

FINAL 2002-2003 PROJECT REPORT
FORESTRY INNOVATION INVESTMENT
RESEARCH PROGRAM
FII R2003-183

*Modelling the effects of changes in turbidity and
channel structure on growth of juvenile salmonids*

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Organization: Fisheries Research, B.C. Ministry of Water Land and Air Protection

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Project Start Date: Dec. 1 2002

Project End Date: March 31 2003

1. ABSTRACT

ABSTRACT:

No models exist for quantitatively estimating the impact of chronic or episodic increases in turbidity on juvenile salmon growth rates. To provide a credible basis for quantifying the impacts of increased turbidity, and to provide a tool for developing monitoring and assessment guidelines for forestry impacts on stream turbidity, we have developed a basic drift-foraging bioenergetics model to predict the impact of turbidity on juvenile salmon growth rates. The model involves developing a function reducing the reactive distance of fish to drifting invertebrates as a function of increased turbidity, and inserting this function into a bioenergetics model that predicts growth of fish based on invertebrate drift-feeding.

Over the 4-month course of this project, model development involved

- 1) a review of the primary literature to identify studies that have documented turbidity-reactive distance relationships for salmonids
- 2) Statistical analysis and data-fitting for these studies to derive an average function describing decrease in reactive distance with increasing turbidity
- 3) Insertion of this function into a bioenergetics drift-feeding model
- 4) Testing of the bioenergetics model to see whether it could predict observed decreases in growth rates of fish experimentally documented in the published literature.

The model appears to be very successful in terms of predicting observed changes in growth rates based on the only published study with sufficient data to test it. The model has enormous potential as a management tool to predict sub-lethal effects of impaired water quality by providing a credible basis for evaluating how changes in turbidity and channel structure affect fish growth. In its final form, this model will provide an accessible tool for developing monitoring and assessment guidelines for forestry impacts on stream habitat and water quality, pending sufficient funding for its development.

KEYWORDS: turbidity, suspended sediment, logging impacts, fish growth, juvenile salmonids, drift-feeding, bioenergetic modelling

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3. INTRODUCTION

Elevated turbidity in stream water is one of the frequent side-effects of forestry. Erosion from road surfaces, hillslopes, or stream banks can result in chronic or episodic increases in turbidity (Murphy 1995). Depending on exposure duration and intensity, this will have direct negative effects on fish growth by inducing physiological stress, and indirect effects by reducing the visual distance over which drift-feeding fish can detect their prey. Although the generally negative impact of decreased water clarity is widely recognized, quantitative models predicting the chronic effects of increased turbidity on metrics of aquatic health are not widely available. In particular, there are no mechanistic models that predict the effects of increased turbidity on growth rates of juvenile salmonids.

At relatively low levels of turbidity energy intake for drift-foraging fishes may be significantly reduced because of shorter visual detection distances for invertebrate prey. Despite a large body of research on the effects of turbidity on fish growth in the laboratory and field, there are at present no quantitative models for predicting the effects of elevated turbidity on fish growth rates. This represents a significant gap in our ability to quantitatively predict and monitor logging impacts, and to calibrate increases in turbidity to meaningful aquatic impacts on aquatic ecosystem health, such as fish growth. Quantitatively predicting the effects of turbidity on fish growth is an essential step towards developing criteria for acceptable levels of turbidity from logging operations, and development of this model will result in a significant addition to the tools available for evaluating and monitoring forestry impacts.

Although many experiments have measured and identified short and long-term effects of exposure to suspended sediments on streams fishes, to our knowledge few have differentiated the effect of suspended solids on foraging efficiency from the general effects of elevated stress on fish or sedimentation effects on benthic invertebrate production (and therefore drift density). To our knowledge there are also no mechanistic models for predicting the impacts of increased turbidity on fish growth. There are empirical measurements of the impact of increased turbidity on fish reactive distance (e.g. Barrett et al. 1992), growth rates (e.g. Sigler et al. 1984), and foraging efficiency, but there is little theoretical basis for extrapolating these empirical observations to other systems, since conclusions were based on empirically derived observations from field studies or experimental systems, rather than mechanistic models that have broad generality. Although general models exist for predicting the qualitative biological effects of suspended sediments based on meta-analysis of published studies (e.g. Newcombe and Jensen 1996), these models incorporate large confidence intervals because of the diversity of studies constituting the data base. These models are most useful for delineating broad ranges of turbidity over which qualitative effects may be expected to occur, but they give no insight into mechanisms of sublethal effects. A mechanistic model has the ability to quantitatively estimate finer sub-lethal effects that are difficult or impossible to detect in experimental studies or field observations because of uncontrolled variation.

We will develop a theoretical model for assessing turbidity effects on fish growth by adapting existing mechanistic models predicting foraging efficiency of drift-feeding fishes (Hughes and Dill 1990, Nislow et al 2000, Guensch et al. 2001) as a function of reactive distance of fish at different levels of water clarity. We will evaluate the predictive accuracy of the model using published experiments in the literature (e.g. Sigler et al. 1984) where fish growth was monitored at different turbidity levels.

This proposed research is consistent with the stated objectives FII RFP - e.g. *More effective policies, regulations, and guidelines* – since the proposed model will provide a scientific basis for understanding turbidity impacts and for informing policy and guideline development. It will also have broad application in locations outside of B.C. wherever drift-foraging fish can be impacted by elevated turbidity from development in a watershed.

The primary research objectives of this project were

- i) to develop a model predicting the effects of increased turbidity on juvenile salmonid growth rates.
- ii) to use this model to generate a preliminary phase-space defining regions of positive growth for small and large juvenile salmonids at different turbidities.
- iii) to validate the assumptions implicit in the drift-foraging model related to variation in drift rates within a stream

The relevance of this research to forestry is that it will provide a credible model to evaluate sublethal impacts on fish from elevated suspended solids, providing a basis for monitoring and adaptive management that will ensure that forest practices are sustainable. This model and the science behind it will also have broad application beyond forest management in British Columbia, since it should be transferable to water quality impacts in any jurisdiction.

The benefit to resource managers will be access to a tool that gives a direct measure of habitat impacts on fish growth rate potential, and which will also provide a quantitative unambiguous measure of impact associated with different management practices. It will also provide a useful tool for setting guidelines for impacts and monitoring standards. These benefits will accrue at the end of the project when the model is available as a management tool, pending additional funding for model development.

4. ACTIVITIES & METHODS

Activities during the 4-month duration of this project focused on

- 1) A review of the primary literature to identify studies that have documented turbidity-reactive distance relationships for salmonids.

This involved intensive searching of primary literature databases, to identify suitable studies and relationships.

- 2) Statistical analysis and fitting of data from these studies to derive an average function describing decrease in reactive distance with increasing turbidity.

This involved screening studies for suitability for entry into a database for estimating an average (or common) function, digitizing scanned data from these published studies, and transformation of data to meet assumptions of model-fitting, and finally fitting a function of percent reactive distance to log-transformed turbidity data. Refer to the enclosed Appendix 1 for more detail.

- 3) Insertion of this function into a bioenergetics drift-feeding model.

To model growth rates of drift-feeding fish, we applied a version of the bioenergetic model developed by Hughes and Dill (1990) and later applied by Rosenfeld and Boss (2001) to estimate growth rates of juvenile cutthroat trout. This model calculates energy intake based on invertebrate abundance in the drift (water column) within the reactive radius of a fish to drifting invertebrate prey. Since the reactive distance of a fish (how far it can see prey) is a function of water clarity, we inserted our derived reactive-distance turbidity relationship into the model, thereby reducing energy intake with increasing turbidity.

- 4) Testing of the bioenergetics model to see whether it could predict observed decreases in growth rates of fish experimentally documented in the published literature.

Having built a basic model predicting the expected effects of increased turbidity on growth of juvenile salmonids, we performed another literature search to identify published experiments documenting the effects of increased turbidity on growth of juvenile salmonids, with the goal of using these experiments to test the predictions of the model. To be suitable for model validation, published studies would have to include:

- growth rate of fish
- concentration of prey items in the drift
- size of prey

- energy content of prey
- current velocity

We found only one study that documented sufficient information to test the model. This was a recent experiment by Sweka and Hartman (2001a), who measured growth of immature brook trout under a suite of turbidity conditions. We used our model and their input parameters to estimate growth rate of brook trout using

- i)* a generalized model using an average reactive distance function for all species
- ii)* a more customized model using a reactive distance function specific to brook trout, a reactive distance – turbidity relationship specific to brook trout, and a maximum consumption relationship specific to the study (Swek and Hartman 2001a, 2001b).
- iii)* a specialized model (as in ii above) that allowed fish to increase their swimming speed (and area searched) to partially compensate for decreased reactive distance at high turbidity.

We then compared our modelled growth rates for each of these scenarios to observed declines in growth rate in Sweka and Hartman (2001). Model fit was visually assessed based on the overlap of predicted growth rates with observed ones.

5) Using the model to define a preliminary phase-space of habitat that would generate areas of positive growth at different turbidities

In theory, if the model produces reasonable estimates of growth rates at different turbidities for different sized fish, then it can be used to define the regions in a phase-space of depth and velocity that will generate positive growth for juvenile salmon (essentially a measure of useable habitat defined by focal velocity and depth). The model could therefore be used to predict how the phase space of useable habitat will shrink with increasing turbidity for different sized fish.

We generated a preliminary phase space of this nature by calculating growth rates for a 2 g and 25 g salmonid at turbidities of 0-50 NTUs (Nephelometric Turbidity Units) for the small fish and 0-17 NTUs for the large fish over a combination of depths ranging from 0-60 cm (simulating a shallow vs. deep stream channel) and velocities of 0-40 cm/s (simulating slow vs. fast water).

6) Processing of invertebrate drift samples to validate the assumption that invertebrate drift has minimal variation within the stream channel

One of the implicit but largely untested and poorly understood assumptions of drift-feeding bioenergetics models is that invertebrate drift abundance is essentially homogenous throughout the stream channel. In order to validate this underlying assumption of the drift-feeding model, we collected drift samples from multiple pools

and riffles within the stream that was used to parameterize the original drift-feeding bioenergetics model. These samples were sorted in the laboratory during this present project as part the model validation process. Understanding how invertebrate drift varies spatially in the stream channel will allow us to better understand the expected deviations in predictions of a model that assumes constant drift densities.

RESULTS & OUTPUTS

1) Deriving an average relationship between turbidity and reactive distance

Seven studies were found that document the relationship between reactive distance and turbidity (see Appendix 1 for details). Only four of these studies were on salmonids, so this was the subset that we used for our model.

The four studies differed substantially in initial maximum reactive distance (Fig. 1), as a consequence of an unknown combination of factors involving prey size, fish size, and factors related to the individual experimental setups.

In order to correct for differences in initial reactive distance between studies, and to determine whether there was a common relationship between the *proportional decrease* in reactive distance with increasing turbidity, we converted all reactive distances to a percent of maximum reactive distance at zero turbidity, and then fitted a relationship between percent reactive distance and turbidity (log-transformed; Fig. 2). There was much less variation in percent reactive distance with increasing turbidity, indicating that increased turbidity tends to cause a much more consistent decline in relative reactive distance than absolute reactive distance.

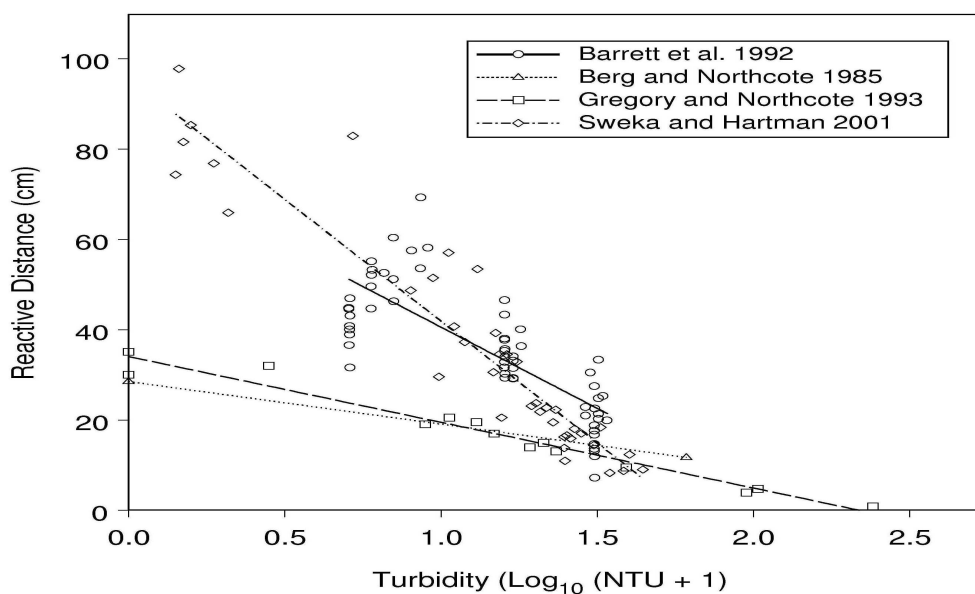


Figure 1. Linear relationships between RD (cm) and log transformed $TURB$ (NTU) for salmonids in four studies

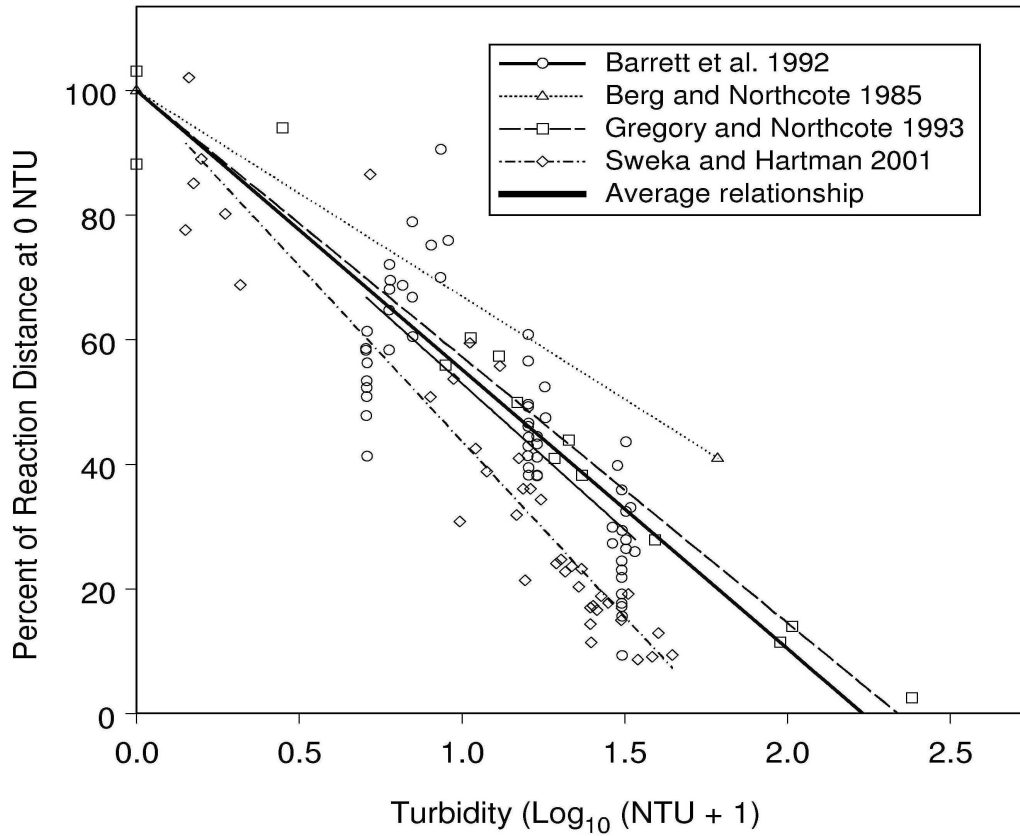


Figure 2. Linear relationship between percent of *RD* at 0 NTU and \log_{10} transformed *TURB* (NTU) for salmonids in four studies

Although significant differences in slope remain for the decrease in percent reactive distance with increasing turbidity (Table 1), they are all reasonably close to the average relationship, which we would argue can be applied as a general relationship in the absence of a specific relationship for the species of salmonids of interest.

Table 1. Summary of linear regression equations modeling the relationship between percent of reactive distance at 0 NTU (PMR) and \log_{10} transformed turbidity (*TURB*) for salmonids in four studies.

Study	N	Equation	s_b	r^2
Barrett et al. 1992	58	$PMR_i = 100 - 47.0 \cdot \log_{10}(TURB_i + 1)$	4.8	0.63
Berg and Northcote 1985	2	$PMR_i = 100 - 33.0 \cdot \log_{10}(TURB_i + 1)$	NA	1
Gregory and Northcote 1993	13	$PMR_i = 100 - 42.7 \cdot \log_{10}(TURB_i + 1)$	2.4	0.96
Sweka and Hartman 2001	38	$PMR_i = 100 - 56.3 \cdot \log_{10}(TURB_i + 1)$	3.8	0.90
Average	4	$PMR_i = 100 - 44.8 \cdot \log_{10}(TURB_i + 1)$	8.4	NA

4) Testing the drift-foraging bioenergetics model using data from Sweka and Hartman (2001)

After we inserted the turbidity-reactive distance formula in the modified Hughes and Dill drift-feeding bioenergetics model (see Appendix 1 for more detail), we tested 3 versions of the model using data from an experiment by Sweka and Hartman (2001a) to assess model performance in predicting observed growth rates. During their study, Sweka and Hartman fed fly larvae to brook trout in experimental channels over a range of turbidities, and did behavioural observations and measured growth of fish over a five day period.

To test the generalizability of our bioenergetic model, we tested 3 versions:

i) a generalized model using an average reactive distance function for all species

ii) a more customized model using a reactive distance function specific to brook trout, a reactive distance – turbidity relationship specific to brook trout, and a maximum consumption relationship specific to the study (Sweka and Hartman 2001a, 2001b). Fish in this model are also assumed to swim at the ambient velocity of 6 cm/s at all turbidities.

iii) a specialized model (as in *ii* above) that allowed fish to increase their swimming speed (and area searched) to partially compensate for decreased reactive distance at high turbidity.

The general model using the average reactive distance – turbidity relationship tended to consistently overestimate growth rates by approximately 2% (0.02 g/g/day), although the decrease in growth rate over the range of experimental turbidities was similar to the drop in growth for the observed data (solid trendline in Figure 3). The customized model that incorporated parameters specific to the Sweka and Hartman (2001) study fit better than the generalized one, but tended to seriously underestimate growth rates at higher turbidities. This is because this model fixes swimming speed at the ambient 6 cm/s available in the experimental channels; Sweka and Hartman (2001a) actually observed fish to increase their swimming speed at higher turbidities, effectively allowing the fish to search a larger area of stream and maintain satiation even at high turbidities. The third scenario we modeled allowed for fish to swim at higher velocities to compensate for decreased reactive distance at high turbidities (as observed in the

experiment), and did a reasonably good job of predicting the observed growth rates (Figure 3).

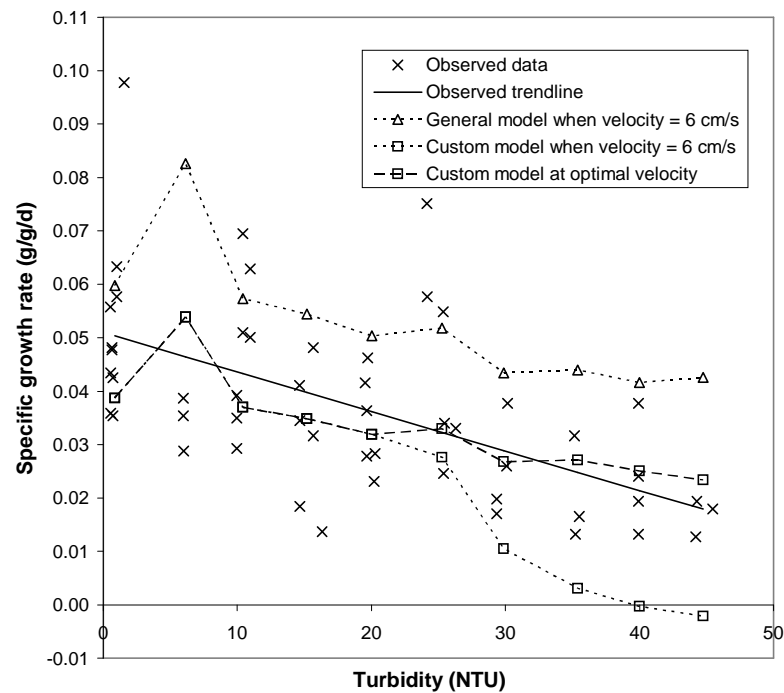


Figure 3. Specific growth rates (g/g/d) of brook reared for five days at different turbidities, as observed by Sweka and Hartman (2001), and as predicted by simulations with our model.

5) Generating a preliminary phase-space of positive growth at different turbidities

We successfully used the model to generate a preliminary phase-space showing growth rates for small (2 g) and larger (25 g) juvenile salmon in a velocity-depth phase space at different turbidities (Figures 4 and 5). These figures show in principle how this approach can be used for determining which habitats (defined in terms of depth and velocity) are bioenergetically available to fish of different sizes, and how increasing turbidity decreases the extent of available habitat. For instance, the model predicts that increasing turbidity to 17 NTUs causes most combinations of depth and velocity to generate negative growth for the 25 g fish, while smaller fish can achieve positive growth over a much larger range of turbidities (but cannot swim at higher sustained velocities because of their smaller size).

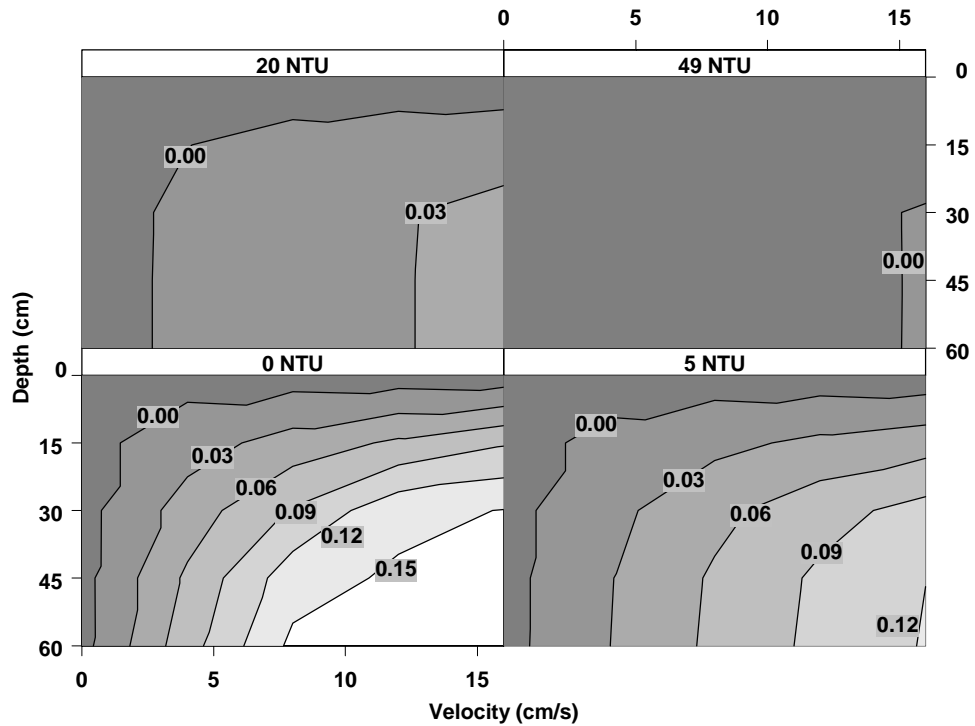


Figure 4. Specific growth rates (g/g/d) predicted by the generalized model for a 2 g salmonid with focal point velocities of 0 and 16 cm/s and at water depths of 0 to 60 cm.

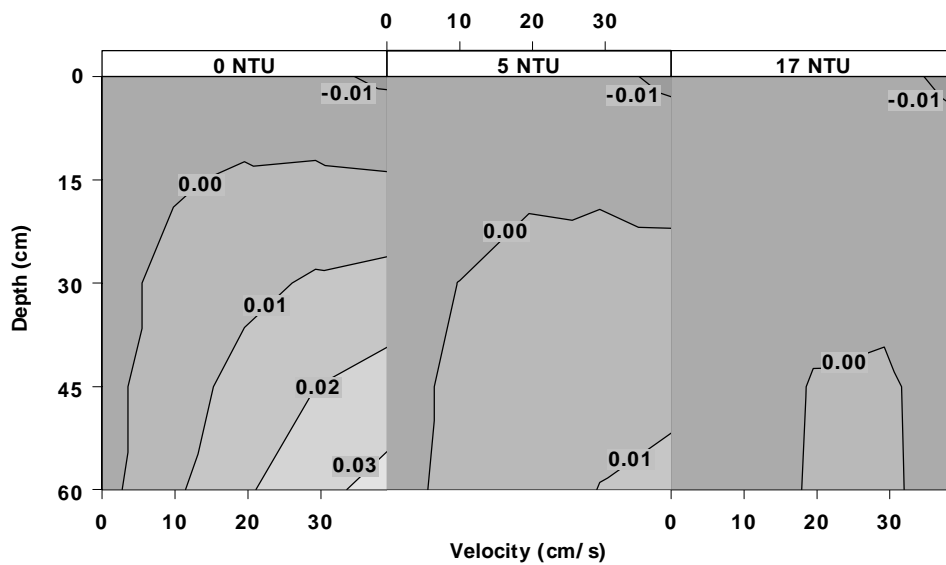


Figure 5. Specific growth rates (g/g/d) predicted by the generalized model for a 25 g salmonid with focal point velocities of 0 and 39 cm/s and at water depths of 0 to 60 cm.

6) Processing of invertebrate drift samples to validate the assumption that invertebrate drift has minimal variation within the stream channel

A set of 45 invertebrate drift samples were processed during the last 2 months of this project. These samples will be digitized and identified in the future, and will serve as the basis for assessing the degree of spatial and temporal variation in invertebrate drift abundance, and the implications of this variation for predicting growth rates using drift-feeding bioenergetics models.

5. OVERVIEW OF PROGRESS AND DELIVERABLES TO DATE

Discussion and Overview Of Progress

Progress on this project to date has been very successful. Over a period of 4 months we were able to build a model predicting the effects of increased turbidity on growth rates of juvenile salmonids and test it using published data in the literature. Based on our incorporation of an average relationship between turbidity and percent decrease in reactive distance, the model has the potential for general application to predict approximate decreases in growth rate for species where specific relationships are lacking, or alternatively can be customized for an individual species when more specific relationships are available.

Testing of the model by comparing model predictions with observed growth rates in Sweka and Hartman (2001a) demonstrated that the general model (upper dotted line in Figure 3) tended to overestimate growth rates by approximately 2%, although the predicted growth rates were still within the range of data (each observed data point is an X), and the decline in average growth rate over the range of turbidities was similar for the observed and modeled data. This indicates that the general model, as it is now parameterized, gives a reasonable approximation of the *decrease* in growth rate with increasing turbidity, but the actual growth rate itself is in this case somewhat overestimated. In this case, this is because the general model assumes a somewhat higher reactive distance than that observed by Sweka and Hartman (2001b), and also a somewhat higher satiation rate than that observed by Sweka and Hartman (2001a). Therefore when the specific parameters for brook trout are included in the model, modeled growth rates become much closer to the observed growth rates.

Sweka and Hartman (2001a) observed that fish became more active as turbidity increased, resulting in maintained food intake because of higher prey encounter rates. When our model allowed fish to increase their swimming speed to partially compensate for decreased visibility of prey at high turbidity, the model fit became quite good (Figure 3). This further supports the ability of the drift-foraging model to incorporate biological realism in terms of behavioral compensation mechanisms.

In summary, this model testing, albeit limited, demonstrates that a model that is well parameterized for a particular species appears to do a very good job of modeling the effects of increased turbidity on growth rates of juvenile salmonids. The more general model, based on average relationships in the literature, does a somewhat worse job of predicting actual growth rates, but seems to do a reasonable job of predicting the *relative decrease* in growth rate with increased turbidity.

Application of the model to generate preliminary phase-spaces of useable habitats (in terms of depth and velocity) at different turbidities (Figures 4 & 5) demonstrates that this approach can be a very powerful way for both understanding, predicting, and illustrating how changes in habitat depth, velocity, and fish size will interact to determine the outcome of changes in turbidity for fish growth. The model, and the specific output of phase-spaces defining regions of impact, will eventually serve as a useful guide for resource practitioners in terms of being able to predict the quantitative effects of increased turbidity on growth rates of juvenile fish.

However, it is very important to note that as the model is now structured, it tends to overestimate optimal swimming velocities of fish, and therefore growth rates at higher velocities. There are two reasons for this; first, the model assumes that fish will capture *all* drifting invertebrates within their reactive distance at all velocities that are less than their maximum burst speed. This is unrealistic, since it is likely that at higher velocities capture success decreases with increased water velocity, and this has been demonstrated experimentally (Hill and Grossman 1993). Second, our model likely also underestimates swimming costs at higher velocities, because it has also been shown that swimming cost formulas based on energy costs from fish swimming in laminar flow (swim mills) tend to underestimate true swimming costs in the wild, where turbulence tends to increase energy required to hold at a focal point.

We are in the process of building functions and corrections factors (extracted from the literature) into an updated versions of the model to correct for these biases.

Deliverables to date

Deliverables in the original proposal were:

1) *A quantitative model to predict the effect of chronic low-level turbidity on growth rates of juvenile salmonids.*

We have now produced this deliverable. The model will be somewhat refined before publication, but the model is essentially complete, and bears validation as described above.

2) *A matrix of duration of exposure vs. turbidity level that will define the phase-space where negative impacts on juvenile salmonid growth will occur.*

We have produced a preliminary phase-space documenting negative growth rates of salmon. Once we have fine-tuned the model for publication, we will in a positions to produce a reliable phase-space of the sort originally envisioned.

3) *A technical report (published in the Provincial Fisheries Research Branch Technical Report series) documenting this research.*

A draft report is attached as Appendix 1. This report is forthcoming.

In addition, we will submit the results of this research for publication in the primary literature (most likely North American Journal of Fisheries Management). The model is novel and useful enough to warrant this.

4) *Presentation of the results at regional (e.g. Pacific Northwest Chapter of the American Fisheries Society) and national fisheries conferences (e.g. Canadian Conference of Fisheries Researchers) and regional government workshops.*

No appropriate conferences for presentation of results have presented themselves since project initiation (Dec. 2003), but we will plan on this in the near future, particularly once the model is refined and finalized.

Operational Variances

The only significant operational variance in this project was the inclusion of processing of invertebrate drift samples to validate the assumption that invertebrate drift has minimal variation within the stream channel as an additional deliverable. It became possible to include this as an additional deliverable because of the late date at which FII informed us that the project was funded, so that there were surplus funds in the project because the start date was much later than in the submitted proposal. This deviation from workplan was approved by FII on Jan. 27, 2003.

6. EXTENSION

Extension activities arising from this project include:

- 1) Publication of a technical report describing the model, it's validation, and application (Draft version as Appendix 1). This will be published in the Provincial Fisheries Technical Series once the model has been finalized.
- 2) Publication of a research paper in the peer-reviewed literature (probably North American Journal of Fisheries Management) documenting the model and its management applications/implications. The model is novel and useful enough to warrant this.

- 3) Presentations of the research results at regional and international workshops and conferences. No appropriate conferences for presentation of results have presented themselves since project initiation, but we will plan on this in the near future, particularly once the model is refined and finalized.

8. REFERENCES CITED

- Barrett, J. C., G. D. Grossman, and J. Rosenfeld. 1992. Turbidity induced changes in reactive distance of rainbow trout. *Transactions of the American Fisheries Society* 121: 437-443.
- Beauchamp, D. A., D. J. Stewart, and G. L. Thomas. Corroboration of a bioenergetics model for sockeye salmon. *Transactions of the American Fisheries Society* 118: 597-607.
- Berg, L, and T. G. Northcote. Changes in territorial, gill-flaring, and feeding behavior in juvenile coho salmon (*Oncorhynchus kisutch*) following short term pulses of suspended sediments. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1410-1417.
- Brett, J. R. 1971. Satiation time, appetite, and maximum food intake of sockeye salmon. *Journal of the Fisheries Research Board of Canada* 28: 409-415
- Cooper, E.L. 1961. Growth of wild and hatchery strains of brook trout.. *Transactions of the American Fisheries Society* 90:424-438.
- Gregory, R. S., and T. G. Northcote. 1993. Surface, planktonic, and benthic foraging by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in turbid laboratory conditions. *Canadian Journal of Fisheries and Aquatic Sciences* 50: 233-240.
- Hartman, K. J., and S. B. Brandt. 1995. Estimating energy density of fish. *Transactions of the American Fisheries Society* 124: 347-355.
- Hecht, T., and C. D. van der Lingen. 1992. Turbidity induced changes in feeding strategies of fish in estuaries. *South African Journal of Zoology* 27(3): 95-107.
- Hill, H. and G. D. Grossman. An energetic model of microhabitat use for rainbow trout and rosyside dace. *Ecology* 74(3): 685-698.
- Hughes, N. F., and L. M. Dill. 1990. Position choice by drift feeding salmonids: model and test for Arctic Grayling (*Thymallus arcticus*) in subarctic mountain streams, interior Alaska. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 1999-2008.
- Jones, D. R., J. W. Kiceniuk, and O. S. Bamford. 1974. Evaluation of the swimming performance of several fish species from the Mackenzie River. *Journal of the Fisheries Research Board of Canada* 31: 1641-1647.
- Katopodis, C., and R. Gervais. 1991 *Ichthyomechanics*. Freshwater Institute. Central and Arctic Region. Department of Fisheries and Oceans Canada.
- Post, J. R., and E. A. Parkinson. Energy allocation strategy in young fish: allometry and survival. *Ecology* 82(4): 1040-1051.
- Rosenfeld, J. S., and S. Boss. Fitness consequences of habitat use for juvenile cutthroat trout: energetic costs and benefits in pools and riffles. *Ecology* 58: 583-593.
- Sweka, J. A., and K. J. Hartman. 2001a. Effects of turbidity on prey consumption and growth in brook trout and implications for bioenergetics modelling. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 386-393.

- Sweka, J. A., and K. J. Hartman. 2001b. Influence of turbidity on brook trout reactive distance and foraging success. *Transactions of the American Fisheries Society* 130: 138-146.
- Tsukamoto, T., K. Kihata, T. Inaba, and M. Funatsu. 1987. Changes in water content during metamorphosis of the Housefly, *Musca domestica*. *Agricultural Biology and Chemistry* 51(8): 2253-2254.
- Venables, W. N., and B.D. Ripley. 1999. *Modern applied statistics with S-PLUS*. 3 ed. New York: Springer.
- Vinyard, G. L., and W. J. O'Brien. 1976. Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). *Journal of the Fisheries Research Board of Canada* 33: 2845-2849.
- Wright, D. I., and W. J. O'Brien. 1984. The development and field test of a tactical model of the planktivorous feeding of white crappie (*Pomoxis annularis*). *Ecological Monographs* 54(1): 65-91.
- Zar, J. H. 1999. *Biostatistical Analysis*. 4th ed. Prentice Hall, NJ.

9. APPENDICES

Appendix 1 has been included as separate document.

10. STATEMENT OF EXPENDITURES

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Budget for year 2:

R2003-0183 Year 1 Budget
Name: Jordan Rosenfeld
Organization: BC Fisheries

The year 1 Budget for the Project was as follows:

Category	1 (Apr 1 –Jun 30)	2 (Jul 1 –Sept 30)	3 (Oct 1 –Dec 31)	4 (Jan 1 –Mar 31)	Year Total
a)Salaries and stipends					
Ecological Modeller	0	0	\$ 4,000	\$ 16,788	\$20,788
b) Employee benefits	0	0	0	\$407	\$407
c) Equipment	0	0	0	0	0
d) Travel	0	0	0	0	
e) Materials, Supplies	0	0	\$100	0	\$100
f) Others	0	0	0	0	0
g) Indirect Costs	0	0	0	0	0
h) Administration Costs	0	0	0	\$710	\$ 710
Year TOTALS	0	0	\$ 4,100	\$17,905	\$22,005

There were no significant deviations from the original approved budget.