246	330	71
	300	6	15.2	9.5	6.6	22	204	270	68
	1000	1	14.8	9.7	6.7	17	843	1400	72
	1000	7	14.9	9.4	6.6	23	790	1400	73
28/07/83	0	4	13.7	9.9	6.6	19	<5	2	70
	0	8	12.8	10.0	6.6	28	<5	3	72
	100	2	14.1	9.6	6.7	20	104	115	68
	100	5	14.1	9.6	6.7	21	102	145	74
	300	3	14.1	9.7	6.6	22	275	490	69
	300	6	14.0	9.6	6.6	19	262	600	70
	1000	1	14.1	9.8	6.7	32	890	1400	71
	1000	7	13.7	10.0	6.6	21	900	1400	72

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
29/07/83	0	4	14.9	9.4	6.6	23	< 5	1	72
	0	8	13.7	10.0	6.4	24	< 5	2	72
	100	2	14.8	9.4	6.7	23	57	75	69
	100	5	15.3	9.2	6.5	24	74	110	74
	300	3	15.1	9.4	6.8	27	256	360	70
	300	6	14.8	9.5	6.6	27	256	340	70
	1000	1	14.8	9.5	6.8	36	880	1440	72
	1000	7	14.6	9.8	6.8	37	890	1600	73
30/07/83	0	4	15.7	9.5	6.4	21	< 5	1	70
	0	8	14.3	9.6	6.4	23	< 5	1	72
	100	2	15.5	9.3	6.4	22	57	85	73
	100	5	16.2	9.2	6.4	22	87	115	73
	300	3	15.9	9.3	6.4	25	268	360	74
	300	6	15.7	9.2	6.4	26	268	390	70
	1000	1	15.3	9.5	6.5	34	860	1600	73
	1000	7	15.4	9.3	6.6	33	847	1600	68
31/07/83	0	4	15.5	9.3	6.3	23	< 5	2	73
	0	8	14.0	9.5	6.4	24	< 5	1	72
	100	2	15.3	9.3	6.4	24	78	90	70
	100	5	15.9	9.4	6.4	24	100	110	69
	300	3	15.7	9.3	6.5	27	282	320	70
	300	6	15.3	9.6	6.5	28	256	350	68
	1000	1	15.1	9.5	6.4	35	930	1560	70
	1000	7	15.0	9.4	6.8	36	920	1480	66

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (^oC)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
01/08/83	0	4	15.6	9.2	6.4	24	<5	1	73
	0	8	14.3	9.4	6.5	26	<5	1	70
	100	2	15.5	9.4	6.4	27	94	96	69
	100	5	16.1	9.2	6.5	27	105	120	70
	300	3	15.8	9.2	6.6	32	290	310	68
	300	6	15.5	9.3	6.6	32	293	310	65
	1000	1	15.3	9.3	6.5	39	950	1480	69
	1000	7	15.4	9.2	6.7	39	1080	1560	65
02/08/83	0	4	14.9	9.4	6.5	22	<5	1	73
	0	8	13.8	9.8	6.5	24	<5	2	71
	100	2	14.9	9.4	6.5	27	108	140	70
	100	5	15.3	9.0	6.6	26	119	140	70
	300	3	15.2	9.4	6.6	28	332	400	70
	300	6	14.9	9.3	6.7	28	294	450	69
	1000	1	14.9	9.5	6.5	35	1070	1800	70
	1000	7	14.7	9.3	6.8	37	1020	1600	66
03/08/83	0	4	15.1	9.4	6.6	24	<5	1	73
	0	8	13.9	9.5	6.5	27	<5	1	72
	100	2	15.0	9.2	6.8	29	122	140	72
	100	5	15.6	9.4	6.6	27	127	100	71
	300	3	15.3	9.4	6.8	29	342	370	71
	300	6	15.1	9.2	6.6	31	376	460	70
	1000	1	14.9	9.6	6.8	38	1160	1800	72
	1000	7	14.9	9.3	6.7	41	1030	1760	66

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
04/08/83	0	4	14.8	9.7	6.4	17	<5	1	71
	0	8	13.7	10.0	6.4	19	<5	1	70
	100	2	14.9	9.2	6.7	31	102	165	69
	100	5	15.3	9.4	6.6	28	79	110	68
	300	3	14.9	9.6	6.7	25	365	410	70
	300	6	14.3	9.8	6.5	25	350	400	68
	1000	1	13.4	10.0	6.6	36	1120	1600	70
	1000	7	13.3	10.2	6.5	29	1110	1600	65
05/08/83	0	4	15.8	9.4	6.5	31	<5	1	74
	0	8	14.6	9.8	6.6	31	<5	1	73
	100	2	15.5	9.4	6.5	31	110	135	72
	100	5	16.3	9.2	6.5	29	118	90	71
	300	3	15.9	9.3	6.6	30	352	450	71
	300	6	15.8	9.3	6.5	30	342	425	69
	1000	1	15.1	9.7	6.7	37	1190	2200	71
	1000	7	15.6	9.5	6.6	39	1100	2000	67
06/08/83	0	4	15.6	9.5	6.4	25	<5	1	70
	0	8	14.4	9.4	6.6	28	<5	1	78
	100	2	15.4	9.3	6.5	28	131	175	75
	100	5	16.1	9.3	6.5	27	146	110	76
	300	3	15.8	9.4	6.7	32	350	450	75
	300	6	15.6	9.5	6.5	33	342	425	72
	1000	1	15.1	9.5	6.7	39	1110	2000	72
	1000	7	15.4	9.3	6.8	41	1120	2000	73

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength (mg·L⁻¹)	Stream no.	Temperature (°C)[a]	Dissolved oxygen (mg·L⁻¹)[a]	pH[a]	Conductance (umho·cm⁻¹)[a]	Nonfiltrable residue (mg·L⁻¹)[a]	Turbidity (FTU)[a]	Inflow rate (ml·min⁻¹)
07/08/83	0	4	15.6	9.3	6.4	23	<5	1	71
	0	8	14.4	9.7	6.4	23	<5	1	75
	100	2	15.3	9.4	6.7	27	144	190	75
	100	5	16.0	9.2	6.4	24	131	140	75
	300	3	15.7	9.4	6.7	28	354	450	73
	300	6	15.6	9.4	6.6	29	306	450	70
	1000	1	15.1	9.6	6.9	37	1100	2000	71
	1000	7	15.4	9.4	6.7	36	1060	1800	74
08/08/83	0	4	15.4	9.5	6.5	26	<5	1	72
	0	8	14.1	9.6	6.4	25	<5	1	76
	100	2	15.2	9.4	6.8	28	117	160	75
	100	5	15.9	9.5	6.5	27	125	125	76
	300	3	15.7	9.4	6.7	31	337	400	74
	300	6	15.4	9.4	6.7	32	290	400	71
	1000	1	15.0	9.5	6.8	37	1090	1900	72
	1000	7	15.2	9.3	6.8	39	1030	1700	73
09/08/83	0	4	15.2	9.3	6.4	27	<5	1	72
	0	8	13.9	9.4	6.4	24	<5	1	76
	100	2	15.1	9.4	6.7	29	120	150	73
	100	5	15.7	9.1	6.5	27	123	110	73
	300	3	15.5	9.3	6.7	31	327	400	71
	300	6	15.2	9.3	6.5	33	312	400	68
	1000	1	14.9	9.4	6.7	38	1130	1900	71
	1000	7	15.1	9.5	6.6	39	1060	1600	70

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength (mg·L-1)	Stream no.	Temperature (°C)[a]	Dissolved oxygen (mg·L-1)[a]	pH[a]	Conductance (umho·cm-1)[a]	Nonfiltrable residue (mg·L-1)[a]	Turbidity (FTU)[a]	Inflow rate (ml·min-1)
10/08/83	0	4	15.4	9.5	6.5	26	<5	1	70
	0	8	14.3	9.6	6.4	25	<5	1	76
	100	2	15.2	9.4	6.6	27	99	120	73
	100	5	15.8	9.2	6.5	29	95	120	75
	300	3	15.6	9.4	6.6	30	334	450	73
	300	6	15.4	9.3	6.5	32	380	400	70
	1000	1	15.1	9.4	6.5	37	1160	2000	72
	1000	7	15.3	9.4	6.5	39	1100	1920	72
11/08/83	0	4	14.9	9.5	6.4	14	<5	1	70
	0	8	13.6	10.0	6.5	14	<5	1	75
	100	2	14.6	9.7	6.5	16	117	130	72
	100	5	15.1	9.5	6.6	16	105	170	72
	300	3	15.1	9.4	6.5	19	303	550	71
	300	6	14.3	9.8	6.5	19	313	500	69
	1000	1	13.8	10.0	6.6	27	1040	2000	71
	1000	7	13.3	9.8	6.6	27	1060	2200	70
12/08/83	0	4	15.4	9.4	6.4	24	<5	1	70
	0	8	14.3	9.6	6.4	23	<5	1	75
	100	2	15.2	9.4	6.6	29	109	105	71
	100	5	15.9	9.2	6.4	30	122	130	72
	300	3	15.7	9.5	6.5	31	331	390	72
	300	6	15.5	9.2	6.5	29	300	400	68
	1000	1	15.1	9.3	6.7	36	1080	1880	70
	1000	7	15.4	9.2	6.5	39	1010	1900	71

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
13/08/83	0	4	15.3	9.4	6.5	27	<5	<1	75
	0	8	14.3	9.8	6.5	26	<5	<1	75
	100	2	15.0	9.4	6.6	27	97	105	76
	100	5	15.9	9.3	6.5	27	98	130	77
	300	3	15.4	9.2	6.6	32	305	380	71
	300	6	15.4	9.5	6.6	31	308	400	76
	1000	1	14.8	9.5	6.6	37	1020	1680	74
	1000	7	15.3	9.4	6.8	38	1010	1600	77
14/08/83	0	4	14.4	9.5	6.5	25	<5	2	74
	0	8	13.6	9.9	6.5	26	<5	1	74
	100	2	14.3	9.7	6.6	27	87	130	75
	100	5	14.8	9.4	6.5	28	83	150	75
	300	3	14.6	9.4	6.7	40	253	250	70
	300	6	14.4	9.1	6.8	41	225	280	74
	1000	1	14.4	9.7	6.7	43	850	1400	70
	1000	7	14.4	9.3	6.7	43	863	1400	75
15/08/83	0	4	15.0	9.3	6.5	27	<5	<1	71
	0	8	13.8	9.7	6.5	25	<5	1	72
	100	2	14.9	9.3	6.6	28	99	110	73
	100	5	15.5	9.1	6.5	28	120	135	74
	300	3	15.2	9.3	6.6	32	271	330	69
	300	6	15.0	9.3	6.5	31	282	350	71
	1000	1	14.2	9.4	6.7	39	1010	1680	69
	1000	7	15.0	9.4	6.7	38	905	1680	72

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
16/08/83	0	4	15.1	9.2	6.5	28	< 5	1	73
	0	8	14.0	9.4	6.4	28	< 5	1	74
	100	2	15.0	9.3	6.7	29	93	125	75
	100	5	15.5	9.2	6.5	29	126	150	74
	300	3	15.3	9.3	6.7	32	314	400	69
	300	6	15.1	9.2	6.5	32	297	400	72
	1000	1	14.8	9.5	6.7	36	1010	1640	69
	1000	7	15.0	9.2	6.6	38	969	1680	73
17/08/83	0	4	14.9	9.2	6.6	33	< 5	1	73
	0	8	13.9	9.5	6.6	29	< 5	1	74
	100	2	14.9	9.2	6.6	35	99	95	73
	100	5	15.3	9.2	6.6	31	113	145	73
	300	3	15.2	9.1	6.7	36	311	350	68
	300	6	14.9	9.1	6.6	35	291	380	72
	1000	1	14.8	9.2	6.7	38	1060	1680	69
	1000	7	14.8	9.1	6.7	41	999	1800	73
18/08/83	0	4	14.9	9.6	6.4	20	< 5	1	72
	0	8	13.8	10.2	6.5	23	< 5	1	74
	100	2	14.8	8.9	6.6	23	101	135	74
	100	5	15.2	9.3	6.5	23	116	160	72
	300	3	15.2	9.3	6.6	25	349	500	68
	300	6	14.6	9.6	6.5	25	283	400	72
	1000	1	14.4	9.2	6.6	34	1310	2000	69
	1000	7	14.2	9.8	6.6	32	1060	1600	72

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength (mg·L^{-1})	Stream no.	Temperature (°C)[a]	Dissolved oxygen (mg·L^{-1})[a]	pH[a]	Conductance (umho·cm^{-1})[a]	Nonfiltrable residue (mg·L^{-1})[a]	Turbidity (FTU)[a]	Inflow rate (ml·min^{-1})
19/08/83	0	4	15.3	9.2	6.5	22	<5	1	74
	0	8	14.0	9.5	6.5	23	<5	1	73
	100	2	15.2	9.4	6.7	24	102	110	73
	100	5	15.6	9.2	6.7	23	113	150	74
	300	3	15.5	9.3	6.7	26	297	410	70
	300	6	15.0	9.2	6.6	26	297	450	73
	1000	1	15.1	9.4	6.7	35	972	1800	69
	1000	7	14.8	9.3	6.7	33	1090	1920	74
20/08/83	0	4	15.3	9.1	6.6	27	<5	<1	76
	0	8	14.3	9.6	6.5	28	<5	<1	74
	100	2	15.2	9.5	6.7	27	74	110	77
	100	5	15.7	9.2	6.6	28	95	145	78
	300	3	15.5	9.1	6.7	31	261	340	73
	300	6	15.3	9.3	6.6	31	255	340	74
	1000	1	15.1	9.4	6.6	36	947	1720	74
	1000	7	15.2	9.2	6.6	40	944	1600	74
21/08/83	0	4	15.8	9.3	6.5	31	<5	1	76
	0	8	14.5	9.4	6.5	31	<5	1	75
	100	2	15.5	9.2	6.6	29	62	120	75
	100	5	16.2	9.0	6.5	29	85	130	76
	300	3	15.9	9.2	6.6	32	281	350	72
	300	6	15.7	9.1	6.6	31	256	330	74
	1000	1	15.4	9.4	6.7	36	918	1600	74
	1000	7	15.6	9.0	6.5	37	896	1400	73

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (°C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
22/08/83	0	4	14.9	9.1	6.5	32	< 5	1	76
	0	8	13.9	9.2	6.6	31	< 5	1	74
	100	2	15.0	9.3	6.6	32	91	115	73
	100	5	15.3	9.0	6.5	32	105	115	72
	300	3	15.2	9.3	6.6	35	307	360	70
	300	6	15.0	9.0	6.5	35	283	340	70
	1000	1	15.0	9.3	6.6	39	972	1520	73
	1000	7	15.0	8.8	6.6	41	935	1400	72
23/08/83	0	4	15.5	9.2	6.5	32	< 5	1	76
	0	8	14.2	9.8	6.5	29	< 5	1	73
	100	2	15.4	9.1	6.6	32	65	130	74
	100	5	15.9	9.2	6.5	30	94	140	74
	300	3	15.7	9.2	6.6	34	264	350	70
	300	6	15.5	9.2	6.6	33	237	360	72
	1000	1	15.2	9.2	6.5	37	868	1600	73
	1000	7	15.4	9.2	6.7	38	854	1400	72
24/08/83	0	4	15.0	9.4	6.4	32	< 5	2	76
	0	8	13.8	9.4	6.4	28	< 5	1	74
	100	2	15.0	9.2	6.6	31	93	120	74
	100	5	15.4	9.3	6.5	31	114	165	73
	300	3	15.3	9.2	6.4	33	335	450	70
	300	6	14.9	9.5	6.5	33	274	380	70
	1000	1	15.0	9.5	6.7	37	942	1720	72
	1000	7	14.8	9.2	6.4	37	912	1280	71

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength (mg·L^{-1})	Stream no.	Temperature (°C)[a]	Dissolved oxygen (mg·L^{-1})[a]	pH[a]	Conductance (umho·cm^{-1})[a]	Nonfiltrable residue (mg·L^{-1})[a]	Turbidity (FTU)[a]	Inflow rate (ml·min^{-1})
25/08/83	0	4	14.9	9.6	6.5	15	<5	<1	74
	0	8	13.8	9.6	6.4	16	<5	1	70
	100	2	14.9	9.5	6.5	18	85	140	71
	100	5	15.2	9.6	6.5	18	82	160	70
	300	3	15.1	9.4	6.5	20	328	450	67
	300	6	14.6	9.4	6.6	20	361	500	69
	1000	1	14.6	9.5	6.6	29	1130	2000	72
	1000	7	14.5	9.7	6.4	30	1130	2000	66
26/08/83	0	4	15.4	9.0	6.7	23	<5	<1	75
	0	8	14.3	9.4	6.6	21	<5	<1	73
	100	2	15.3	9.3	6.8	21	54	125	72
	100	5	15.8	9.0	6.6	23	68	130	72
	300	3	15.5	9.4	6.8	27	216	325	69
	300	6	15.3	9.2	6.7	24	226	325	70
	1000	1	15.1	9.2	6.8	33	833	1500	72
	1000	7	15.3	9.0	6.8	34	798	1500	71
27/08/83	0	4	15.5	9.5	6.6	27	<5	<1	76
	0	8	14.3	9.8	6.6	28	<5	<1	75
	100	2	15.3	8.9	6.7	26	59	115	76
	100	5	16.0	9.0	6.7	28	73	135	75
	300	3	15.7	8.9	6.8	30	314	300	72
	300	6	15.6	9.0	6.6	31	302	350	74
	1000	1	15.2	8.9	6.7	37	978	1700	74
	1000	7	15.4	9.1	6.7	37	876	1680	76

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (^{o}C)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
28/08/83	0	4	15.1	9.6	6.5	24	< 5	1	76
	0	8	14.0	10.0	6.5	23	< 5	< 1	74
	100	2	15.2	9.0	6.7	24	86	115	72
	100	5	15.5	8.9	6.6	23	86	140	74
	300	3	15.4	9.1	6.8	27	218	350	71
	300	6	15.1	9.1	6.6	26	212	350	68
	1000	1	15.2	8.9	6.6	34	933	1600	70
	1000	7	15.1	9.4	6.6	33	867	1500	72
29/08/83	0	4	15.3	9.1	6.5	29	< 5	< 1	77
	0	8	14.2	9.2	6.6	29	< 5	< 1	76
	100	2	15.4	9.0	6.7	29	57	105	73
	100	5	15.8	8.9	6.5	30	69	110	73
	300	3	15.6	9.0	6.7	36	251	270	72
	300	6	15.3	9.0	6.6	34	230	325	66
	1000	1	15.3	9.1	6.7	38	895	1440	70
	1000	7	15.3	8.8	6.6	42	834	1200	72
30/08/83	0	4	15.5	9.1	6.6	28	< 5	< 1	75
	0	8	14.3	9.3	6.6	25	< 5	< 1	73
	100	2	15.3	9.1	6.7	30	58	115	72
	100	5	15.9	9.0	6.6	29	64	110	73
	300	3	15.7	9.1	6.8	34	197	230	71
	300	6	15.5	9.0	6.6	32	206	300	66
	1000	1	15.3	9.4	6.9	35	820	1400	70
	1000	7	15.5	9.0	6.6	39	779	1200	72

[a]Sampled/determined mid-stream.

APPENDIX 1 (cont'd.)

Date	Nominal sediment strength ($mg \cdot L^{-1}$)	Stream no.	Temperature (^oC)[a]	Dissolved oxygen ($mg \cdot L^{-1}$)[a]	pH[a]	Conductance ($umho \cdot cm^{-1}$)[a]	Nonfiltrable residue ($mg \cdot L^{-1}$)[a]	Turbidity (FTU)[a]	Inflow rate ($ml \cdot min^{-1}$)
31/08/83	0	4	15.2	9.5	6.6	28	< 5	< 1	76
	0	8	14.1	9.8	6.6	25	< 5	< 1	76
	100	2	15.1	9.7	6.6	29	76	125	72
	100	5	15.6	9.5	6.5	29	85	125	72
	300	3	15.4	9.5	6.6	33	277	260	69
	300	6	15.2	9.5	6.7	32	255	325	65
	1000	1	15.0	9.9	6.6	38	990	1400	69
	1000	7	15.1	9.3	6.7	39	859	1400	70
01/09/83	0	4	15.1	9.9	6.4	35	< 5	< 1	75
	0	8	14.1	10.6	6.6	30	< 5	< 1	77
	100	2	15.2	9.8	6.4	36	55	110	72
	100	5	15.5	9.9	6.5	35	66	115	72
	300	3	15.4	9.9	6.5	37	217	300	69
	300	6	15.0	9.9	6.5	39	253	340	64
	1000	1	15.2	9.9	6.4	49	855	1400	69
	1000	7	15.0	9.8	6.5	50	846	1360	70

[a]Sampled/determined mid-stream.