Fisheries and Oceans / Pêches et Océans
Pacific Region

DFO Pacific Region
Habitat Status Report 2000/01 E

Effects of sediment on fish and their habitat

Placer Mining - Yukon Territory

Abandoned placer gold dredge

Aerial view of river altered by placer mining

Washing the land to remove the "overburden"

Background

The input of sediment into water has been recognized as a potential threat to the well being of aquatic organisms. While natural seasonal variations in sediment levels occur, the input of sediment through catastrophic events such as volcanic eruptions and floods, and human activities such as road building, mining, logging, spilling water from dams etc., have the potential to harm aquatic organisms and reduce biological productivity.

It is the mandate of Fisheries and Oceans Canada to ensure the protection of fish and their habitat and it is an offense under the Fisheries Act to deposit a deleterious substance into waters frequented by fish and to carry out activities that result in the harmful alteration, disruption or destruction fish habitat. Sediment that is added to waters has the potential to harm fish and their habitat and thereby contravene these provisions of the Fisheries Act.

This document was written to assist in understanding the potential effects of sediment on fish and their habitat. It also refers to criteria and guidelines that were developed for the protection of aquatic resources from sediment. The application of these guidelines and criteria is a challenge for environmental managers who must assess the risks to aquatic organisms associated with human activities. Birtwell (1999) provides a more thorough and technical review of the topic in the research document upon which this report is based.

Summary

- This document provides information on the potential effects that sediments may have on fish and their habitat. It is intended for those who require a synopsis of the effects of sediment in aquatic systems, and at the same time it provides information on pertinent guidelines and recommendations designed to protect such waters.

- Elevated levels of sediment and turbidity (a measure of the lack of clarity of water) can reduce the biological productivity of aquatic systems. Both these related factors have the potential to decrease plant growth (primary productivity) that may have consequences to secondary productivity (organisms that feed on the plant material) which are, in turn, fed upon by other organisms such as fish.

- Examples of the lethal and sublethal effects of sediment on fish and their habitat (such as effects on feeding and growth, cover and risk of predation, avoidance and displacement, cumulative effects, egg development and survival, primary and secondary productivity) and factors such as temperature, particle size and angularity, and duration of exposure, that influence some of these effects, are presented in the report.

- The concentrations of suspended sediment that have been determined to kill fish over a short time period (hours) typically range from the hundreds to hundreds of thousands of milligrams of sediment per litre, while concentrations which may harm them but not kill them directly (sublethal effects) are often in the tens to hundreds of milligrams of sediment per litre.

- Guidelines have been formulated to protect aquatic resources from the effects of elevated levels of suspended sediment. Those that rely on determinations of the weight of suspended sediment in a known volume of water are recommended for use over those that rely solely on turbidity (the majority of sediment-effects information is based on determinations of the concentration of sediment in waters). However, if the relationship is known between suspended sediment and turbidity, then turbidity may be used as a surrogate for suspended sediment.

- The use of guidelines that incorporate the duration of exposure to sediments provide useful analytical information for predictive purposes, but caution is warranted when attempting to predict the effects of low (less than, or equal to, tens of milligrams per litre) levels of sediment over protracted periods of time.

- It is concluded that elevated levels of sediment (typically over background) may be harmful to fish (i.e. acutely lethal, or elicit sublethal responses that could compromise their well-being and jeopardize survival), and in addition, negatively impact on their habitat.

Issue

Sediments occur naturally and are integral components of aquatic systems. Nearly all waters have some solid matter in suspension that may be of physical, chemical or biological origin, and the quantities of this material usually vary with season. This natural variation in suspended sediment concentrations occurs, typically, in response to events (e.g. rain fall, snow and glacial melting) which increase both water flows and levels resulting in land erosion and sediment input to waterways. The increased energy within watercourses may move the stream-bed substrate and also increase the amount of material in suspension. Accordingly, aquatic organisms are subjected to these natural variations in their environment. They have adapted their life cycle to accommodate them and in so doing ensured the survival of the species.

In addition to natural seasonal fluctuations of sediment levels in the aquatic environment, there are catastrophic events, such as volcanic eruptions, and certain anthropogenic activities that have the potential to add unusually large amounts of sediment to a water body, thereby markedly affecting its physical, chemical, and biological structure and integrity. Such activities as logging, road building, dredging, and placer (gold) mining, etc., may cause significant environmental changes proximal to the activity and at distances further downstream.

Guidelines and criteria have been formulated, based on scientific literature, to facilitate the protection of aquatic organisms from elevated levels of sediment in their environment.

Assessment of the Issue

Although sediment, and its associated effects on water clarity and turbidity, is an inherent component of aquatic systems, it is apparent from the literature that there is an increased risk to the survival and well-being of aquatic organisms when levels exceed background values for a particular period of time.

Research has shown that elevated levels of sediment, above background values, can be detrimental to aquatic biota; this understanding has led to the formulation of water quality criteria, guidelines and recommendations.

A perspective on the potential effects of sediment in aquatic systems may be obtained from some of the world-wide body of literature. Of particular note are those documents that present a scientific review of the literature on the effects of sediment on aquatic organisms and their habitat that were used during the formulation and recommendation of water quality criteria and guidelines.

Criteria and guidelines

In 1964, the European Inland Fisheries Advisory Commission (EIFAC), assessed the literature that was available on the effects of suspended solids on aquatic organisms and concluded that there are at least 5 ways in which an excessive amount of sediment might be harmful to a fishery. These are by a) acting directly on the fish swimming in the water in which solids are suspended, and either killing them or reducing their growth rate, resistance to disease etc., b) preventing the successful development of fish eggs and larvae c) modifying natural movements and migrations of fish d) reducing the abundance of food available to the fish and, e) affecting the efficiency of methods for catching fish.

Following their review EIFAC (1964) deduced the following criteria for the protection of fisheries resources:

> <25 parts per million* (ppm) of suspended solids - no evidence of harmful effects on fish and fisheries;
>
> 25 - 80 ppm - it should be possible to maintain good to moderate fisheries, however the yield would be somewhat diminished relative to waters with <25 ppm suspended solids;
>
> 80 - 400 ppm - these waters are unlikely to support good freshwater fisheries; and
>
> 400 ppm suspended solids - at best, only poor fisheries are likely to be found.

* Parts per million approximate ($mg \cdot L^{-1}$)

Numerous criteria and guideline documents have been formulated since those put forward by EIFAC, and the most recent have been based on the analyses of Newcombe and MacDonald (1991), Anderson et al. (1996), and Newcombe and Jensen (1996) and Caux et al. (1997). These authors state that aquatic biota respond to both the concentration of suspended sediments and the duration of exposure to them, and relate the two through an “index of pollution intensity (stress index)”. It was Newcombe and MacDonalds’ (1991) recommendation that the use of the “stress index” would provide resource managers with a method to predict the effects of “pollution episodes on aquatic biota”. Although the original concept was criticized because of its inaccuracy as a predictive tool, more rigorous analyses and additional information reveal the utility of the approach. Models that utilize a function of concentration and duration of exposure to predict potential harm (Newcombe and MacDonald 1991; Newcombe and Jensen 1996; Caux et al. 1997; BCMELP 1998; CCME 1999), reveal that an increasing duration of exposure to sediment potentially results in increasing harm to fish, life cycle stages, and to other aquatic organisms. Such trend identification is of value in predicting the potential effects of sediment on aquatic organisms, but caution must be exercised when assessing the effects of low concentrations [less than or equal to tens of milligrams per litre ($mg \cdot L^{-1}$)] of suspended sediment over protracted periods of time.

The British Columbia Ministry of Environment, Lands, and Parks (BCMELP) (1998), and the Canadian Council of Ministers of the Environment (CCME) (1999) guidelines are the most recent documents on this topic, and they are based, in part, on the publication by Caux et al. (1997).

Listed below are some of the proposed CCME (1999) recommendations for suspended sediments, turbidity, and stream-bed substrate (at the time of writing, these recommendations were unpublished).

Suspended sediments

Clear flow: Maximum increase of 25 mg·L^{-1} from background levels for short-term (e.g. <24 h) exposures, and a maximum average increase of 5 mg·L^{-1} from background for longer-term exposures (e.g. 24 h to 30 d).

High flow: Maximum increase of 25 mg·L^{-1} from background levels at any time when background levels are between 25 mg·L^{-1} and 250 mg·L^{-1}. Should not increase more than 10% of background levels when background levels are >250 mg·L^{-1}.

Turbidity

Turbidity, measured through the use of nephelometry (light scattering), relates the scattering of light in a water sample to a range of known turbidity standards, and provides values that are presented as Nephelometric Turbidity Units (NTUs).

Clear flow: Maximum increase of 8 NTUs from background levels for short-term (e.g.<24 h) exposures, and a maximum average increase of 2 NTUs from background for longer-term exposures (e.g. 24 h to 30 d).

High flow or turbid waters: Maximum increase of 8 NTUs from background levels at any time when background levels are between 8 NTUs and 80 NTUs. Turbidity should not increase more than 10% of background levels when background levels are >80 NTUs.

Stream-bed substrate

Fine sediments: The quantity in stream-bed substrates should not exceed 10% of particles <2 mm, 19% of particles <3 mm, and 25% of particles <6.35 mm.

Caux et al. (1997), and CCME (1999) provide details regarding the derivation of the above criteria. The ratio of the concentration of suspended solids to turbidity is considered to be about 3 to 1 (CCME 1999), but depending on the nature of the material in suspension this ratio can vary substantially from that used in the guideline. Accordingly, it is critical to establish the relationship between suspended sediment and turbidity if values of the latter are to be used in guidelines for the protection of aquatic organisms. Lloyd (1987) states that measurements of turbidity can be used to identify at least threshold levels of suspended sediment concentrations for a broad range of watersheds.

An assessment of the application of sediment criteria and relevant literature occurred during the revision of the Yukon Placer Authorization (Government of Canada 1993). This document describes the conditions under which placer mining can occur in the Yukon Territory and the sediment levels that may be discharged to streams.

The document recognizes the importance of placer mining in the Yukon and permits the "harmful alteration, disruption or destruction of fish habitat" in certain streams, and/or the discharge of sediment subject to compliance with the standards of allowable sediment discharge which are described in the Authorization. The compliance schedule that the placer miners must meet for the discharge of sediment into streams has been categorized according to the water's biological resources and their current and potential uses. For example, since January 1994 there was to be no increase in the concentration of sediments above background levels in salmon spawning streams, whereas for salmonid rearing streams the permissible increase is less than 200 mg·L^{-1}.

It was recognized that there was some level of risk to aquatic organisms depending upon the sediment levels discharged and the sensitivity of the organisms in the receiving stream. After a review of available information it was determined that the impacts could be classified in relation to the levels of risk to which the fish habitat would be subjected, and that these impacts would be best assessed using increases in the concentration of suspended sediment above background levels.

The levels of risk and the corresponding concentrations of sediment follow:

Sediment increase ($mg{\cdot}L^{-1}$)	Risk to fish and their habitat
0	No risk
<25	Very low risk
25 - 100	Low risk
100 - 200	Moderate risk
200 - 400	High risk
>400	Unacceptable risk

Examples of the effects of sediment on the lives of fish

It has been determined that certain concentrations of sediment kill fish directly. These concentrations typically range from the hundreds to hundreds of thousands of $mg{\cdot}L^{-1}$ of sediment.

The typical test that determines the lethality of a pollutant is generally carried out over 96 hours. The concentration (lethal concentration - LC) of a substance that kills 50% of the test organisms in 96 hours is referred to as the 96-h LC50; it is a basic toxicological test. By determining the 96-h LC50 values for a range of substances, their relative short-term toxicity can be compared. Such values do not indicate the effects of a more prolonged exposure to the contaminant, they do not address the onset of death in the test fish (which is of great significance to the individuals of a population), nor do they relate to effects on fish habitat. Therefore, the results of the 96-h LC50 test have limited value for predicting effects in the wild and at best they are but a coarse indicator of the short-term effects of a contaminant.

The effect of angularity and the size of sediment particles on fish has received little attention in the literature, but they are factors that influence the response of fish to suspended sediments. For example it was found that the lethality of natural Fraser River sediments to under-yearling sockeye salmon increased with increasing particle size. It has also been determined that the shape of suspended sediment particles may affect physiological stress and hence mortality in fish.

In general it has been determined that angular suspended sediment particles cause mortality at lower concentrations than do those of less angular materials, and that such effects may be exacerbated under “natural” conditions. The highly angular volcanic ash (tephra) that entered the streams in Washington, USA as a result of the Mount St. Helens eruption was considered to be a major contributing factor to the loss of fishery resources in the affected areas.

In their natural environment, the survival of fish depends upon many factors not the least of which are finding food, predator avoidance, immune system health and reproduction; for salmonids, sediment has the potential to affect all of these factors.

For many fish the successful capture of prey is a fundamental requirement in order to obtain food, and for facultative and opportunistic sight feeding juvenile salmonids this process may be affected by variations in suspended sediments. For example, in laboratory streams it was demonstrated that under-yearling Arctic grayling exposed to suspended sediment for six weeks had impaired feeding activity and reduced growth rates at concentrations above 100 $mg{\cdot}L^{-1}$.

There is evidence that some juvenile salmonids may benefit from the occupation of turbid waters through a reduced risk of predation and whereas visual ability may be affected in turbid waters there can be increased feeding because of a reduced risk of predation. This premise is valid for predators that rely on sight to locate prey, but may not be as tenable for those predators that locate their prey by other means and are adapted to feed in turbid environments. However, at more elevated turbidities and suspended sediment concentrations the visual ability of juvenile chinook becomes substantially impaired and foraging ability is reduced regardless of any concurrent gains.

Coho salmon smolts reduced or ceased feeding when exposed to 100 $mg{\cdot}L^{-1}$ and >300 $mg{\cdot}L^{-1}$ suspended sediment, respectively. Juvenile coho and chinook salmon also displayed abnormal surfacing behavior when exposed to concentrations of suspended sediment above 2,550 $mg \cdot L^{-1}$. Such surfacing behavior at elevated sediment levels may well increase the risk to avian predators; an activity that has been documented in relation to the discharge of pollutants and on visually-impaired salmon released from a hatchery.

The relevance of sublethal effects due to exposure to sediment is not easy to deduce. In the highly competitive environment in which aquatic organisms live, the maintenance of health and performance are prerequisites for survival. It is apparent, for example, that even brief exposure of juvenile salmon to a contaminant at the sublethal level can jeopardize survival by increasing their susceptibility to predation. An increasing body of information indicates that the sublethal exposure of juvenile fish to a stressor, or combination of stressors, increases their susceptibility to predation and hence jeopardizes survival and potentially compromises physiological performance.

Information in the scientific literature regarding the sublethal effects of sediment on fish reveal that a variety of responses may be evoked, some of which are stressful to the exposed individuals. Stressful conditions are known to reduce the adaptive responses of salmonid fish to natural environmental fluctuations and increase their susceptibility to disease.

Sediment impacts on salmonid reproduction has been investigated particularly in relation to effects on eggs and the survival of embryos and alevins. "Settleable solids" in river waters have the potential to be deposited in the stream, especially under reduced flow conditions, where they may exert a detrimental influence on salmonid egg and alevin survival in spawning beds. It is also probable that the deposition of material could reduce the quality of substrate in that salmon eggs are deposited in the stream-bed substrate where they are particularly susceptible to in-stream disturbances and the deposition of material. Chapman (1988) undertook a critical review of the "variables used to define the effects of fines in redds of large salmonids" and described the effects, both primary and secondary, that the intrusion of fine sediment may have on the survival and emergence of embryos and alevins within and external to the "egg pocket." Chapman (1988) comments that "survival to emergence usually relates negatively to percentages of small fines."

In addition to the effects of deposited sediments on the reproductive success of salmonids, concern is also warranted over the maintenance of spaces among substrate components that are utilized by juvenile fish and other organisms. The nocturnal habit of certain species of juvenile salmonids during winter, allied to their use of inter-cobble substrate habitat, emphasizes the need to prevent stream-beds from becoming impacted and the interstitial spaces filled with fine sediment.

General effects on the aquatic environment

Lloyd et al. (1987) showed that the productivity of aquatic systems could be reduced by turbid conditions. Increases in turbidity reduced light penetration in lakes and streams which led to decreased quantities of plant material and hence reduced primary production, decreased abundance of fish food organisms (secondary production) and decreased production and abundance of fish.

Invertebrate populations (secondary production) depend upon primary production, and the latter also may be adversely affected by elevated levels of sediment. Certain benthic invertebrates are grazers and depend on periphyton for food, while others may be filter feeders which could have their feeding structures clogged by sediment thereby reducing feeding efficiency and reducing growth rates. Some direct effects of sediment on aquatic invertebrates include a) physical habitat change due to the scouring of stream-beds and the dislodgment of individuals, b) smothering of benthic communities, c) clogging of the interstices between substrate components which affects microhabitat, and d) abrasion of respiratory surfaces and interference of food uptake for filter-feeders.

The degree to which the major stream substrate particles are surrounded by fine material (the degree of embeddedness) was found to have a strong correlation with macroinvertebrate assemblage richness and composition. Many of the organisms that are favored as food items (e.g. mayflies, caddisflies and stoneflies) by stream-dwelling fish prefer relatively coarse stream-bed substrates and are harmed by intrusions of fine sediments, while others (e.g. midges) are considered to be more tolerant.

Examples of human activities affecting exposure of aquatic organisms to sediment

The draining of an impoundment produces negative effects on aquatic communities by, in part, elevating sediment levels. For example, the flushing of British Columbia's Shuswap Falls dam in 1970, resulted in the elevation of suspended sediments. The "stressing" of whitefish, trout, and chinook salmon, and the clogging of gills was evident at suspended sediment levels of 10,000 $mg \cdot L^{-1}$.

The potential for the release of water to elevate suspended sediment levels and with it the concomitant impact on different trophic levels is exemplified in a number of reports. However, caution should be exercised over concluding the cause of the biological changes that were observed. In addition to suspended sediment other factors such as reduced levels of dissolved oxygen, and increases in ammonia are often associated with the draining of dams, and they may cause cumulative impacts or act synergistically.

In a study on the effects of sediment from placer mining operations on a number of streams in the Yukon Territory, it was deduced that taxonomic diversity, density, and the quantity of benthic macroinvertebrates was reduced in addition to effects on fish. Un-mined creeks were found to support a standing stock of fish 40 times that of placer-mined streams. Overall, streams that had seasonal suspended sediment concentrations in excess of 50 $mg \cdot L^{-1}$ did not support "significant" numbers of under-yearling Arctic grayling or chinook salmon.

Conclusions

It is concluded that elevated levels of sediment (typically over background) may be harmful to fish (i. e. acutely lethal, or elicit sublethal responses that compromise their well-being and jeopardize survival), and in addition, negatively impact on their habitat. Lethal levels of sediment, determined through laboratory experimentation over different exposure times, typically range from hundreds to hundreds of thousands of $mg \cdot L^{-1}$ suspended sediment, whereas sublethal effects are typically manifest in the tens to hundreds of $mg \cdot L^{-1}$ suspended sediment. Some species of aquatic organisms are more tolerant of suspended and deposited sediment than others, and this variation must be recognized when assessing potential effects.

Although elevated levels of suspended sediment elicit adverse responses in individual aquatic organisms, it is difficult to extrapolate effects to the population or ecosystem levels. However, the biological productivity of turbid systems has been shown to be less than that of non-turbid systems. Anthropogenic activities, such as some placer mining operations, have resulted in lowered densities of aquatic organisms in watersheds through the elevation of suspended and deposited sediments.

Criteria, guidelines and recommendations, though having been formulated by different agencies, all tend to be mutually supportive. At the same time they have application limitations, especially relating to the protection of aquatic organisms from the effects of sediment concentrations $\leq$ tens of $mg \cdot L^{-1}$. Application of the criteria must be done while recognizing potential impacts on aquatic organisms at both the lethal and the sublethal level. Particle size and nature of the sediment must be considered as well. Bioassay information that reveals the lethal effect of sediment over a short period of time (such as 96 h), provides only a coarse indication of the effects of elevated levels of sediment in the wild. Accordingly, and when available, the more appropriate criteria which incorporate sublethal and lethal effects knowledge should be used.

Criteria documented in this report that are based on suspended sediment levels are appropriate and endorsed for use.

Recent guidelines have related elevated sediment levels to the natural hydrological regimes in streams and the associated variation in suspended sediment concentrations (CCREM 1987; BCMELP 1998; CCME 1999). In addition, the use of risk criteria in relation to the elevation of sediment concentrations above background (Government of Canada 1993) have merit and are supportive of, and based on, earlier published criteria.

Models that utilize sediment concentration and duration-of-exposure to predict harm (Newcombe and MacDonald 1991; Newcombe and Jensen 1996; Caux et al. 1997; BCMELP 1998; CCME 1999) reveal significant trends in increasing harm to fish and other aquatic organisms with increasing duration of exposure. Such trend identification is of value in predicting the potential effects of sediment on aquatic organisms, but caution must be exercised when assessing the effects of low concentrations ($\leq$ tens of $mg \cdot L^{-1}$) of suspended sediment over protracted periods of time. Furthermore, it is likely that there would be increased variation in the response among individuals and life stages of organisms to the effects of elevated, but lower and sublethal levels of sediments, relative to less variable responses at higher sediment levels, due to a greater severity of effect and less scope for adaptation, tolerance and resistance. Because of this, judicious application of these models is warranted when assessing the potential impacts of exposure to low levels of suspended sediment.

Criteria that rely solely on the use of turbidity to protect aquatic organisms from elevated levels of suspended solids are not generally recommended for use because the typical site-specific and highly significant relationship that exists between turbidity and suspended solids is not universally applicable. Turbidity determinations integrate the effects of suspended and dissolved material on the penetration of light in waters which, in turn, affects biological productivity. Depending upon the nature of the sediment in suspension and of the dissolved material, the ratio between turbidity and suspended sediment will vary, usually by a factor less than 10. If, however, the relationship between suspended sediment concentrations and turbidity is known for a particular area (watershed, stream, reach etc.), then turbidity *per se* may be used as a surrogate for suspended sediment and the appropriate criteria for the latter applied. Turbidity is, therefore, a useful, but approximate, indicator for suspended sediment.

For more information

Contact:

Ian K. Birtwell, Research Scientist
Marine Environment and Habitat Sciences Division,
Fisheries and Oceans Canada,
West Vancouver Laboratory,
4160 Marine Drive,
West Vancouver, BC, Canada, V7V 1N6
Tel: 604-666-7909
Fax: 604-666-3497
E-mail: birtwelli@dfo-mpo.gc.ca

References

Anderson, P. B. Taylor, and G. Balch. 1996. Quantifying the effects of sediment release on fish and their habitats. Can. Manuscr. Rep. Fish. Aquat. Sci. 2346. 110p.

Birtwell, I.K. 1999. The effects of sediment on fish and their habitat. DFO Can. Pacific Science Advice and Review Committee Habitat Subcommittee Res. Doc. Canadian

Stock Assessment Secretariat Resesarch Document 99/139.

British Columbia Ministry of Environment, Lands, and Parks (BCMELP). 1998. Ambient water quality guidelines (criteria) for turbidity, suspended and benthic sediments: overview. Water Management Branch, Environment and Resource Division, British Columbia Ministry of Environment, Lands and Parks. Victoria, BC.

Canadian Council of Resource and Environment Ministers (CCREM). 1987. Total suspended solids. In: Canadian Environmental Quality Guidelines, Environment Canada, Ottawa, ON.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian water quality guidelines for the protection of aquatic life: total particulate matter. In: Canadian Environmental Quality Guidelines, 1999, Environment Canada, Winnipeg, Manitoba. (In preparation).

Caux, P.-Y., D.R.J. Moore, and D. MacDonald. 1997. Ambient water quality guidelines (criteria) for turbidity, suspended and benthic sediments: technical appendix. Prepared for the British Columbia Ministry of Environment, Lands and Parks. Water Quality Branch, Environment and Resource Management Division, Victoria, BC. 82p.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Trans. Amer. Fish. Soc. 117:1-21.

European Inland Fisheries Advisory Commission. 1964 (EIFAC). Water quality criteria for European freshwater fish. Report on Finely Divided Solids and Inland Fisheries. European Inland Fisheries Advisory Commission. Food and Agriculture Organization of the United Nations. Rome. EIFAC/1. 21p.

Government of Canada. 1993. The Yukon Placer Authorization and supporting documents, applicable to placer mining in the Yukon Territory. Ottawa, ON. 36p.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. North Amer. J. Fish. Management. 7:34-45.

Newcombe, C.P., and J.O.T. Jensen. 1996. Channel suspended sediment and fisheries: A synthesis for quantitative assessment of risk and impact. North Amer. J. Fish. Management 16: 693-727.

Newcombe, C.P., and D.D. MacDonald. 1991. Effects of suspended sediment on aquatic ecosystems. North Amer. J. Fish. Management. 11:72-82.

Seakem Group Ltd. 1992. Yukon Placer Mining Study. Volume 1 Executive Summary. Prepared for the Yukon Placer Mining Implementation Review Committee. Sidney, British Columbia. 17p.

This report is available:

PSARC Secretariat
Pacific Biological Station
Nanaimo, BC V9R 5K6
Phone: (250) 756-7208
Fax: (250) 756-7209
E-Mail: psarc@pac.dfo-mpo.gc.ca
Internet Address: (www.dfo-mpo.gc.ca/csas)

ISSN 1480-4913 (for English series)
ISSN 1480-4921 (for French series)

La version française est disponible à l'adresse ci-dessus.

Correct citation for this publication

DFO, 2000. Effects of sediment on fish and their habitat. DFO Pacific Region Habitat Status Report 2000/01.