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MINING AND FISHERIES PROTECTION:
Sediment Impact Models

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ABSTRACT

Review of the available water quality literature yields two promising water quality "models" for assessing sediment impact in aquatic ecosystems. One is relatively new (1996, 1997), and the other several decades old (1965). Both are of potential use in remediation or in the design and implementation of a mine reclamation program.

The new model is based on a compendium of data which links *dose* (concentration of suspended sediment [mg/L] and duration of exposure [hours]) and *response* (ill effect) in fishes and aquatic invertebrates. "Dose" is expressed as $mg \cdot h \cdot L^{-1}$ (milligram-hours per liter), and ill effect is expressed on a 15-step semi-quantitative scale. This "dose-response" model (the first of its kind in this branch of fisheries science) offers predictive capability much needed in environmental reclamation and remediation. It has potential utility in the design of mitigation measures when environmental impacts are unavoidable; and (potentially) in the field of pollution credit trading when there is a need to establish functional equivalence among disparate sediment pollution events, thereby to balance credits and debits.

The older model is a classic. It offers two parts of interest here: the first describes half a dozen modes of action of suspended sediment on fishes; the second draws general conclusions about the effect of ambient suspended sediment and the size of fish populations. This "model" is an excellent primer because it offers a concise summary of knowledge available up to 1965. Its "modes of action" and "general conclusions" are still current today. This reflects the thoroughness of the review on which the model is based, and the relatively slow pace at which new sediment impact knowledge is created.

INTRODUCTION

Although sediment control during mine construction and reclamation protects aquatic ecosystems by limiting the release of excess sediment into streams, industry and regulators need ways to interpret water quality data to gauge the success of their programs. Empirical sediment impact models are a means to this end.

Water quality criteria for suspended sediment have been available for several decades but most of these, with a couple of notable exceptions, are poorly adapted to the needs of mine construction and reclamation. This limitation reflects our traditional focus on a threshold of ill effect. It also reflects our willingness, in the past few decades, to overlook what we know about the nature of ill effects as a function of suspended sediment (SS) concentration and duration of exposure[1].

The two promising exceptions are (1) semi-quantitative guidelines, largely ignored by North American regulatory agencies, developed by the European Inland Fisheries Advisory Commission (FAO, UN) (Eifac 1965), and (2) suspended sediment (SS) toxicity models for fishes and invertebrates (Newcombe and Jensen 1996, models for "Salmon and trout;" and Newcombe 1997, model for "Aquatic invertebrates").

These two — the European fisheries guidelines (Eifac 1965), and the Newcombe-Jensen toxicity models — differ from traditional criteria: both provide information about aquatic ecosystem quality over a wide range of sediment concentrations and durations. Eifac guidelines describe ambient sediment conditions and relate these to fish production: concentration ranges are given, and the implicit timeline is continuous from one year to the next. The Newcombe-Jensen models describe sediment pollution episodes in terms of average concentration, duration of exposure, and potential ill effect. Where the first two variables are known or predicted, the third (a potential ill effect) can be derived by computation (or found in the "look-up" tables created for this purpose). Combined, these two models are more powerful than either alone, and much more useful than traditional criteria.

Partial contents of three papers are presented here, in concise form, with emphasis on material — potential impacts to aquatic life — most likely to be of use in the context of mining reclamation

[1] Traditional criteria simply define a single threshold SS concentration beyond which some specified harm might occur. This interpretation of the available information might have been suitable for enforcement under the Fisheries Act in the past, but it offers little insight into the nature and extent of the probable harm caused by excess sediment. Nor

and remediation. The two main references (peer reviewed and cited above) require no special comment. The third reference (Newcombe 1997) contains a model for aquatic invertebrates. This model (not peer reviewed but identical in form and function to the ones that are) should find broad application in the field of mine reclamation and remediation: invertebrates are excellent indicators of pollution impacts caused by excess channel sediment.

Conditions suitable for clear water invertebrates are also ideal for clear water fishes. Invertebrates typically found in pristine streams succumb rapidly to the ill effects of excess suspended sediment, at relatively low concentrations. Their acute sensitivity is similar to that of eggs and larvae of salmon and trout (compare the aquatic invertebrate model provided here with the ones for fish eggs and larvae in Newcombe and Jensen 1996; or, see Newcombe 1997, which contains both models). Sediment abatement measures that protect the most vulnerable aquatic invertebrate species (or the most sensitive life stages of these species; see Table 2) should, therefore, protect the whole aquatic ecosystem, fish included.

Notwithstanding these parallels, harm to invertebrate populations is a much less serious matter than harm to fish larvae or eggs. Invertebrate populations can rebound to good health in as little as a few weeks; moreover, clean water invertebrates are not generally considered endangered. In contrast, harm to any fish life-history phase can take much longer (one or more life-cycles, 1-year each), and some fish populations (coho in particular, but also steelhead) are considered to be in decline, nearing endangerment. They are in need of the best possible protection.

MODELS

1. European Inland Fisheries Advisory Commission

1.1 Fisheries and Channel Suspended Sediment; Six Modes of Harmful Effect[2]

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does it offer insights into the kind of benefit likely to result when planned reductions in suspended sediment loading are achieved.

[2] Based on Eifac Working Party on Water Quality Criteria for European Freshwater Fish. 1965. Water quality criteria for European freshwater fish. Report on finely divided solids and inland fisheries. EIFAC Technical Paper (1), 21 pages; amended in 1997 by C. P. Newcombe, Habitat Protection Branch, Ministry of Environment, Lands and Parks, Victoria, British Columbia, Canada. EIFAC is the European Inland Fisheries Advisory Council, Food and Agriculture Organization (F[7]AO), United Nations, Rome

Although suspended sediment (finely divided mineral solids) occurs naturally in streams, there are at least six ways that such particles might be harmful to a fishery in a river or a lake:

[1] by acting directly on the fish swimming in water in which solids are suspended (potential effects include alarm reaction, increased morbidity — reduced resistance to disease, abrasion of gill tissue — and, increased mortality).

[2] by preventing the successful development of fish eggs and larvae. Physical and chemical effects of excess channel sediment include reduced rate of percolation flow, reduced concentration of oxygen within a redd, and, barriers to larval emergence by the accumulation of fine particles that tend to cement the superficial layer of the stream bed. "Cementing" causes fry to become trapped, delaying or preventing their emergence;

[3] by modifying the natural movements and migrations of fish. Fish may avoid traditional spawning or rearing areas;

[4] by reducing the abundance of food available to the fish. Food organisms may drift or die because of sediment scour and deposition;

[5] by altering habitat. Deposition of excess sediment may change the particle size composition of the stream bed, and it may also cause changes in channel morphology; and,

[6] by affecting the efficiency of methods for catching fish. Turbidity caused by suspended solids can reduce catch per unit effort.

These modes could operate singly or together to harm a fishery.

1.2 General Patterns

General conclusions about harm caused by excess channel sediment[3], as enunciated by the EIFAC, are as follows:

[1] There is probably no sharply defined concentration or duration of exposure above which fisheries are damaged and below which they are quite unharmed.

[2] Apparently any increase in the normally prevailing concentration of suspended sediment (or bedload) can cause some decline in the health status or productivity status or value of a fishery.

[3] The degree of risk to a fishery caused by suspended sediment may be divided into four arbitrarily defined categories based on a range of concentrations, where ambient SS exposure is ongoing, or repeated in successive hydrological cycles. (To reach the conclusions listed below in situations where exposure is occasional, or discontinuous, it may be necessary to assume that at least one life history phase is harmed, and i:hat harmful exposures recur annually, cpn Ed. Note):

[3] From the EIFAC (1965) report on finely divided solids (UN FAO), amended by C.P. Newcombe. Ministry of Environment, Lands and Parks, Resource Stewardship Branch, Victoria, British Columbia, Canada

(a) waters with less than 25 mg SS/L should support excellent fisheries; however, the best trout streams are characterized by clear water with less than 5 mg SS/L for most of the hydrological cycle.

(b) it should usually be possible to maintain good or moderate fisheries in waters that normally contain 25 to 80 mg SS/L suspended solids;

(c) waters that normally contain 80 to 400 mg SS/L suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations in this range;

(d) at best, only poor fisheries are likely to be found in waters that normally contain more than 400 mg SS/L suspended solids.

[4] In addition, although several thousand mg SS/L might not kill fish during several hours or days exposure, such temporary high concentrations should be prevented in rivers where good fisheries are to be maintained. Severity of ill effect is worse in seasonably warm water than in seasonably cold water, or when particle size is greater than 75 microns, or both, other variables being constant.

2. Dose-Response Models

Creation of the suspended sediment dose-response models (Newcombe and Jensen 1996) involved three recent developments not found in the EIFAC review, including,

a) an expanded database of harmful effects to fishes and invertebrates associated with documented pollution episodes of known suspended sediment concentration (mg SS/L) and known duration of occurrence (hours) (Newcombe 1994);

b) a semi-quantitative scale of ill effects ranging from nil to 100 per cent mortality, including habitat damage (Newcombe 1996); and,

c) a mathematical model, and a user-friendly way to display calculations (Newcombe 1996) depicting potential ill effects.

The semi-quantitative scale is a key component of the models (Table 1, *Salmon and trout;* and Table 2, *Aquatic invertebrates).* It recognizes four main classes of ill effect: nil, behavioral, sub-lethal (including moderate habitat damage) and lethal (a class that includes paralethal[4] effects like severe habitat damage and delayed hatching). Within each of these four broad classes are one or more descriptions of ill effect reported by researchers in the field (see compendium,

[4] Paralethal effects can increase morbidity, leading to reduced population size. Although paralethal effects are less obvious than lethal effects — they are a) *subtle;* reduced rate of percolation flow in a redd can lead to reduced rate of egg to fry survival; or, b) *difficult to measure;* altered timing of emergence leading to sub-optimal rearing conditions and reduced survival from fry to juvenile, or, c) *invisible;* there are no dead fish to count, or d) *not currently recognized,* our knowledge base is small — they are as important as direct toxicity and acute lethality, perhaps more so.

Newcombe 1994). The 15-step SEV scale ranges from O (nil effect) to 14 (80% - 100% mortality). The scale is open ended; catastrophic events can cause extreme habitat damage that exceeds the arbitrary maximum (100 % mortality of fishes).

Probable ill effects of excess SS are depicted in a matrix format (see: Figure 1, *Salmon and trout;* and Figure 2. *Aquatic invertebrates).* Intersecting columns and rows (representing SS concentration and duration of exposure, respectively) create the cells in this matrix. Within these cells, the SEV value represents the probable impact for the concentration-duration scenario defined by row and column values[5]. Interpretation of the significance of the SEV value can be based on the table of ill effects (Table 1 ; *Salmon and Trout: Adult and Juveniles,* Newcombe and Jensen 1996); Table 2; *Aquatic Invertebrates,* Newcombe 1997)[6]. These are only two of the eight models now available.

Care in the use of the model is very important. Here are some of the design characteristics to consider:

a) duration of exposure ranges from 1-hour to 30 months, and suspended sediment concentrations range from 1 mg SS/L to more than 162,000 mg SS/L

b) cell coordinates represent the geometric mid-point of a range of concentrations and durations[7].

c) successive cell coordinates increase by a factor of about 2.7183 (the base of natural logarithms).

d) for practical applications like reclamation and remediation, the severity-of-ill-effect (SEV) values in the matrix can be accepted as shown. However, several variables, especially particle size and water temperature, may produce an *effective* SEV value that differs slightly from the *calculated* SEV value. Reasons for this effect are explained below:

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[5] For convenience, half-95% confidence intervals for each calculated score are shown in adjacent columns in italics (e.g., SEV = 7 ± *0.3).*

[6] A more detailed interpretation based on documented cases can be found in the compendium (Newcombe 1994). Chapters in this compendium are arranged in order of increasing dose (where close is the product of concentration, expressed in mg SS/L, and duration, expressed as hours). Serial numbering, used to organize the entries in the compendium, are generated by the natural logarithm of dose. Serial numbers increase as a function of close and range from a minimum of approximately O to a maximum of approximately 19.

[7] Ranges for each interval have been calculated, see Newcombe 1997 (Table 5). For example, the mid-point identified as "30-months" spans a time interval from 18 to 48 months. When these durations are expressed as $\log_e$ (hours), the mid-point (30 months) becomes 10, the minimum becomes 9.5, and the maximum <10.5.

- *particle size:* Particles large enough to abrade gill tissue or scour benthic invertebrates (75 microns diameter and greater) are much more capable of causing physical harm to living tissue than smaller, clay-sized, particles. But clay is capable of causing harm to aquatic habitat (cementing of spawning gravels before spawning or during egg incubation), and to fish populations (turbidity and reduced opportunity to feed).

- *water temperature:* severity of ill effect for salmon (and probably trout too) is known to be a function of temperature greater than or less than 7 ^{0}C[8]. Ill effect is usually worse in seasonably warm water than it would be in seasonably cold water. Dissolved oxygen concentrations in water decrease as a function of increasing temperature; but, the fish's respiration rate (requirement for oxygen) increases correspondingly. At temperatures between 7 ^{0}C and O ^{0}C, fish sensitivity to ill effects of SS is known to increase somewhat even though the metabolic requirements diminish.

e) although particle size and water temperature are capable of modifying the severity of ill effect caused by excess suspended sediment, SEV scores should be accepted as given in the tables (1, and 2). This is particularly true when the purpose in using the models is to plan activities related to mine construction, reclamation or remediation.

HABITAT DAMAGE AND RECOVERY TIMES

Habitat damage is a paralethal effect because it does not necessarily produce dead fish. Rather, it alters the age-specific survival rate for one or more life history phases. The permanence of paralethal effects could be a matter of concern to fisheries managers and remediation specialists.

Fortunately, most habitat damage is not permanent[9]. Paralethal effects can be reversed by natural processes. The Newcombe-Jensen (1996) sediment impact models can be used to monitor the rate of return to normal conditions. Since rate of recovery is highly variable[10] a quick look at case studies might help to establish the spectrum of realistic timelines (from almost immediate recovery to long term):

- SEVERAL MONTHS: benthic communities in a. lake *partially* disturbed by dredging may be rehabilitated almost immediately (Carline and Brynildson 1977);

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[8] Salmon are hardiest at 7°C.
[9] Loss of genetic diversity is one immediate consequence of severe habitat damage. Restoration of genetic diversity is likely to be a slow process, requiring many generations, and perhaps centuries of time.
[10] Stream or lake rehabilitation by natural processes can take one or more hydrological cycles after an extreme event. Each cycle lasts one year.

- SEVERAL YEARS: benthic communities in a lake *completely* disturbed by dredging may be rehabilitated by natural processes in a year or two (Carline and Brynildson 1977);

- ONE OR TWO DECADES: loss of aquatic ecosystem diversity caused by excess channel sediment released by strip mining in Tennessee: recovery is expected to take place gradually over a period of 15 to 20 years (Vaughan and others 1978).

- SEVERAL DECADES: loss offish populations caused by excess channel sediment released by timber harvest in the San Juan River drainage, British Columbia. Recovery is expected to occur gradually over a period of several decades — three decades at least, but perhaps as many as four or five decades.

Pristine water quality is the gift of an untrammeled landscape. Land development leading to increased erosion is the cause of excess channel sediment. Roads are the main source. In general, therefore, remediation and reclamation efforts should focus on healing the landscape. Stream channels should be left to repair themselves by the sorting action of flowing water. We can not improve on natural geofluvial processes. And when we try, the stream erases our efforts. Fortunately the energy of flowing water — the driving force of restorative geofluvial processes — is free. Money saved by letting the stream rework its own channel can be used to redouble efforts on the riparian and upland zones.

CONCLUDING REMARKS

This condensed guide should be seen as an introduction. To apply the quantitative models in settings where there is risk of impact involving valued fisheries or aquatic resources refer to the parent document (Newconnbe and Jensen 1996). To gain a better understanding of stream conditions where excess sediment is a chronic condition see the semi-quantitative report by the European Inland Fisheries Advisory Commission (Eifac 1965). Pre-project preparations should also include a review of recent primary literature, including the American Fisheries Society monograph on sediment in streams — sources, biological effects, and control (Waters, T. F. 1995; see annotated reference). Additional information on water quality and non point sources (NPS) of pollution, including soil erosion, can be found at the home page of North Carolina University, *[http://www.bae.ncsu.edii/bae/programs/extension/wqg/index.html]*.

Table 1. Scale of the severity (SEV) of ill effects in fishes exposed to excess suspended sediment.

Class	SEV[11]	Potential Effects
Nil	0	No behavioral effects
Behavioral	1	Alarm reaction
	2	Abandonment of cover
	3	Avoidance response
Sub-lethal	4	Short-term (<2–h) reduction in feeding rates
		short-term (<2–h)reduction in feeding success
	5	Minor physiological stress
		increase in rate of coughing
		increased respiration rate
	6	Moderate physiological stress
	7	Moderate habitat degradation
		impaired homing
	8	Indications of major physiological stress
		long-term (nominally >2–h)[12] reduction in feeding rate
		long-term (nominally >2–h)[13] reduction in feeding success
		poor condition
Lethal or paralethal	9	Reduced growth rate
		delayed hatching
		reduced fish density
	10	0–20% mortality
		increased predation
		moderate to severe habitat degradation
	11	>20–40% mortality
	12	>40–60% mortality
	13	>60–80% mortality
	14	>80–100% mortality

[11] From Newcombe and Jensen 1996. See References Cited.
[12] In practical terms, probably on the order of ≥24 hours..
[13] *ibid.*

SALMON and TROUT [1]

Duration of exposure to Suspended Sediment ($\log_e$ hours)

Average severity-of-ill-effect (SEV) scores (calculated) (**)

mg SS/L	0	(±)	1	(±)	2	(±)	3	(±)	4	(±)	5	(±)	6	(±)	7	(±)	8	(±)	9	(±)	10	(±)	$\log_e$ mg SS/L
162755	10	0.9	11	0.8	11	0.8	12	0.8	~~12~~	~~0.7~~	~~13~~	~~0.7~~	~~14~~	~~0.8~~	~~14~~	~~0.8~~	-	-	-	-	-	-	12
59874	9	0.8	10	0.7	10	0.7	11	0.6	12	0.6	12	0.6	~~13~~	~~0.7~~	~~13~~	~~0.7~~	~~14~~	~~0.7~~	-	-	-	-	11
22026	8	0.7	9	0.6	10	0.6	10	0.5	11	0.5	11	0.5	~~12~~	~~0.6~~	~~13~~	~~0.6~~	~~13~~	~~0.7~~	~~14~~	~~0.7~~	-	-	10
8103	8	0.6	8	0.6	9	0.5	10	0.4	10	0.4	11	0.4	11	0.5	12	0.5	13	0.6	13	0.7	~~14~~	~~0.8~~	9
2981	7	0.6	8	0.5	8	0.4	9	0.4	9	0.4	10	0.4	11	0.4	11	0.5	12	0.5	12	0.6	~~13~~	~~0.7~~	8
1097	6	0.6	7	0.5	7	0.4	8	0.3	9	0.3	9	0.3	10	0.4	10	0.4	11	0.5	12	0.6	12	0.7	7
403	5	0.6	6	0.5	7	0.4	7	0.3	8	0.3	9	0.3	9	0.4	10	0.5	10	0.5	11	0.6	~~12~~	~~0.7~~	6
148	5	0.6	5	0.5	6	0.4	7	0.4	7	0.4	8	0.4	8	0.4	9	0.5	10	0.6	10	0.7	~~11~~	~~0.8~~	5
55	4	0.6	5	0.6	5	0.5	6	0.5	6	0.5	7	0.5	8	0.5	8	0.6	9	0.6	9	0.7	~~10~~	~~0.8~~	4
20	3	0.7	4	0.7	4	0.6	5	0.6	6	0.6	6	0.6	7	0.6	8	0.7	8	0.7	9	0.8	9	~~0.9~~	3
7	3	0.8	3	0.7	4	0.7	4	0.7	5	0.7	6	0.7	6	0.7	7	0.8	7	0.8	8	0.9	9	~~1.0~~	2
3	2	0.9	2	0.8	3	0.8	4	0.8	4	0.8	5	0.8	~~5~~	~~0.8~~	~~6~~	~~0.9~~	~~7~~	~~0.9~~	~~7~~	~~1.0~~	~~8~~	~~1.0~~	1
1	1	1.0	~~2~~	~~1.0~~	~~2~~	~~0.9~~	~~3~~	~~0.9~~	~~3~~	~~0.9~~	4	~~0.9~~	~~5~~	~~0.9~~	~~5~~	~~1.0~~	~~6~~	~~1.0~~	~~7~~	~~1.1~~	~~7~~	~~1.1~~	0
	1		3		7		1		2		6		2		7		4		11		30		
	Hours						Days						Weeks				Months						

Fig. 1. Severity-of-ill-effect scores predicted for salmon and trout. Shaded areas represent extrapolations beyond empirical data; extrapolations have been capped at 14 (upper limit of the "effects" scale, although higher values are possible). Diagonal terraced lines denote thresholds of sublethal (lower left) and lethal effects delineated by the model. Severity of ill effect (SEV) ranges from O (nil effect) to 14 (>80 -100% mortality) on a 15-step scale.

(*) Half-95% confidence intervals around predicted severity-of-ill effect scores are shown in small italics.

[1] Newcombe, C. P. and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16:693-727.

Table 2. Scale of the severity (SEV) of ill effects among invertebrates exposed to excess suspended sediment.

Class	SEV[14]	Potential Effects
Nil	0	No harmful effects
Behavioral	1	No Data. Intermediate value
	2	No Data. Intermediate value
	3	Increased drift
Sub-lethal	4	Short-term (<1–h)[15] minor (≤10%) reduction in feeding rates short-term reduction in feeding success
	5	Short-term (<1–h)[16] reduction in feeding rate, (≤90 %) including efficiency of ingestion and incorporation
	6	No data. Intermediate value
	7	No data. Intermediate value
	8	Silt-intolerant species less abundant long-term (>24–h)[17] reduction in feeding rate long-term (>24–h)[18] reduction in feeding success temporary changes in community structure invertebrates at risk of starvation
Lethal or paralethal	9	No data. Intermediate value
	10	Number of taxa; standing crop reduced by 0 – 20% survival and fecundity reduced species or taxonomic diversity reduced gills or gut, or both, are clogged with particles 0 – 20% mortality; increased predation; abundance reduced by similar percentage
	11	>20 – 40% mortality; or abundance of invertebrates reduced by similar percentage
	12	>40 – 60% mortality; abundance reduced by similar %
	13	>60 – 80% mortality; or abundance reduced by similar %
	14	>80 – 100% mortality; or abundance reduced by similar %

[14] From Newcombe, 1997. See References Cited.
[15] Refers to duration of effect, which is not necessarily the same as duration of suspended sediment pollution.
[16] *Ibid.*
[17] *Ibid.*
[18] *Ibid.*

AQUATIC INVERTEBRATES[1]

Duration of exposure to Suspended Sediment ($\log_e$ hours)

Average severity-of-ill-effect (SEV) scores (calculated) (*)

mg SS/L	0	1	2	3	4	5	6	7	8	9	10	$\log_e$ mg SS/L
162755	10 *1.5*	11 *1.4*	11 *1.4*	12 *1.4*	13 *1.4*	14 *1.4*	14 *1.4*	- -	- -	- -	- -	12
59874	9 *1.3*	10 *1.3*	11 *1.2*	12 *1.2*	12 *1.2*	13 *1.2*	14 *1.2*	- -	- -	- -	- -	11
22026	9 *1.1*	10 *1.1*	10 *1.1*	11 *1.1*	12 *1.0*	13 *1.0*	14 *1.0*	- -	- -	- -	- -	10
8103	8 *1.0*	9 *0.9*	10 *0.9*	11 *0.9*	12 *0.9*	12 *0.9*	13 *0.9*	14 *0.9*	- -	- -	- -	9
2981	8 *0.8*	9 *0.8*	10 *0.7*	10 *0.7*	11 *0.7*	12 *0.7*	13 *0.7*	14 *0.7*	14 *0.8*	- -	- -	8
1097	8 *0.7*	8 *0.6*	9 *0.6*	10 *0.6*	11 *0.6*	11 *0.6*	12 *0.6*	13 *0.6*	14 *0.6*	14 *0.7*	- -	7
403	7 *0.6*	8 *0.5*	9 *0.5*	9 *0.5*	10 *0.4*	11 *0.4*	12 *0.5*	13 *0.5*	13 *0.6*	14 *0.6*	- -	6
148	7 *0.6*	7 *0.5*	8 *0.4*	9 *0.4*	10 *0.4*	10 *0.4*	11 *0.4*	12 *0.5*	13 *0.5*	14 *0.6*	- -	5
55	6 *0.6*	7 *0.5*	8 *0.4*	8 *0.4*	9 *0.4*	10 *0.4*	11 *0.4*	12 *0.5*	12 *0.5*	13 *0.6*	14 *0.7*	4
20	6 *0.6*	7 *0.6*	7 *0.5*	8 *0.5*	9 *0.5*	10 *0.5*	10 *0.5*	11 *0.6*	12 *0.6*	13 *0.7*	14 *0.8*	3
7	5 *0.7*	6 *0.7*	7 *0.7*	8 *0.6*	8 *0.6*	9 *0.6*	10 *0.7*	11 *0.7*	11 *0.7*	12 *0.8*	13 *0.9*	2
3	5 *0.9*	6 *0.8*	6 *0.8*	7 *0.8*	8 *0.8*	9 *0.8*	9 *0.8*	10 *0.9*	11 *0.9*	12 *0.9*	12 *1.0*	1
1	4 *1.0*	5 *1.0*	6 *1.0*	7 *1.0*	7 *1.0*	8 *1.0*	9 *1.0*	10 *1.0*	10 *1.0*	11 *1.1*	12 *1.1*	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

Fig. 2. Severity-of-ill-effect scores predicted for aquatic invertebrates. Shaded areas represent extrapolations beyond empirical data; extrapolations have been capped at 14 (upper limit of the "effects" scale, although higher values are possible). Diagonal terraced lines denote thresholds of lethal (lower left) and supra-lethal effects established by the model. Severity of ill effect (SEV) ranges from O (nil effect) to 14 (>80 -100% mortality) on a 15-step scale.

(*) Half-95% confidence intervals around predicted severity-of-ill effect scores are shown in small italics.

[1] Newcombe, C. P. 1997. Channel suspended sediment and fisheries: a concise guide. Resource Stewardship Branch, Ministry of Environment, Lands and Parks. Victoria, British Columbia, Canada. 37 pages.

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