QUANTITATIVE ASSESSMENT OF SUSPENDED SEDIMENT CONCENTRATION ON COHO SALMON IN FRESHWATER CREEK

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ABSTRACT

The objective of this study was to apply the Newcombe and McDonald (1996) model to assess the impact of suspended sediment concentration on coho salmon (*Oncorynchus kisutch*) using turbidity and suspended sediment data collected at Freshwater Creek California. Researchers Newcombe and Jensen (1996) proposed a mathematical model predicting biological response, specifically called severity of ill-effect (SEV), as a function of suspended sediment concentration (mg/L) and duration (hr). For this study, thresholds of biological response developed by Newcombe and Jensen (1996) were used as criteria for impact assessment. Freshwater Creek water quality data was used to ascertain duration intervals (hr) for five thresholds of suspended sediment concentration: 50, 80, 140, 300, 1,200 mg/L. The Newcombe and Jensen (1996) model was calibrated separately for data specific to juvenile and underyearling age classes. The Freshwater Creek Water quality data was used as input for the two calibrated models to calculate SEV, and thus infer the biological impact. Results yielded a mean SEV of 6 and standard deviation 1 for both juvenile and underyearling coho salmon for by HY 1999 and HY 2000. An SEV of 6 ± 1 SEV unit correlates to the sub-lethal effect category of biological response: minor to moderate physiological stress, increased respiration rate, and moderate habitat degredataion (Newcombe and Jensen, 1996). The maximum predicted juvenile coho SEV was 7.4 occurring with suspended sediment concentration of 50mg/L for approximately 72 hours (1/14/2000 00:45 to 1/17/2000 01:00). The maximum observed underyearling coho SEV was 7.1 occurring with a suspended sediment concentration of 1,200 mg/L over an 8 hr period (1/11/2000 00:30 – 1/11/2000 08:15). Both of these seprate events occurred within a five-day period, yielding little recovery time for both age classes of coho salmon. The Newcombe and Jensen model (1996) infers that both age classes of coho salmon are stressed biologically in Freshwater Creek, conditions being most severe in winter months, but that suspended sediment concentration is not likely to be causing species mortality.

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NOTATION

Symbol		Description	Units
SEV	-	Ranked severity of ill-effect, biological response to sediment concentration and durational stress	[-]
ln	-	The natural logarithm with base e	[-]
a	-	Regression intercept	[-]
b	-	Regression slope term for the natural log of duration	$[\ln(\text{hr})]^{-1}$
C	-	Suspended sediment concentration, measurement of suspended sediment mass to total volume of sample	[mg/L]
c	-	Regression slope term for the natural log of concentration	$[\ln(\text{mg/L})]^{-1}$
Q	-	Water discharge	$[\text{ft}^3/\text{sec}]$
n	-	TURB - SSC regression intercept	[Power: mg/L*$(\text{NTU})^{1/m}$; Linear: mg/L]
m	-	TURB – SSC regression exponent or slope	[Power: unitless; Linear: NTU^{-1}]
x	-	Duration of exposure	[hr]
y	-	Concentration threshold of exposure	[mg/L]
α	-	Power function intercept	$[\text{mg/L}*(\text{ft}^3/\text{sec})^{1/\beta}]$
β	-	Power function exponent or "slope"	[-]

ABBREVIATIONS

Symbol		Description	Units
HY	-	Hydrologic year, October 1 to September 30	[-]
J	-	Juvenile coho salmon	[-]
POR	-	Period of record	[-]
SEV	-	Ranked severity of ill-effect, biological response to sediment concentration and durational stress	[-]
SS	-	Suspended sediment	[mg]
SSC	-	Suspended sediment concentration	[mg/L]
TTS	-	Turbidity Threshold Sampling	[-]
TURB	-	Turbidity, measure of light refraction in water	[NTU]
U	-	Underyearling coho salmon	[-]

UNITS

Unit		Unit Description	Unit Designation
NTU	-	Neflometric Turbidity Units, measure of turbidity	SI
mg/L	-	Milligrams per liter, measure of concentration	SI
hr	-	Hours, measure of time	SI
cm/sec	-	Centimeters per second, measure of velocity	SI
sq-mile	-	Square mile, measure of area	English
ft	-	Feet, measure of length	English

INTRODUCTION

The mobilization of fine inorganic particles and their subsequent deposition in sensitive habitats has become one of the most pervasive problems facing environmental managers. The transition from natural to managed lands has led to increases in suspended sediment concentration in streams and rivers. Research has shown that substantial increases in suspended sediment can result in negative impacts on aquatic biota. Furthermore, anadromous fish species like coho salmon (*Oncorynchus kisutch*) continue to be classified as endangered or threatened under the Endangered Species Act as population numbers decline.

Until recently, researchers in this field have provided environmental managers with little practical guidance for making crucial decisions. As a result, many regulatory decisions have avoided establishing thresholds or introduced arbitrary thresholds because data is not available to define background or undisturbed conditions. Environmental resource managers generally agree on the need for a quantitative model that relates adverse biological effects of suspended sediment on aquatic biota. However, there is little consensus on how to meet this need using studies available in the literature. Most recent research has moved away from a concentration-response model, classically used to predict biological response, to a time dependent concentration-response model because toxicological effects of suspended sediment as a function of duration of exposure has become better understood (Newcombe and McDonald, 1991). Unfortunately, water quality data sets of semi-continuous suspended sediment concentration in rivers where anadromous fish populations are declining, is virtually non-existent.

The non-profit organization Salmon Forever established a monitoring station in 1999 on Freshwater Creek (Salmon Forever, 2000). This monitoring station would be used both as a demonstration site and as a research tool. Among the research objectives for the Freshwater site was to determine whether the current turbidity and suspended sediment regimes are deleterious to salmonids. Freshwater Creek is also unique in that it is home to one of the last runs of coho salmon, a species that has been officially classified by the EPA as threatened, endangered, and even extinct in regions of the Pacific North Coast. In this study the Newcombe and Jensen (1996) time dependent concentration-response model is applied using the water quality data from Freshwater Creek to determine the biological impact of suspended sediment concentration on coho salmon.

PROJECT OBJECTIVE

The objective of this project is to assess the impact of suspended sediment on juvenile and underyearling coho salmon using a time dependent concentration-response model proposed by Newcomb and Jensen (1996) and water quality data collected at Freshwater Creek. This assessment will also demonstrate how the Newcombe and Jensen (1996) model can be applied by environmental resource managers for other sites with a semi-continuous data set of suspended sediment concentration. To meet this objective the following tasks must be accomplished:

1. develop a semi-continuous suspended sediment concentration data set using available data (Salmon Forever, 2000),
2. define thresholds of biological response of juvenile and underyearling coho salmon using studies from the literature based on measured suspended sediment concentration and durations,
3. calibrate the mathematical model proposed by Newcombe and Jensen (1996) to juvenile and underyearling coho salmon to predict severity of ill-effect based on threshold designations using classical statistical regression,
4. apply the calibrated mathematical model to Freshwater Creek using the semi-continuous suspended sediment concentration data set.

LITERATURE REVIEW

INTRODUCTION TO THE PROBLEM

Public attitudes are changing to reflect a more conservative outlook towards our natural resources, and our natural resource management policy. Research has helped us understand more completely the impacts and tradeoffs associated with how our natural resources are used. In some cases resource managers have turned to restoration objectives to 'undo' negative impacts uncovered by research. Restoration of aquatic ecosystem and riparian areas is a fundamental challenge facing land managers in the next century, in a time when a legacy of historical land use practices has erupted into an intense debate over appropriate practices for effective ecosystem management (Gregory, 1993).

Research implies that increases in the suspended sediment load directly resulting from anthropogenic land use practices has caused massive declines in fish populations. Logging and urbanization have been implicated as the major culprits in massive declines of anadromous fish populations on the Pacific North Coast (see Brown et al., 1994). The impacts of logging on aquatic species has remained extremely controversial and is still being debated due to a lack of researchers' ability to sufficiently isolate the causes and effects of logging (Ziemer and Hubbard, 1991; Reid, 1993; Nakamoto, 1998). Both logging and urbanization unquestionably increase road density in a watershed, which is also a major contributor of sediment to streams (Lewis, 1998; Reid, 1998; Noss, 2000).

An increase in the suspended load in a river or creek is potentially destructive to anadromous fish in many ways, such as the increase of fine sediments in spawning gravels that cement eggs limiting oxygen supply (Phillips et al., 1975; Tappel and Bjornn, 1983). One study showed that as much as 25% fines in spawning gravels can reduce fry emergence by 50% (Noss, 2000). Increased levels of suspended sediment have been shown to damage gill structure of salmonids (Newcombe and McDonald, 1991). Removal of the riparian zone, in logging for example, further confounds the issue of stresses on aquatic ecosystems by increasing both sedimentation and water temperature from a loss of direct shade in the channel. Unfortunately, little research has been dedicated to constructing reliable methods for quantifying and assessing the impacts of suspended sediment concentration, SSC, on aquatic species (Newcombe and McDonald, 1991).

MANAGEMENT TOOLS: PREDICTING ECOSYSTEM RESPONSE TO SUSPENDED SEDIMENT

Presentation of Dose-Response Model

Many toxicological studies have been performed on the effects of SSC on aquatic species (Noggle, 1978; Bison and Bilby, 1982; Sigler et al., 1984; and others). Traditionally most studies focused on the classic concentration-response model. The approach of this type of research is to maintain suspended sediment concentration at a specific level in a test chamber and record the biological response. Variation among studies includes those that specifically target chemically toxic materials, sediment size classes, quantity of SSC maintained over extended time intervals, and temporally variable rising and falling SSC.

Newcombe and McDonald (1991) compiled all studies of salmon, trout, and benthic invertebrate species that recorded both duration (hr) and SSC (mg/L) along with biological response. Their intent was to compare the classical concentration-response model to a time dependant concentration-response model (also referred to as the dose-response model) by ranking the biological effects. Unfortunately, most studies in the literature did not include duration of exposure information and, thus, could not be included in model formulation. Dose was defined as the natural log of the product of SSC (mg/L) and duration (hr). The biological responses recorded by researchers were ranked from least severe to most severe yielding a scale of 1 to 14 (Table 1). Newcombe and McDonald (1991) then showed that the dose-response model correlated better with observed biological response than the classical concentration-response model (Newcombe and McDonald, 1991).

Criticisms of the Dose-Response Model

Controversy in this field is inevitable, and the newly proposed Newcombe and McDonald (1991) dose-response model was no exception. The major problem with the proposed dose-response model was the simplicity, subjectivity of ranked responses, and lack of a well-defined mathematical model. The model was far too general and imprecise to be adequately applied as a management tool.

Gregory et al. (1993) criticized the Newcombe and McDonald (1991) model on four major points. The first was that the variance in the data compiled by Newcombe and McDonald (1991) was large, reducing the predictive power of the model, stating that it is "unrealistically simplistic." Also no validation procedure was performed to compare model predictions with actual field observations. The second major criticism by Gregory et al. (1993) was that Newcombe and McDonald (1991) had not established threshold durations or concentrations beyond which impacts would not occur. Without well-defined thresholds, the model is open ended in the sense that small concentrations over long periods predict the same effect as short duration high concentration events, whereas the actual biological response may be quite different. The third major point made by Gregory et al. (1993) was that impacts will be variable not only with species, but also with life stage. Lastly Gregory et al. (1993) argued that other significant water quality variables such as water temperature or sediment size were not included in their model formulation, where in fact they may play a major role in biological response.

Newcombe and McDonald (1993) responded the comments made by Gregory et al. (1993). Newcombe and McDonald (1993) began by restating the purpose of the first paper (Newcombe and McDonald, 1991); to simply compare the classic concentration-response model with the dose-response model. Their intention was not for the general dose-response model to be used as a precise management tool, rather that it should guide evaluation and further research in the subject area. Newcombe and McDonald (1993) also recognized that biological response is highly variable and depends upon many variables, but that the dose-response model showed promise as a means of quantifying general severity of biological response.

Newcombe and McDonald (1993) reformulated their listing of ranked severity of ill-effects, or SEV, defining specific thresholds levels, behavioral effects, sublethal effects, and lethal effects (Table 1). Newcombe and McDonald (1993) also took recent data from a study by Servizi and Martens (1992) to reveal that species life stage does have a different characteristic impact on biological response for a particular species. Specifically, they showed that underyearling coho salmon were less sensitive to sediment doses than juvenile coho salmon (Newcombe and McDonald 1993).

Final Revision of Dose-Response Model

Recognizing the potential for the dose-response model as a quantitative tool for resource managers, Newcombe and Jensen (1996) refined the SEV model pooling 264 field studies from the literature in their final formulation. Table 1 gives the ranked severity of ill-effects where 0 implies no impact and 14 is greater than 80-100% mortality.

Table 1. Revised Ranking of Severity of Ill-Effects (SEV) of Suspended Sediments on Fish and Aquatic Life Grouped by Threshold (Newcombe and Jensen, 1996).

Rank	Description of effect
	Behavioral Effects
0	No adverse effects observed
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response: change in swimming behavior
	Sublethal Effects
4	Short-term reduction in feeding rate: short term reduction in feeding success
5	Minor physiological stress: increased rate of coughing or respiration, or both
6	Moderate physiological stress
7	Moderate habitat degradation: impaired homing ability
8	Indication of major physiological stress: long term reduction of feeding rate; long term reduction in feeding success; poor condition
	Lethal Effects
9	Reduced growth rate: delayed hatching; reduced fish density
10	0-20% mortality: increased rate of predation; moderate to severe habitat degradation
11	>20-40% mortality; reduced size of population
12	>40-60% mortality; severe habitat degradation
13	>60-80% mortality
14	>80-100% mortality

Newcombe and Jensen (1996) also refined the mathematical model used to define the dose-response model to allow for species-specific regressions on predicted and observed ranked severity of ill-effects. In their study, regressions were developed for six specific taxonomic groups distinguished by lotic, lentic, and estuarine fishes, life stage of species, and particle sizes of suspended sediments (Newcombe and Jensen, 1996). The general form of the Newcombe and Jensen (1996) dose-response model is shown as Equation 1.

$$SEV = a + b\ln(x) + c\ln(y) \tag{1}$$

where SEV - Ranked severity of ill-effect, biological response to SSC and durational stress

ln - The natural logarithm with base e

a - Regression intercept

b - Regression slope term for the natural log of duration $[\ln(\text{hr})]^{-1}$

c - Regression slope term for the natural log of concentration $[\ln(\text{mg/L})]^{-1}$

x - Duration of exposure [hr]

y - Concentration threshold of exposure [mg/L]

The results from the Newcombe and Jensen (1996) study supports the use of the dose-response model for predicting behavioral and sublethal effects predicting within 1 SEV unit from observed, but was unreliable for predicting lethal effects. Newcombe and Jensen (1996) concluded that in most instances their model underestimated species mortality in the lethal effects threshold category (Table 1). Thus, this model lacks precision in identifying acute biological response, but shows great promise in predicting and identifying thresholds of biological tolerance.

A significant range in variability in species response to SSC is unavoidable even when similar species age classes and types are lumped as in Newcombe and Jensen (1996). To reduce the uncertainty with the dose-response model in this analysis, the model was separately regressed to data on juvenile and underyearling coho salmon. Water quality data from Freshwater Creek (Salmon Forever, 2000) is then input to the model to assess the biological impact of SSC on juvenile and underyearling coho salmon.. Data compilation and dose-response model regressions are subsequently described in the project activities section following the literature review. Background information on coho salmon species and turbidity threshold sampling are presented in the ensuing sections of this literature review.

Identification of Quantifiable Thresholds for Analysis of Biological Impact

Identification of turbidity and SSC thresholds were essential in impact assessment of suspended sediment on the likelihood of survival for coho salmon in Freshwater Creek. The mathematical model proposed by Newcombe and Jensen (1996), Equation 1, is not precise enough to pinpoint the exact effect of suspended sediment on the quality of life of juvenile and underyearling coho salmon. It was used in this study as a tool to gage whether biologically intolerable thresholds have been reached. In this subsection, studies in the literature were combined to develop the meaningful thresholds of biological response needed to assess the impact of SSC on juvenile and underyearling coho salmon in Freshwater Creek.

In order to define these thresholds, studies compiled by Newcombe and Jensen (1996) were combined with additional research. Newcombe and Jensen (1996) concluded in their study that toleration of suspended sediment varied with species class and even age class. Model accuracy improves significantly if a single species age and size class is targeted. In this study the juvenile and underyearling coho salmon were selected as the target species. However, steelhead could just have easily been selected. The main reason coho salmon were chosen for this study was due to data availability.

Three threshold categories were used to assess biological impact. These categories were developed by Newcombe and McDonald (1993) and later refined by Newcombe and Jensen (1996) and are presented in Table 1. The threshold responses are classified in three categories: behavioral effects, sublethal effects, and lethal effects. Studies compiled from the literature yielded a database of 26 observations, and are presented in Tables 2 and 3 for juvenile and underyearling coho salmon, respectively. Separate models were regressed to data available for underyearling and juvenile coho and are presented in the project activities section and subsequently analyzed in the discussion.

Behavioral Effects

Behavioral effects alter the normal foraging and social behavior of juvenile coho salmon. The most severe behavioral effect is an avoidance response, and the less severe response simply being an alarm reaction or simply no observed effect. Few studies have looked closely at the short-term effects of brief sediment pulses on aquatic salmonids. In one study, Berg and Northcote (1985) observed avoidance behavior in young juvenile coho at a

Table 2. Studies Quantifying the Severity of Ill-Effect (SEV) of Suspended Sediment Concentration and Duration on Juvenile Coho Salmon.

Concentration (mg/L)	Duration (hr)	Description	Severity of Ill-Effect	Reference
		Behavioral Effects		
53.5	0.02	Alarm reaction	1	Berg (1983)
88	0.02	Alarm reaction	1	Bison and Bilby (1982)
53.5	12.0	Changes in territorial behavior	3	Berg and Northcote (1985)
88	0.08	Avoidance behavior	3	Bison and Bilby (1982)
6,000	1.0	Avoidance behavior	3	Noggle (1978)
		Sublethal Effects		
25	1.0	Feeding rate decreased	4	Noggle (1978)
100	1.0	Feeding rate decreased to 55% of maximum	4	Noggle (1978)
250	1.0	Feeding rate decreased to 10% of maximum	4	Noggle (1978)
300	1.0	Feeding ceased	4	Noggle (1978)
53.5	12.0	Increased physiological stress	6	Berg and Northcote (1985)
1,547	96.0	Gill damage	8	Noggle (1978)
		Lethal Effects		
102	336.0	Growth rate reduced	9	Sigler et al. (1984)
1,200	96.0	Mortality rate 50%	12	Noggle (1978)
35,000	96.0	Mortality rate 50%	12	Noggle (1978)

turbidity threshold of 30NTU (equivalent to about 16 mg/L in Freshwater Creek) where avoidance behavior was defined "as changes in feeding, breathing, and territorial behaviors." Research by Bisson and Bilby (1982) in test chambers indicated an avoidance response at a slightly higher threshold of 70NTU (approximately 80 mg/L for Freshwater) for fresh water acclimated juvenile coho and 100NTU (approximately 160 mg/L for Freshwater) for turbid acclimated coho. Avoidance response is clearly the most severe behavioral response (ranked as a 3 in severity of ill effect, Table 1) and can be used to determine whether this threshold is reached. Avoidance response over long time spans is likely to cause more severe effects as discussed below.

Table 3. Studies Quantifying the Severity of Ill-Effect (SEV) of Suspended Sediment Concentration and Duration on Underyearling Coho Salmon.

Concentration (mg/L)	Duration (hr)	Description	Severity of Ill-Effect	Reference
		Behavioral Effects		
20	0.05	Coughing frequency not increased	1	Servizi and Martens (1992)
300	0.17	Avoidance behavior within minutes	3	Servizi and Martens (1992)
		Sublethal Effects		
2,460	0.05	Coughing behavior manifest within minutes	5	Servizi and Martens (1992)
2,460	1	Cough frequency greatly increased	6	Servizi and Martens (1992)
20	24	Cough frequency increased 5-fold	6	Servizi and Martens (1992)
530	96	Blood glucose levels increased	6	Servizi and Martens (1992)
2,460	24	Fatigue of the cough reflex	8	Servizi and Martens (1992)
3,000	48	High level sublethal stress: avoidance	8	Servizi and Martens (1992)
		Lethal Effects		
35	312	2/3 reduction in density and ¾ reduction in biomass	9	(Sigler et al., 1984)
121	336	Nearly 100% reduction in density and biomass	9	(Sigler et al., 1984)
8,000	96	Mortality rate 1%	10	Servizi and Martens (1992)
22,700	96	Mortality rate 50%	12	Servizi and Martens (1991)

Sublethal Effects

Sublethal effects are more severe and include reduction in feeding over longer periods of time and physiological stress such as difficulty breathing. Thresholds of behavioral effects continuing over numerous days will lead into the sublethal effect thresholds. Also, intensity of sublethal effects will increase with duration as effects change from short term to long term (see Table 1). Bisson and Bilby (1982) found that feeding effectiveness is impaired within the 70NTU (approximately 80 mg/L for Freshwater) to 100NTU (approximately 160 mg/L for Freshwater) range over extended periods of time.

Lethal Effects

If elevated suspended sediment levels persist, then growth rate will inevitably decrease and species mortality will occur. Lethal effects can occur in one of two ways: either by low levels of suspended sediment over long time spans in the first four months of species life (March – June), or with high suspended sediment concentrations over short durations in the winter (December – February). As will be discussed later in this section, growth rate and size have significant implications for species survival (Bilton et al., 1982). This relationship in not well defined and is currently being researched. Noggle (1978) reported that juvenile coho species ceased feeding at a suspended sediment concentration of 300 mg/L. Noggle (1978) also observed 50% mortality of juvenile coho species at concentrations of 1,200 to 35,000 mg/L over 96 hours.

COHO SALMON, *ONCORHYNCHUS KISUTCH*

Biology and Life Cycle

The scientific name of coho salmon is *Oncorhynchus kisutch*, from the Greek roots onkos (hook), rynchos (nose), and kisutch (Stream Net, 2000). Coho salmon follow the general life patterns of anadromous salmonids; fish are hatched in freshwater spawning grounds, rear in freshwater, migrate to sea where they mature before finally returning back to native spawning grounds (Figure 1). Spawning occurs anywhere from November to January, with the eggs hatching the following spring (Brown et al., 1994; Stream Net, 2000). Coho fry remain in streams for over a year or more before migrating seaward in late March to early April. Coho salmon spend anywhere from 18 months to 3 years in the ocean before returning to spawn, where as jacks, a name used to describe mature male coho, may return after only one or two growing seasons in the ocean (Brown et al., 1994; Stream Net, 2000).

The far Western range of coho extends from Northern Japan to the Anadyr River in Siberia. In California coho can be found as far south as Monterey Bay in California to Point Hope in Alaska. Major U.S. spawning grounds are in Alaska, Washington and Oregon (Stream Net, 2000).

Coho salmon possess deep, laterally compressed bodies with large median and paired fins, which are thought to facilitate rapid turns and quick, but transient burst swimming (Bisson et al., 1988). Mature coho salmon may grow to 38.5 inches in length and weigh up to 31 pounds. In saltwater, coho salmon are bluish-black with silver sides and characteristic black spots on the back and upper part of the caudal fin (Stream Net, 2000). The bellies of spawning males change to pink or light red while females remain bluish-black (see Figure 2).

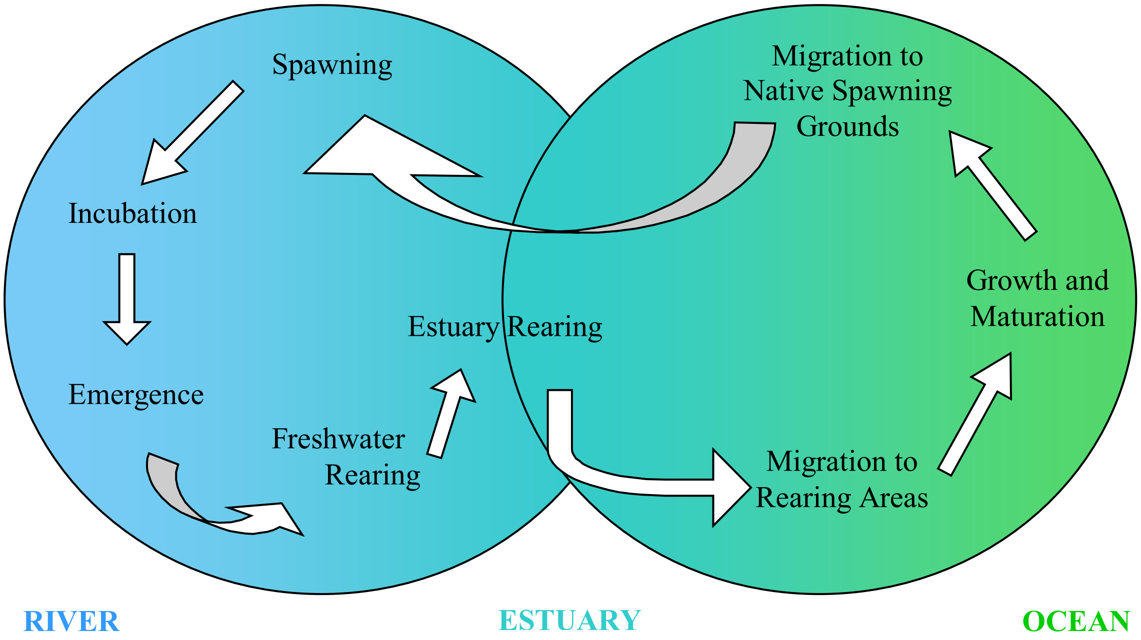

Figure 1. Life Cycle of Coho Salmon (Spence et al., 1996).

Coho salmon are ectothermic organisms, which means they cannot regulate their body temperature, and depend highly on suitable temperature regimes in the environment for survival. Optimal growth temperatures for coho range from 11.8 to 14.6°C (Nielsen, 1992). Temperatures greater or less than their optimal temperature range will stress organisms, reducing growth rates (Bilton et al., 1982) and making them more susceptible to disease and parasites (Bilton et al., 1982; Spence et al., 1996).

Behavior and Feeding

Ideal habitat for juveniles are deep pools ($\geq$ 1m) containing logs, rootwads, or boulders in heavily shaded streams (Brown et al., 1994). Coho prefer lower focal point velocity ($\leq$ 20 cm/sec) than steelhead, for example, which characteristically occupy swift riffles (Bisson et al., 1988; Dolloff and Reeves, 1990).

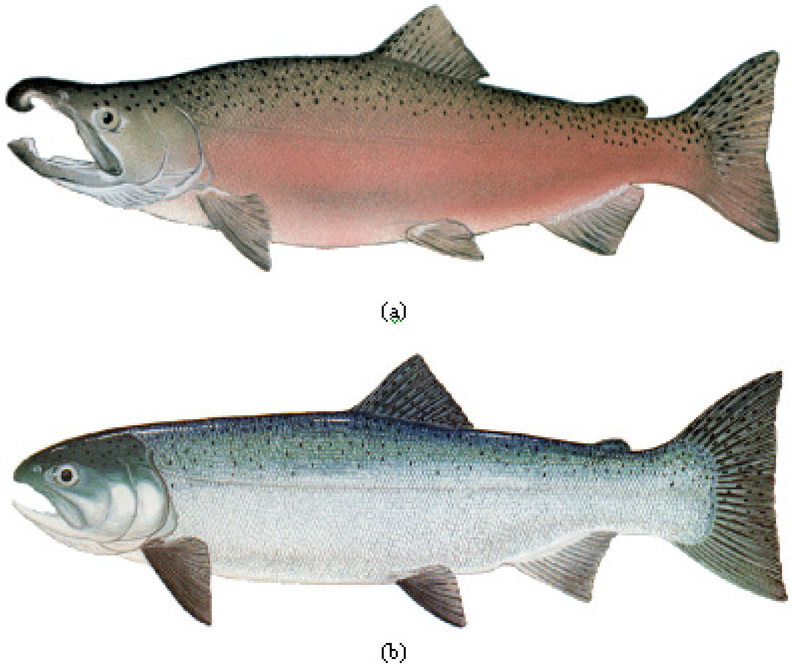

Figure 2. Spawning Colors of Adult Coho Salmon, (a) Male, and (b) Female (Stream Net, 2000).

Nielsen (1992) used field observations to classify two distinct foraging behaviors exhibited by juvenile coho salmon within stream pools. The first were those participating in a dominance subdominance hierarchy, defending forage stations in ranks determined by the ability or willingness of the fish to defend access to drifting food resources. The second were nonhierarchical "floaters" who occupied, "foraging stations in low-velocity microhabitats in an overlapping mosaic of forage arenas." Focal point velocity, the velocity of water at a feeding station, was shown by Nielsen (1992) to be a useful variable for distinguishing between these two behavioral classes.

Most juvenile coho are highly territorial forage hunters or drift feeders (Berg and Northcote, 1985). Dolloff and Reeves (1990) observed that juvenile (0+ and 1+) coho salmon had a common tendency to occupy midwater positions that were defended from other fish. Dominance has become well understood as an important coho salmon trait both in inter- and intra-species interactions (Dolloff and Reeves, 1990; Nielsen, 1992). Dominant coho tend to occupy more desirable feeding stations, like the upstream boundary of a pool, or under large wood. Research has also shown that the success of foraging juvenile coho salmon depends on visibility, flotation, and background contrast (Bission and Bilby, 1982).

Population Declines

Overview

Increased sedimentation resulting from anthropogenic land use practices has been implicated in severe ecosystem degradation. Coho salmon are one of many species whose populations are threatened by urbanization and logging (see Spence et al., 1996). Mortality of coho salmon is especially high during freshwater life stages when juveniles are more sensitive to increased sedimentation from land use practices (Stream Net, 2000).

Brown et al. (1994) estimate that the total number of coho salmon entering salmon streams in California from 1987 to 1991 averaged about 31,000 fish per year, with hatchery populations making up 57% of this total. There are now probably less than 5,000 native coho salmon with no known hatchery ancestry left spawning in California, many of them with populations less than 100 individuals.

As one travels along the west coast from Alaska to Southern California, designations of coho populations increase with severity from "no distinguishable effect" to "extinct" (Spence et al., 1996). The most obvious extinctions are in locations where dams have restricted habitat use such as the Columbia River Basin where coho salmon populations are estimated to be reduced by as much as 45% compared to historic estimates (Spence et al., 1996). The most significant government response to large decreases in anadromous fish populations has been through the use of the Endangered Species Act. As of 1996, coho salmon have been classified as either an endangered or threatened species in California (*Federal Registrar*, Vol. 61(225), November 11 November 1996).

History of Coho and Freshwater Creek California

In the early 1950's Hallock et al., (1952) netted 8,642 juveniles in Freshwater Creek. As numbers of coho began to drop in California, Freshwater Creek later became the focus of early restoration efforts by the Humboldt Fish Action Council, which began rearing coho and Chinook salmon for population enhancement in the early 1970s. In 1986 to 1987, 454 juveniles where thought to have migrated out of the system, and in 1987-1988, 834 juveniles

(68% hatchery fish) were estimated to have migrated to the ocean (Brown et al., 1994). As of this report, Freshwater Creek is still home to one of the last coho salmon runs in California.

Important Factors Affecting Growth and Survival of Coho Salmon

Many factors, both natural and induced, affect growth rates of coho salmon due to their unique life history (Figure 1). Coho salmon are subjected to competition in freshwater streams, a wide range of predators in both fresh and saltwater environments, and ocean harvest pressures. Coho salmon are commercially fished from Northern California up to Alaska where 75% of the total U.S. catch is harvested (Stream Net, 2000).

Juvenile growth (i.e. size and weight) of coho salmon is important in determining likelihood of survival to spawn (Bilton et al., 1982), and dominance in their natural habitat. As alluded to earlier, dominant species tend to have higher growth rates because they occupy better forage stations, thus attaining more access to food sources (Bission and Bilby, 1982; Dolloff and Reeves, 1990). Nielsen (1992) found that dominant coho salmon grew faster than subdominant fish, and subdominant fish grew faster than behavioral "floaters" within each of four natural pools sampled. Growth may also be related to probability of survival to spawn (Bilton et al., 1982), but more research is needed to quantify this relationship.

Other factors like density of other fish populations may also have an effect on coho growth rates. Interactive segregation occurs when differences in patterns of resource use between fish species are increased by the interactions (i.e. competition, predation) among species members (Dolloff and Reeves, 1990). In other research, interactive segregation, or patterns of differing resource use between species groups, has been shown to occur between coho salmon and steelhead trout (Harvey and Nakamoto, 1996; Bisson et al., 1988; Sheppard and Johnson, 1985). In Dolloff and Reeves (1990), riffle depths were adequate for steelhead occupation; populations of steelhead and coho spread out in the stream, occupying characteristically different habit types: steelhead in riffles and coho dominant-subdominant groups in pools. Harvey and Nakamoto (1996) showed that growth rate of coho salmon were negatively correlated to density of juvenile steelhead populations, but the differences observed in their study may also be a function of resource availability.

Environmental factors are also important in influencing salmonid survival. Reeves et al. (1993) found that salmonids species diversity is positively related to habitat complexity in streams. Thus, the environment appears to be a controlling factor that influences species interaction. Bilton et al. (1982) suggested five environmental factors that affect coho salmon survival: (1) genetic differences between stocks; (2) local geographic, climatic, and ecological conditions; (3) gross geographic, climatic, and ecological differences (e.g. Alaska vs. California); (4) differences between species, including those associated with variation in freshwater residence and years of marine life before maturity; and (5) annual differences in climatic and oceanographic events. Other environmental factors such as lack of available habitat at key times in the first year of residency may prove detrimental to coho salmon. For example, lack of available winter habitat is thought to limit coho salmon smolt production in many Oregon Coastal Streams (Nickelson et al., 1992).

Finally, suspended sediment, another environmental mechanism, has also been recently correlated with growth and survival. Research quantifying biological response of fish species to elevated turbidity and suspended sediment (SS) is somewhat contradictory and highly controversial. For example, predation rates of juvenile salmonids by predators are thought to decrease with increasing turbidity. Turbidity reduces visibility of prey, increasing the likelihood for survival. However, a study by Gregory and Levings (1996) showed that predation rates of adult cutthroat trout on juvenile salmonids were not affected by increased turbidity, and that turbidity substantially reduced juvenile salmonid use of vegetation as an avoidance mechanism. Juveniles have been observed to have a reduction in avoidance response with increases in turbidity. Decreases in visibility also reduce foraging by young juvenile salmonids, which is thought to have a negative affect on growth. Sigler et al. (1984) tested the effects of low-level turbidity over longer temporal regimes. Observed growth rates were consistently higher in clear water tanks versus tanks with elevated turbidity. Fish did not vary substantially by length, but had greater biomass in clear water as compared with turbid water.

Other research has established negative biological impacts of SS on fish species. Elevated levels of SS and turbidity can lead to mild responses such as avoidance to deleterious responses such as damage of gill tissue or even death (Newcombe and McDonald, 1991). In one study testing the impact of turbidity on juvenile coho, most fish emigrated out of the channels with turbid water within the first two diel cycles of the experiment, giving strong evidence that such conditions were stressful to the fish (Sigler et al., 1984). Bisson and Bilby (1982) observed an increased activity referred to as "fright behavior" in both field observations and in laboratory experiments with levels of turbidity greater than 150NTU (approximately 260 mg/L in Freshwater Creek). Fright behavior is defined as rapid swimming often into more turbid areas in the channel (presumably) for cover. Suspended sediment can also smother incubating eggs within spawning gravels and measurements of fines affecting size and permeability of spawning gravels have been the subject of numerous studies (see Lisle and Lewis, 1992; Lisle and Hilton, 1992; Barnard and McBain, 1994).

Clearly, establishing thresholds of biological impact is essential to assessing the impact of SS on anadromous fish. In the activities section, studies from the literature are used to develop SSC thresholds that will be applied to Freshwater Creek to determine durations and predict severity of ill-effect. The Newcomb and Jensen (1996) model also requires hourly SSC measurements at minimum, which has been technically impossible until recently. Discussion of measurement of semi-continuous SSC data is the subject of the next section of this literature review.

SUSPENDED SEDIMENT MONITORING

Overview: Why Monitor Continuous Suspended Sediment?

The Newcombe and Jensen (1996) model has reluctantly been applied in other assessments due to a lack of reliable SSC data on temporal scales of an hour or less. Monitoring semi-continuous SSC data has been a fundamental problem in the fields of hydrology and geomorphology for applications such as watershed sediment load estimation, evaluation of sediment transport to oceans, geomorphological studies of denudation and rates of erosion, assessment of soil erosion and soil loss, reservoir sedimentation, environmental impact assessment, water treatment, and problems of sediment-associated nutrients and pollutants (Walling, 1977). For clarity, suspended load is sediment that is supported by upward turbulent currents and remains suspended for considerable lengths of time (Thomas, 1985). Suspended sediment is generally much smaller than bedload, which is also mobilized during high flows. The focus of this report is on suspended sediment.

Historical Approaches to Suspended Sediment Monitoring

Introduction

As of this study, no technology has been developed to provide real-time, accurate, semi-continuous measurements of SSC in the field. Historical measurements of SSC were often sporadic, and most often a single sample was taken over a twenty-four hour period. Unfortunately, due to the large variation and timing of storm events, such sampling protocol only provides crude estimates of temporal variation of SSC, which varies with channel morphology, hydrodynamic velocity gradient, geologic source, and size class distribution. Suspended sediment concentration can vary quite rapidly with discharge as illustrated by Thomas (1985) in the following quote; "it is not unusual to find situations where more than one-half of the sediment is carried by flows that account for less than 15 percent of the water volume that occur, perhaps, 2 percent of the time."

Classic Approach

The classic approach to collecting a more complete record of SSC variation is monitoring of an alternate variable such as turbidity or stage (often correlated by regression with discharge). As will be discussed below, stage or turbidity are collected on a semi-continuous time interval of 10 or 15 minutes. Point samples, representative samples of sediment-laden water at a single point along a cross section, are removed from the stream using predetermined protocol. The point samples are later correlated with stage, or turbidity using classical statistical regression. This statistical regression can then be applied to infer a semi-continuous record of SSC.

As mentioned in the previous section, SSC cannot be determined in the field. Point samples must be taken onsite and transported to a laboratory where suspended solids can be analyzed using laboratory tests such as "Total Suspended Solids Dried at 103-105°C" as described in Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1995). Since samples must be analyzed in a laboratory, monitoring semi-continuous SSC would be laborious and quite costly: if a sample is taken every 15 min this would mean 35,040 samples would be taken per year or 96 samples a day! With this in mind, continuous stage or turbidity data is more feasible because measurements can be obtained directly in the field and stored electronically using data loggers.

Before technology allowed the use of data loggers, scientists generally used a graph or an equation, most commonly a power function, relating daily average SS to daily average discharge or daily average SSC to discharge (Walling, 1977). The standard form of the power function is shown below as Equation 2.

$$C = \alpha Q^{\beta} \tag{2}$$

where C - Suspended sediment concentration, measurement of suspended sediment mass to total volume of sample [mg/L]

Q - Water discharge [ft^3/sec]

α - Power function intercept [mg/L*(ft^3/sec)$^{1/\beta}$]

β - Power function exponent or "slope"

The use of Equation 2 is classically referred to as the rating approach. The rating approach was originally developed by researchers Campbell and Bauder (1940) and was first thoroughly analyzed by Miller (1951). Error in the rating approach comes from the monitoring program design, or more specifically how samples are collected in the field, laboratory procedures, and unreliable discharge records (Walling, 1977). The largest problem in applying the rating relationship is, "the inadequacy of defining the detailed temporal record of suspended sediment concentration" because of infrequent discharge and SSC samples (Walling, 1977). Walling (1977) determined that sediment load estimate errors from the rating approach were on the order of ±50%; but the magnitude of error in applying the rating approach to estimate sediment loads depended on the nature of the catchment, time interval the load was calculated over, and procedure used to construct the rating relationship. Figure 3 illustrates the variance in the rating relationship both for a single basin and among basins using data from the United States Geological Survey (2000). Note that all of these rivers are in the same geographic region of Pacific Northwestern California and the data in the plot do not represent concurrent period of records.

Monitoring of SSC and discharge over smaller time scales, on the order of an hour or less, has revealed another significant source of variation in the rating approach. When plotting SSC against discharge for a single storm event one can discern a histeresis effect (Figure 4). The histeresis effect essentially means that for a given discharge, the rising limb of a hydrograph will have a higher SSC than the falling limb. Fitting a rating curve might capture the average relationship, but will not adequately describe the temporal variation of SSC with discharge. Some scientists have approached this problem by fitting multiple regressions for the rising and falling limbs with limited success (Walling, 1977).

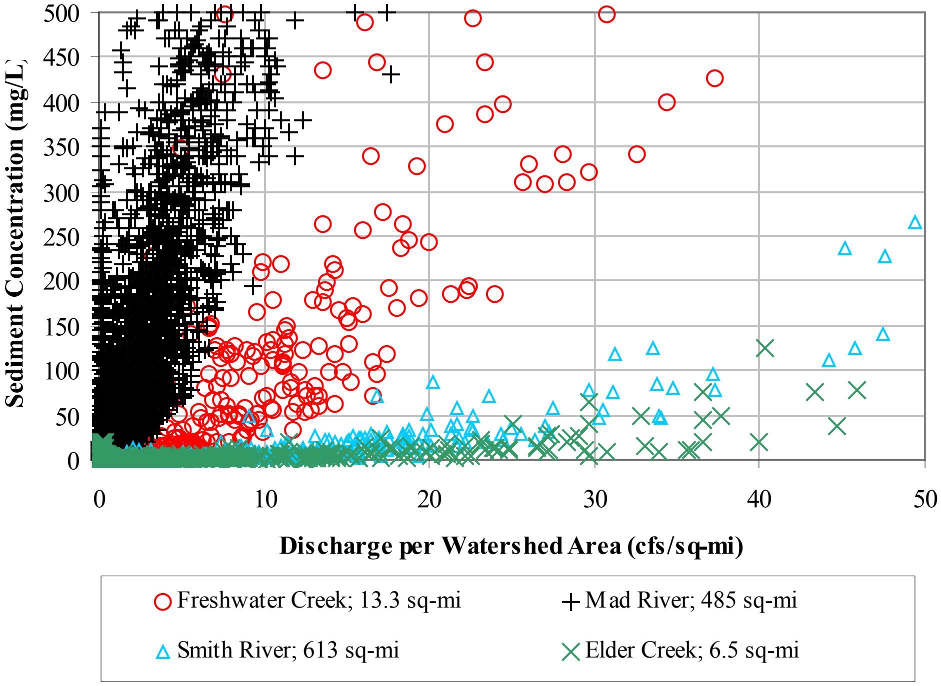

Figure 3. Suspended Sediment Concentration with Discharge for Northern California Coastal Region.

Turbidity Threshold Sampling, TTS

Turbidity is a measure of water clarity by refraction of light or laser with units of Nephalometric Turbidity Units or NTUs. Using turbidity to infer suspended sediment concentration in streams has been employed since the 1960s. Walling (1977) was one of the first to show how turbidity could be used to infer continuous SSC. Walling (1977) found that, "recording turbidity meters can provide worthwhile information of fluctuation in suspended sediment concentration providing that the instruments are field calibrated for a particular site and they are used on small- or medium-sized catchments with relatively homogenous rock type and predominantly silt- and clay-sized load."

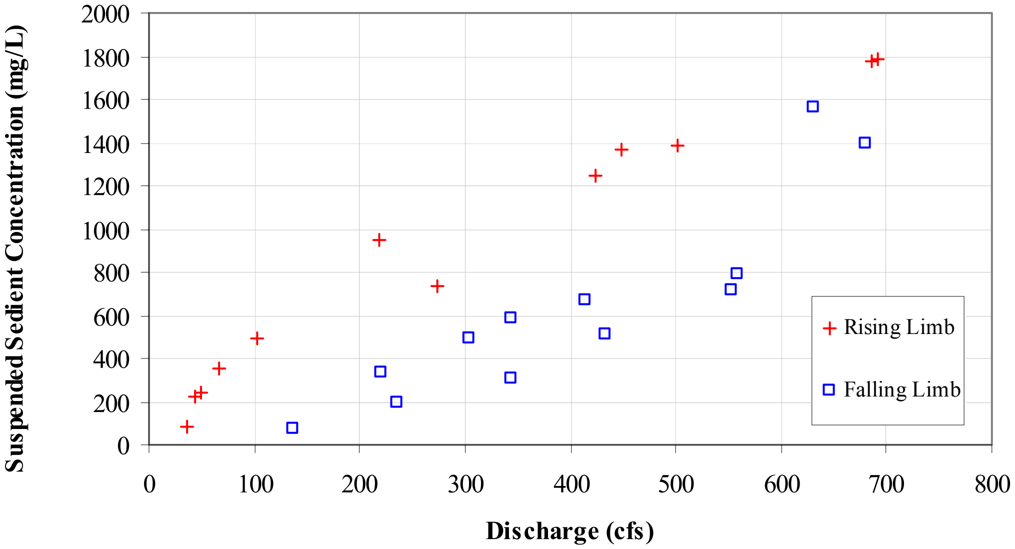

Figure 4. Example of the Histeresis Effect Using Freshwater Creek data set.

Though technology allowed the use of automated turbidity in combination with pumped samplers, the question still remained: when to take a sample? Two general approaches to collection of SSC data have been developed; time series, or independent (Thomas, 1985). For time series collection, ordering of the data in time is important in sample design. In independent sampling the samples are taken in such a way so as to ensure sample independence. Threshold sampling is a form of time series sampling where order and magnitude of previous samples determine when the next sediment sample is taken; however, unlike traditional time series sampling, time intervals are not constant but variable depending on thresholds (Thomas, 1985). In the past five years, researchers at USDA Forest Service Redwood Sciences Laboratory have applied, refined, and analyzed this method in what has become known as the Turbidity Threshold Study or TTS (Lewis, 1996; Lewis and Eads, 1996; Lewis et al., 2000; Lewis and Eads, *in press*). Figure 5 outlines all the aspects that comprise the turbidity threshold sampling method.

Figure 5. Components of the Turbidity Threshold Study.

Turbidity thresholds for sampling are based on the expected turbidity range for a given stream and number of desired samples (Lewis and Eads, *in press*). The details of threshold logic is described in Lewis and Eads (*in press*) and available online from Lewis et al. (2000). Essentially, the TTS program records the mean of 150 stage readings during each 10 to 15 minute time interval to increase measurement precision, and 61 turbidity readings are taken over a 30 second interval to reduce the influence of outlier values. (Lewis and Eads, *in press*). Also, because the falling limb is usually much longer than the rising limb, the falling limb often has more thresholds and thus more samples are pumped (Lewis and Eads, 1998).

In recent applications Campbell CR510 and CR10x programmable data loggers have been used to automate sampling. Pressure transducers, turbidimeters, ISCO pump samplers, an IBM PC, an electronic tipping bucket, temperature probes, and wires connecting all these electronic probes to their data logger unit have all been combined to set up pilot monitoring stations. Important to note is that a monitoring station also requires carefully designed housing shelters for equipment protection and in some cases proper use. It is crucial that the turbidity probes be mounted in such a way that they are not impacted by bedload, and must also be accessible at most times so debris can be dislodged or the optics cleaned if necessary. Also, ranges of turbidity sensing capability will vary with manufacturer, the HACH turbidity probe, for example, ranges from 0 – 2000NTU.

Discussion of TTS precision and problems with TTS

Research has shown that turbidity sampling has allowed estimation of semi-continuous suspended sediment with significantly reduced error compared with traditional rating approaches. Lewis (1996) specifically analyzed TTS methodology using measurements of SSC and turbidity collected at 10 minute intervals from five storm events in a small mountainous watershed, Caspar Creek. Using simple linear regression, the five loads were estimated with root mean square errors between 1.9 and 7.7%, compared to errors of 8.8 to 23.2% for sediment rating curves based on the same sample sizes of 4 to 11 samples per storm. Lewis (1996) also determined that sample sizes of five suspended sediment specimens per storm were generally adequate to estimate storm loads with root mean square error no greater than 5% of the correct values.

Turbidity sampling has other advantages over the rating curve method in addition to reducing variance in estimating semi-continuous SSC. For similar accuracy using the rating method, measuring stage or discharge rather than turbidity, the best available estimation methods require sample sizes 3 to 10 times larger; and for this reason are much more costly in terms of field work and laboratory processing (Lewis and Eads, 1996). Turbidity probes have also been able to track sediment pulses, landslides or stream bank failures unrelated to discharge (Lewis and Eads, 1996).

Using turbidity and pumped suspended sediment samples is not without its flaws. Variance of the load estimate calculated from turbidity threshold sampling is difficult to calculate and imprecise due to the small sampling size, which infers the potential for significant statistical bias (Lewis, 2000). More detailed analysis of SSC samples and turbidity measurements taken on 10-min and 15-min intervals is currently being researched. Additionally, organics have been known to foul turbidimeters; thus, sensors must be cleaned regularly. Housing design of the probes is crucial and is also discussed in Lewis and Eads (*in press*). One advantage of the rating relationship over regressions on turbidity and SSC is that the use of a power function in the rating approach does not allow for negative predictions of SSC. For this reason rating curves of discharge against suspended sediment concentration correlate to field data on the lower ranges of SSC more accurately than linear regressions of turbidity versus SSC.

Other sources of variance that occur in both the rating method or TTS result from how suspended sediment samples are collected and analyzed. In most instances pumped samplers, like the commercial model ISCO from Campbell Scientific, are used to pump point samples of the stream. Most pumped samplers are designed for wastewater treatment and are not well equipped for dealing with widely varying velocities in a natural stream channel (Thomas, 1985). Also sediment may get trapped in the intake of samplers giving falsely high suspended sediment concentrations (Thomas, 1985; Eads and Lewis, *in press*). Furthermore, when sampling a coarse load commercially available samplers can simply not produce the vacuum required to obtain a representative sample from the stream (Lewis and Eads, *in press*). Transportation or malfunctions of the sampler can lead to contamination or loss of sample volume biasing or simply reducing the volume of valuable data. Clearly, an accurate monitoring effort is not only costly but labor intensive.

Laboratory precision is also an issue in processing the suspended sediment samples. Negative trends in a linear regression model of turbidity at low concentrations may result from the use of 1-micron filters in the lab. Lewis and Eads (*in press*) showed that in 1-micron filtrate from 65 samples collected at 8 Caspar Creek gauging stations, an average of 15.5 mg/L was measured on the 0.22-micron filters. This effectively drops the intercept of the regression below zero, predicting negative SSC given low values of turbidity, a result that is physically not possible.

TTS in Freshwater Creek, a Cooperative Study

Beginning in January 1996, a monitoring station has been operated in the lower mainstem of Freshwater Creek by a cooperative effort among research personnel from the USDA Forest Service Redwood Sciences Laboratory, Humboldt State University Faculty, the Environmental Protection Agency, and community members in Freshwater, California. At this gauging station stage, turbidity, water temperature, and rainfall are continuously monitored on 15-minute time intervals. Suspended sediment samples are removed from the river when turbidity thresholds are exceeded under the turbidity threshold methodology developed by researchers at Redwood Sciences Laboratory (Lewis and Eads 1996, 1998, *in press*). There were many purposes of this study as listed below.

Goals of the Freshwater Creek TTS Site:

- Test the effectiveness of a new setting.
- Describe the current turbidity regime at the site.
- Estimate the annual suspended sediment yield at the site.
- Determine whether the current turbidity regime is potentially deleterious to salmonids.
- Provide information needed to develop an effective protocol for grab sampling.
- Provide a data set for testing hypotheses of factors controlling suspended sediment transport.

Semi-continuous measurements of turbidity, stage, and time along with data sets of pumped samples are available online from the Salmon Forever (2000) website for Hydrologic Year (HY) 1999 (POR 1/13/1999 – 8/1/1999) and HY 2000 (POR 8/1/1999 – 5/26/2000). Depth integrated samples tend to correlate closely with pumped samples (Bray, 2000); thus pumped samples are considered the true concentration in the stream. Regression analysis is needed to infer semi-continuous SSC from the turbidity measurements, and will be the first task completed in project activities, the next section of this report.

PROJECT ACTIVITIES

OVERVIEW

The impact of suspended sediment concentration on juvenile and underyearling coho salmon was assessed using the dose-response model (Equation 1) proposed by Newcombe and Jensen (1996). The dose-response model predicted the severity of ill-effect, or SEV. The SEV was then used to determine the biological impact as ranking within three biological thresholds: behavioral, sublethal, and lethal effects. However, before the dose-response model can was applied several project tasks had to be completed. First, a semi-continuous SSC data set for Freshwater Creek was constructed from measurements of turbidity. Then, thresholds of biological impact were defined with respect to juvenile and underyearling coho salmon species using studies from the literature. Next, the mathematical model (Equation 1) proposed by Newcombe and Jensen (1996) was calibrated for juvenile and underyearling salmon using data from the literature. Finally, the Newcombe and Jensen (1996) model is applied using both the mathematical model and threshold categories to identify biological impact. This section describes the general procedures followed to complete the project tasks.

CONSTRUCTION OF A SEMI CONTINUOUS SUSPENDED SEDIMENT CONCENTRATION DATA SET

Development of a semi-continuous SSC data set is one of the most crucial steps in meeting the objective of this project. In this study, the entire annual record is of interest because of juvenile coho residency. The most accurate way of converting the semi-continuous turbidity measurements would be to divide up the entire hydrologic year by storms and periods of little activity and then perform regressions on the suspended sediment samples with turbidity or stage taken over the discrete time intervals. These regressions could be used to infer semi-continuous SSC, which can then be pieced together over the entire hydrologic year. However, due to time constraints for this study, two regressions were applied over a given hydrologic year. The following procedure describes the steps taken to develop the regressions.

Inferring Semi-Continuous Suspended Sediment Concentration from Turbidity

The first task was to perform regressions on turbidity and suspended sediment samples collected at the Freshwater Creek site. Two different regression models were applied: a power equation was applied for turbidity range 0 – 100NTU (Equation 3) and a linear regression was applied for turbidity range 101 – 700NTU (Equation 4) where suspended sediment concentration is the dependent variable and turbidity is the independent variable.

$$SSC = n[TURB]^{m} \tag{3}$$

$$SSC = m[TURB] + n \tag{4}$$

where SSC - Suspended sediment concentration, measurement of suspended sediment mass to total volume of sample [mg/L]
$TURB$ - Turbidity, measure of light refraction in water [NTU]
n - Regression intercept [Power: mg/L*$(\mathrm{NTU})^{1/m}$; Linear: mg/L]
m - Regression exponent or slope [Power: unitless; Linear: NTU^{-1}]

To complete the regressions, ten steps were followed as outlined below:

1. Download the files "ftr99_sed.txt" and "ftr00_sed.txt" from the salmon forever website (Salmon Forever, 2000). These files are in space-delimited format.
2. Open "ftr99_sed.txt" using MS EXCEL. Remove any samples with suspended sediment codes or any obvious outliers (i.e. any zero concentration bottles).
3. Sort the data first by turbidity and then by suspended sediment concentration.
4. Split up the data set by turbidity range, one is selected for the lower turbidity range (0 – 100NTU) and a higher range (101 – 700NTU).
5. Set up a new column of the spreadsheet to predict the concentration based on turbidity using desired regression function; linear or power for both groups. Reference the slope and intercept parameters of the model in other cells and supply an initial guess.
6. Determine the residual concentration by subtracting the observed concentration by the predicted concentration in a new column.
7. In the next column square the residual.
8. Set the objective cell in MS EXCEL to the sum of the square residual concentration.

9. Use MS EXCEL Solver to minimize this objective cell by changing the model slope and intercept parameters.
10. Repeat this procedure for the HY 2000 data set contained in the file "ftr00_sed.txt."

The period of record (POR) for the HY 1999 suspended sediment data file, "ftr99_sed.txt", extends from January 16, 1999 to May 7, 1999 and for the HY 2000 suspended sediment data file, "ftr00_sed.txt", extends from November 16, 1999 to May 15, 2000. For the final regression analysis, a total of 146 samples from HY 1999 and 200 samples for HY 2000 were used to construct regressions of turbidity and suspended sediment concentration. The complete POR for HY 1999 and HY 2000 are plotted in Figures 6 and 7, respectively.

Table 4 shows the regression parameters for both HY 1999 and HY 2000 obtained by following the ten procedural steps listed above. The regressions for HY 1999 contained 95 samples in the range of 0 – 100NTU (Figure 8) and 51 samples ranged from 101NTU – 700NTU (Figure 9). More samples were collected in HY 2000, though most were in the lower turbidity range; 144 samples were in the range of 0 – 100NTU and 56 samples ranged from 101 – 700NTU. Figures 10, and 11 show the two regressions for HY 2000. Spreadsheets used in the optimization procedures for both HY 1999 and HY 2000 are provided in the Appendix A.

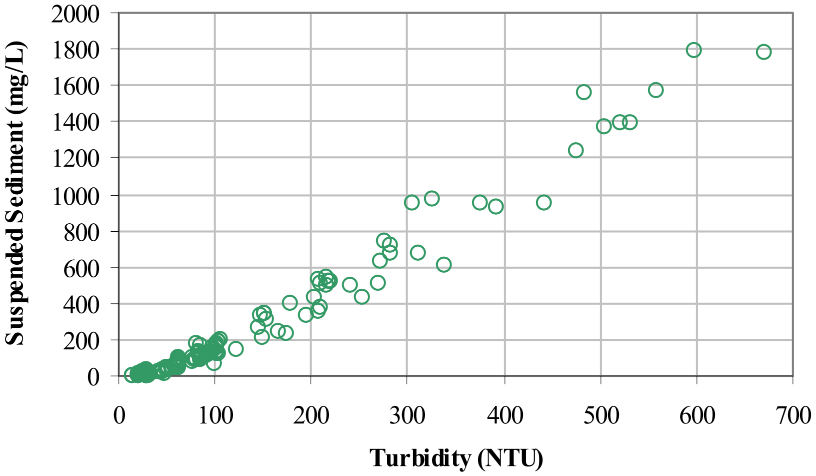

Figure 6. Turbidity vs. SSC, HY 1999 Complete POR.

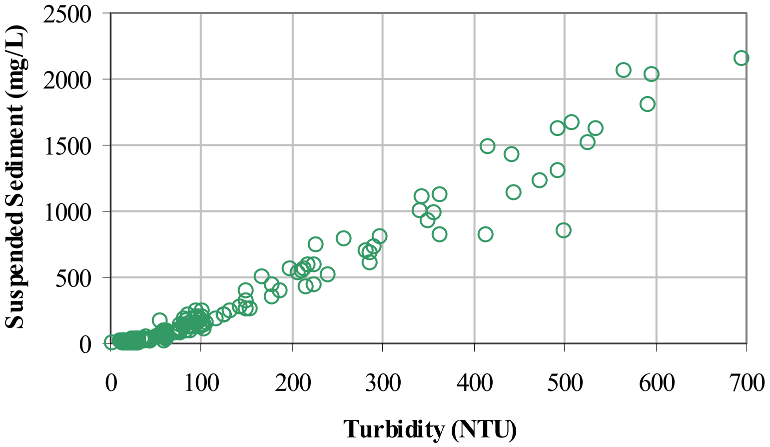

Figure 7. Turbidity vs. SSC, HY 2000 Complete POR.

Table 4. Regression Parameters

Hydrologic Year	Turbidity Range (NTU)	Regression Model	*m*	*n*
1999	0 – 100	Eqn. 3 – Power	1.851	0.0284mg/L*(NTU)$^{1/m}$
	101 – 700	Eqn. 4 – Linear	3.033NTU^{-1}	-178.5mg/L
2000	0 – 100	Eqn. 3 – Power	1.948	0.0229mg/L*(NTU)$^{1/m}$
	101 – 700	Eqn. 4 – Linear	3.348NTU^{-1}	-195.7mg/L

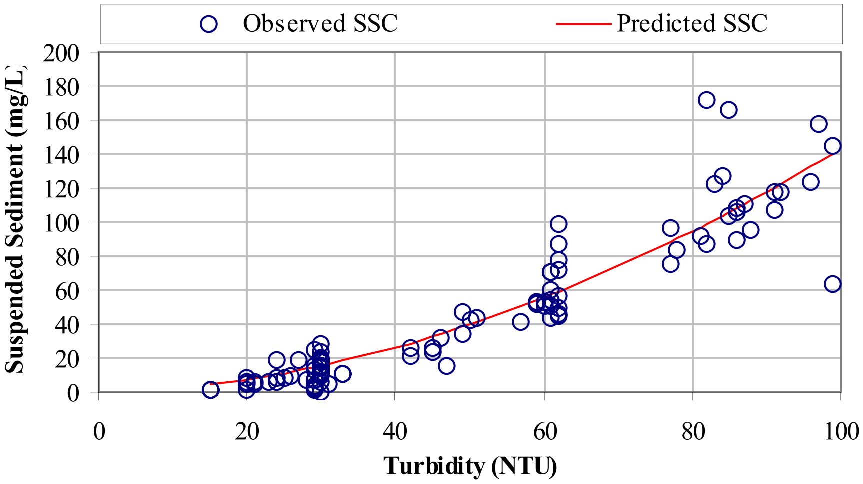

Figure 8. Regression Fit Turbidity vs. SSC, Scale 0 - 100NTU, HY 1999.

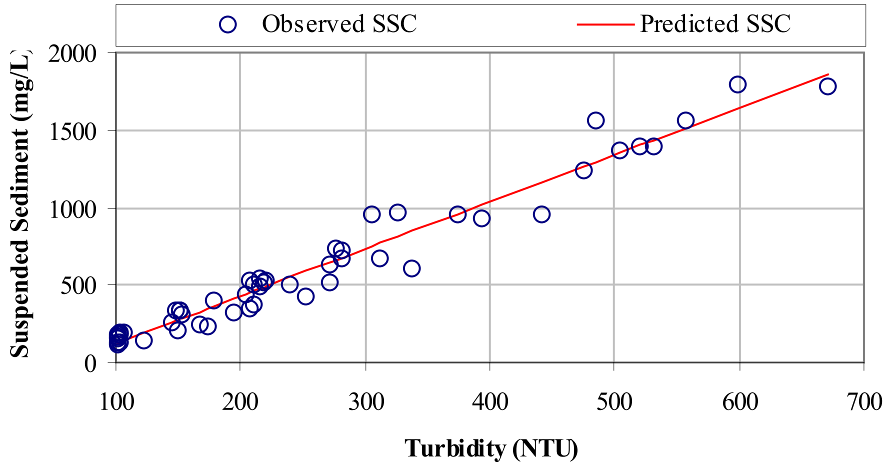

Figure 9. Regression Fit Turbidity vs. SSC, Scale 101 - 700NTU, HY 1999.

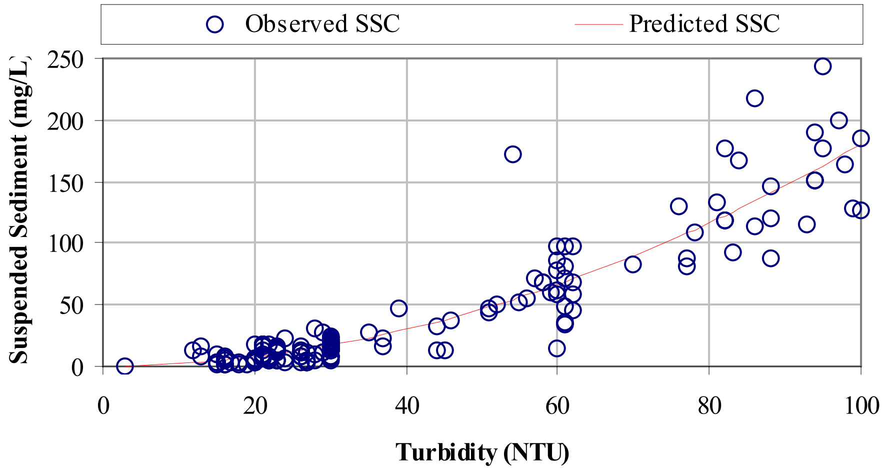

Figure 10. Regression Fit Turbidity vs. SSC, Scale 0 - 100NTU, HY 2000.

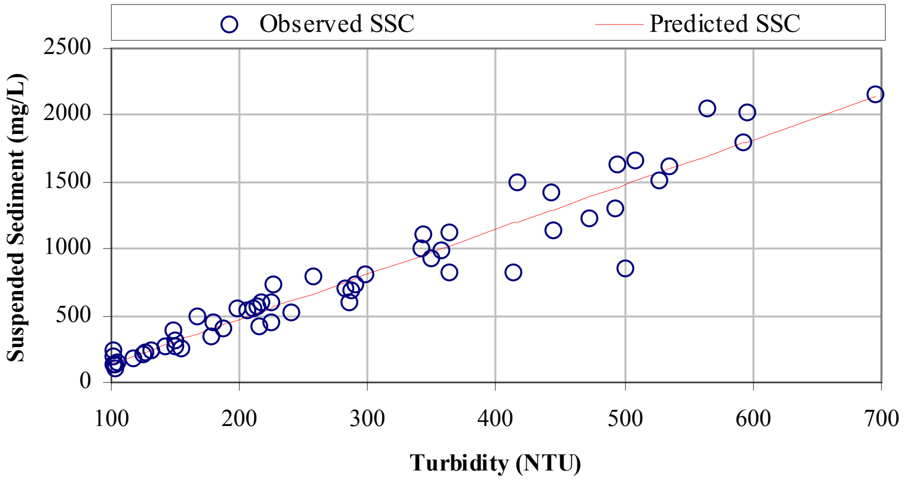

Figure 11. Regression Fit Turbidity vs. SSC, Scale 101 - 700NTU, HY 2000.

The next major task was to apply the regressions obtained from the steps above to each corresponding yearly hydrologic data set. To complete this project activity, the following procedure was implemented.

1. Download the semi-continuous turbidity record for HY 1999, "ftr99_15min.txt", and HY 2000, "ftr00_15min.txt", the salmon forever website (Salmon Forever, 2000). These files are also in space-delimited format.
2. Import these files into MS EXCEL. Delete all cells except date, time, and turbidity.
3. Using an IF-THEN construct in MS EXCEL, apply the regression equation based on the range it was derived. For example, if turbidity is 30 apply the regression equation derived for turbidity range 0 – 100NTU.
4. Repeat for both hydrologic years.

Following the process described above, two semi-continuous data sets for HY 1999 (598KB) and HY 2000 (899KB) were assembled. The size of the data files are large considering each data file contains date, time, turbidity, and estimated SSC observations for fifteen minutes over an entire hydrologic year; thus data processing becomes an issue. To streamline this analysis a program in FORTRAN90 was written. Discussion of this program is presented in the modeling subsection below.

Mathematical Model Calibration

The mathematical model proposed by Newcombe and Jensen (1996), Equation 1, was calibrated using data presented in Table 2 and Table 3. The parameter estimation method used to regress turbidity and SSC data was also used to determine the model coefficients a, b, and c (Equation 1) for both juvenile and underyearling coho salmon. The sum of the square of the residuals was minimized where the residual is the difference of observed and predicted values. In this case, we are comparing observed SEV and predicted SEV. To carry out the calibration procedure, the following steps were performed.

1. Transfer data shown in Table 2 and Table 3 into MS EXCEL. The data from Tables 2 and 3 includes the concentration, duration, and observed severity of ill-effect (SEV), which take up three columns in an MS EXCEL worksheet. Note that data for juveniles and underyearling should not be grouped but separated, either using different columns on the same worksheet or different worksheets.
2. Calculate the predicted SEV by applying the Newcombe and Jensen (1996) model (Equation 1) in a fourth column. Make sure to use cells to reference the intercept and slope parameters a, b, and c in different cells.
3. In the column next to predicted SEV, determine the residual by taking the difference between observed SEV and predicted SEV.
4. In the next column square the residual.
5. Construct the objective cell by summing the column of residuals squared.
6. Open MS EXCEL Solver from the 'tools menu. Minimize the objective function, z, by changing the slope and intercept parameters of the model.
7. Repeat steps 2 through 7 for both juvenile and underyearling species separately, yielding two different sets of parameter values.

Following the procedure above yielded the Newcombe and Jensen (1996) model parameters *a*, *b*, and *c* (Equation 1) for juvenile and underyearling coho salmon. The model parameters are shown below in Table 5. For the regressions, 14 observations (Table 2) were available for juvenile salmon, and 12 observations (Table 3) for underyearling salmon. Parameter results were quite similar (Table 5), though the objective function was much improved in the underyearling coho regression.

Table 5. Optimization Results for Newcombe and Jensen (1996) Model Parameter Estimation.

Coho Salmon Age Class	a -	b $\ln[(hr)^{-1}]$	c $\ln[(mg/L)^{-1}]$	z -
Juvenile	1.87	0.87	0.46	31.3
Underyearling	1.60	0.72	0.57	12.5

In an ideal world a model predicts exactly what is observed or measured. When the predicted variable is plotted against the measured variable, a linear plot with a slope of one and intercept zero should be obtained. To show how the two SEV models compared with observed biological response, predicted severity of ill effect was plotted against observed severity of ill effect (Figure 12). The diagonal line of slope one and intercept zero represents the SEV model, the diamonds and squares show how the model predicts for underyearling and juvenile coho, respectively. Figure 12 shows how the model predicts for both age classes of coho salmon where the model is represented by the line of slope 1 and intercept zero. Take note that the diagonal line represents two different models with parameters given in Table 5 above. From Figure 12, it is evident that the model will underestimate the lethal effects threshold, a conclusion reached by Newcombe and Jensen (1996) during model calibration. The model also tends to be conservative for the juvenile coho salmon behavioral effects threshold.

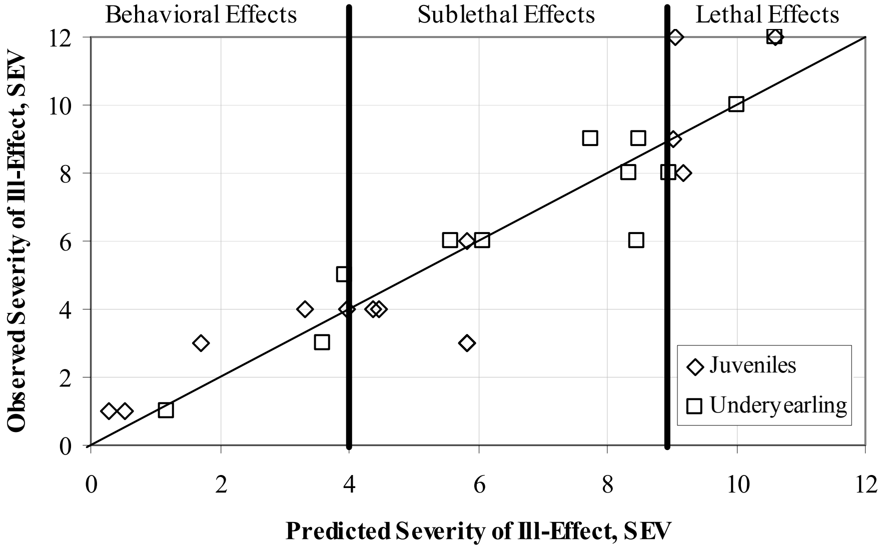

Figure 12: Optimization fit of Newcombe and Jensen (1996) SEV Model to Juvenile and Underyearling Coho Salmon.

Model Application

The final task to be completed to meet the objective was to apply the calibrated mathematical models to the semi-continuous SSC data sets from Freshwater Creek. Again the data sets are extensive; thus automating the analysis procedure undoubtedly saved time. Depending upon the scientist, there are a number of ways to proceed with automating data processing. In this study, a FORTRAN90 processing routine was constructed to determine time interval ranges over which a user specified threshold concentration is input (step 2 in the procedure below). The processing routine required that estimated SSC data for a given HY be saved in comma-delimited format (.csv extension file) using MS EXCEL. Processing routine output includes the start date, end date, and time in both days and hours that the user specified threshold was exceeded. The information was then imported back into MS EXCEL and SEV values were calculated using the calibrated Newcombe and Jensen (1996) model. The processing routine is presented in **APPENDIX B** along with sample input and output information.

The Newcombe and Jensen (1996) model (Equation 1) was used to predict the biological impact quantitatively in the form of SEV. After calculating SEV, Table 1 was then used to predict the threshold category and general biological response behavior of juvenile and underyearling coho in Freshwater Creek. The procedure listed below outlines the steps taken to calculate SEV from the Newcombe and Jensen (1996) model (Equation 1).

1. Determine a suspended sediment concentration classified in the data sets shown in Tables 2 and 3 that could be correlated to a given threshold.
2. Determine all periods in hours that the threshold concentration was exceeded.
3. Calculate the SEV using equations fit to juveniles and underyearlings (determined from the subsection *Mathematical Model Calibration*).
4. Summarize this data in tabular form.
5. Use the MS EXCEL Descriptive Statistics Package to determine the mean, maximum and standard deviation of predicted SEV for Freshwater Creek.
6. Repeat steps 2 through 6 using each concentration threshold for both HY 1999 and HY 2000 data sets designated in Step 1.

Before the Newcombe and Jensen (1996) model could be applied, the Freshwater data had to be grouped by SSC (mg/L) and duration (h). This information could then be used directly as input to the calibrated Newcombe and Jensen (1996) model (Equation 1) for juvenile and underyearling coho salmon yielding SEV. Steps 1 and 2 in the procedure above, essentially describe the preprocessing of the Freshwater Creek data required before Equation 1 could be used to calculate SEV (Step 3). These two steps are subsequently discussed below.

For the above procedure, the first step was to adopt SSC thresholds using data presented in the **LITERATURE REVIEW**. Five SSC thresholds were selected to target the three threshold categories of biological impact (Table 1). These SSC thresholds and target impact category are displayed below in Table 6.

Table 6. Threshold SSC and Targeted Response Category.

Suspended Sediment Concentration (mg/L)	Targeted Threshold Effect Category
50	Behavioral Effects
80	Sub-lethal Effects
140	Sub-lethal Effects
300	Lethal Effects
1,200	Lethal Effects

The next step was to determine the time intervals or durations over which the SSC thresholds (Table 6) were exceeded. As described above, this task was completed using a FORTRAN90 processing routine (**APPENDIX B**). The output from the processing routine displaying each SSC threshold for each HY is shown in **APPENDIX C**. This data and SSC thresholds were then input into the Newcombe and Jensen model (1996) to obtain SEV. In the following section, **RESULTS**, the Newcombe and Jensen (1996) model output is presented along with predicted threshold category and general biological response behavior of juvenile and underyearling coho.

RESULTS

The last step in this analysis was to apply the Newcombe and Jensen (1996) model (Equation 1) to calculate severity of ill-effect or SEV, and thus predict biological impact of suspended sediment on coho salmon. In the **PROJECT ACTIVITIES** section, the Newcombe and Jensen (1996) model was calibrated for juvenile and underyearling coho salmon using studies from the literature. Also in the **PROJECT ACTIVITIES**, Freshwater Creek water quality data was processed to yield suspended sediment concentration (mg/L) and duration (hr) data sets, requiredto calculate SEV using Equation 1. All SEV values were then grouped by species age class and hydrologic year, and descriptive statistics were prepared for each group using MS EXCEL. Table 7 shows the summary of descriptive statistics for juvenile (J) and underyearling (U) salmon for each hydrologic year (HY). The complete spreadsheets including the dates of threshold exceedence and SEV values are included in **APPENDIX D**.

Table 7. Statistics Summary for Predicted SEV Among Juvenile (J) and Underyearling (U) Coho Salmon, HY 1999 and HY 2000.

Statistic	HY 1999		HY 2000	
	J	U	J	U
Mean	5.55	5.54	5.71	5.69
Standard Error	0.12	0.10	0.12	0.10
Median	5.70	5.66	5.88	5.81
Mode	5.90	5.70	5.64	5.49
Standard Deviation	1.05	0.88	1.06	0.91
Sample Variance	1.10	0.78	1.12	0.82
Kurtosis	-0.44	-0.31	0.31	0.50
Skewness	-0.58	-0.59	-0.86	-0.86
Range	4.12	3.61	4.31	3.78
Minimum	3.05	3.35	3.05	3.35
Maximum	7.17	6.95	7.36	7.13
Sum	416.34	415.66	434.32	432.19
Count	75	75	76	76

The mean, median, and mode SEV for both juvenile and underyearling coho salmon and for both hydrologic years was 6. Also, the standard deviation for both age classes and HY was approximately 1. Referring back to Table 1, an SEV of 6 ± 1 SEV unit is well within the sublethal effects category. Specifically, an SEV of 6 corresponds to moderate physiological stress. One standard deviation lower, an SEV of 5, is described as minor physiological stress, and increased rate of coughing, or respiration, or both. The predicted impact of an SEV of 7, the maximum observed SEV for both juvenile and underyearling coho salmon, is moderate habitat degradation, and impaired homing ability.

For each SSC threshold, the SEV was calculated sequentially in a spreadsheet for each time interval the threshold was exceeded (see **APPENDIX D**). Using these data for each SSC threshold, SEV and start date of the duration interval were plotted to show the temporal variation of impact with time. Figures 13 and 14 show the variation of juvenile coho salmon SEV with time for HY 1999 and HY 2000, respectively. Similar plots are shown for underyearling coho salmon in Figures 15 and 16.

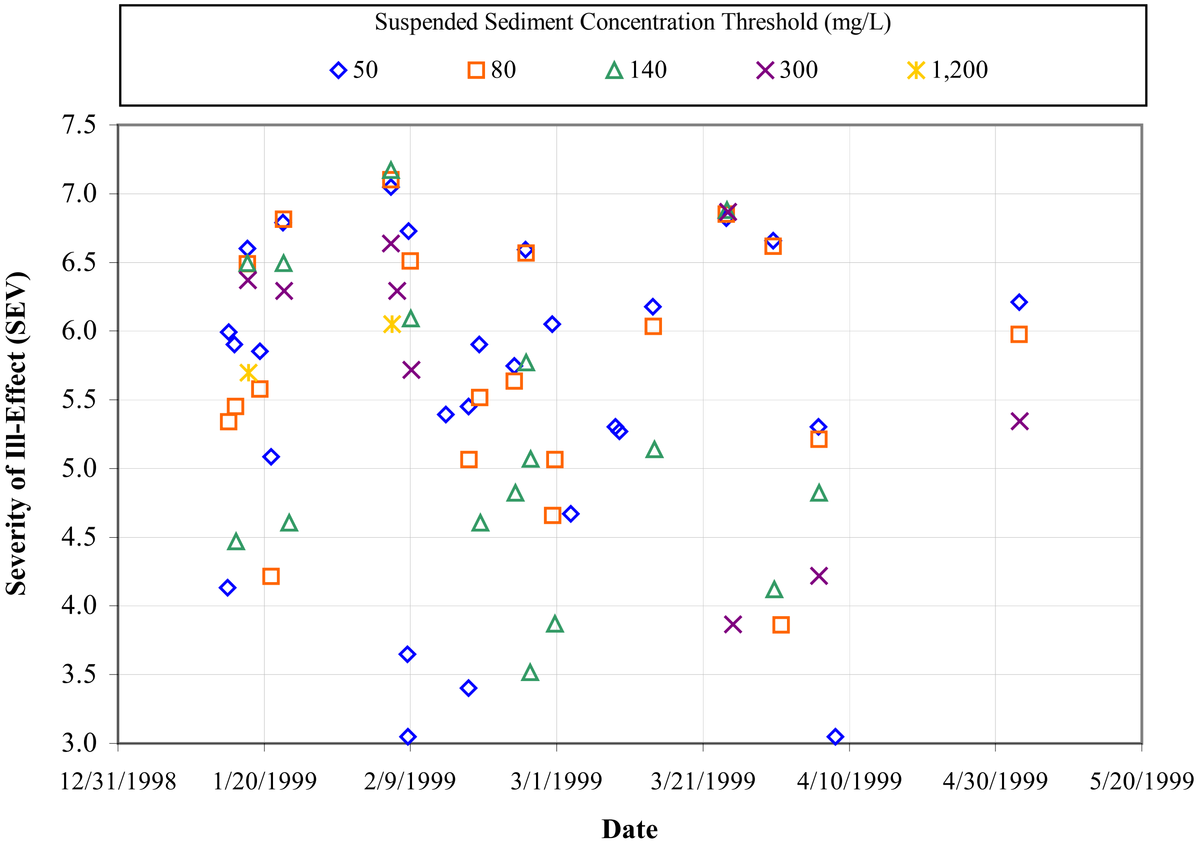

Figure 13. Temporal Variation of SEV, Juvenile Coho Salmon, HY 1999.

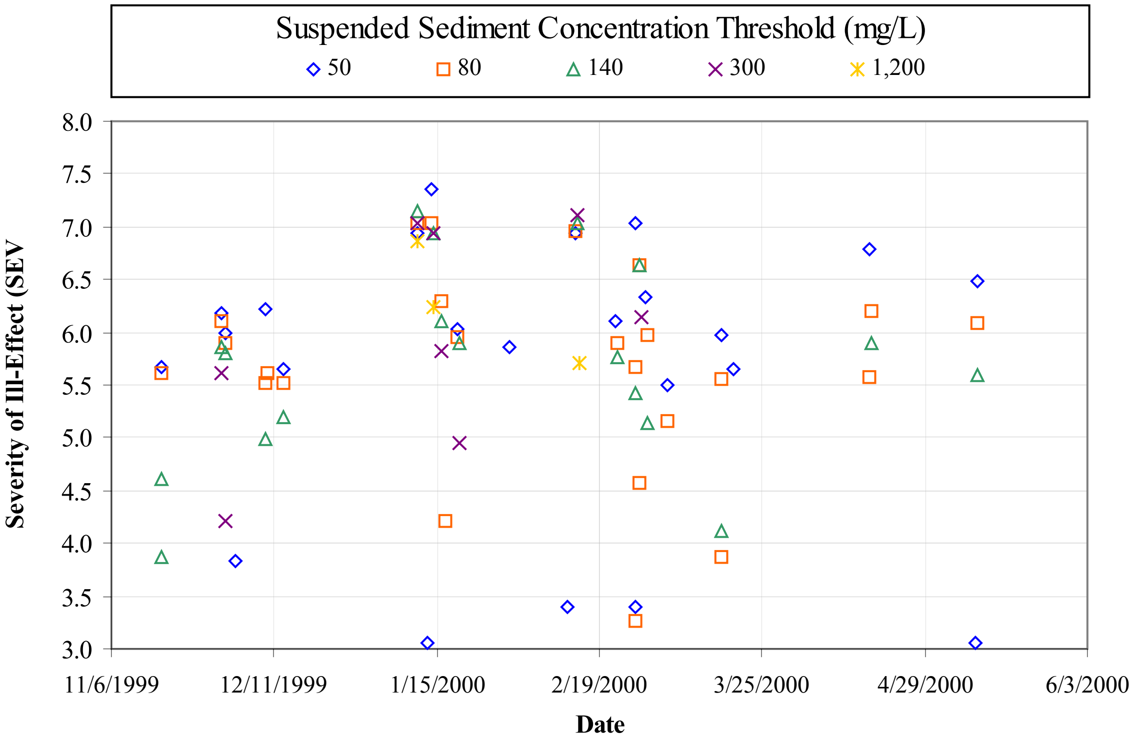

Figure 14. Temporal Variation of SEV, Juvenile Coho Salmon, HY 2000.

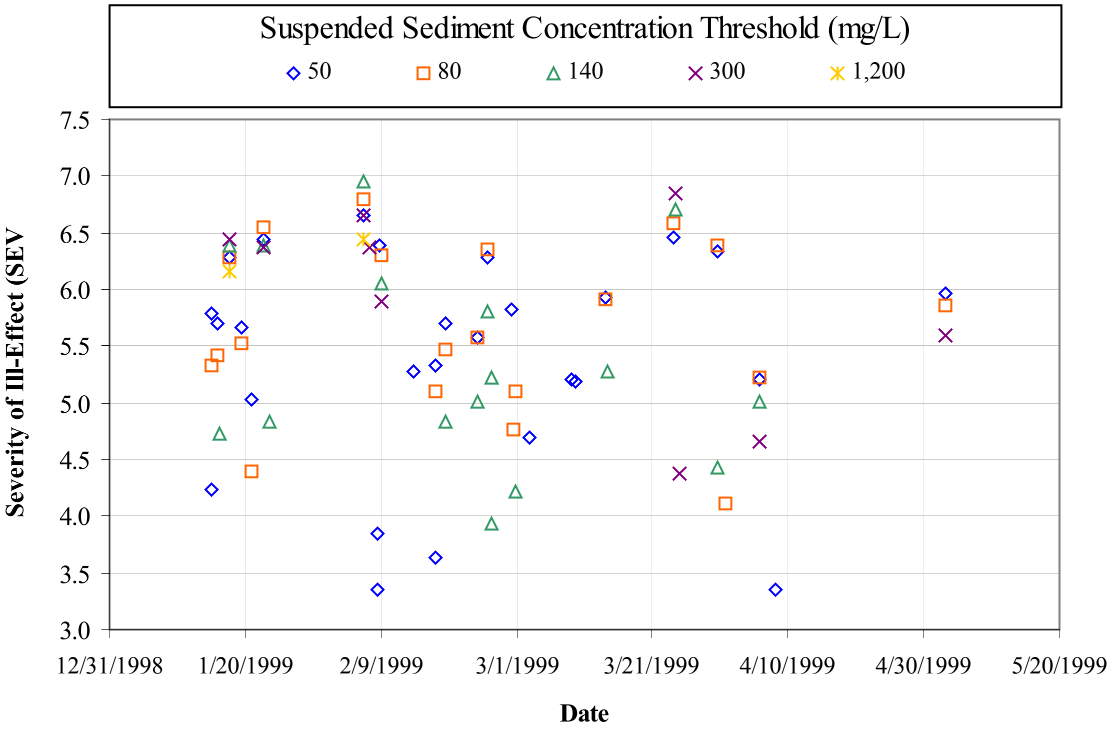

Figure 15. Temporal Variation of SEV, Underyearling Coho Salmon, HY 1999.

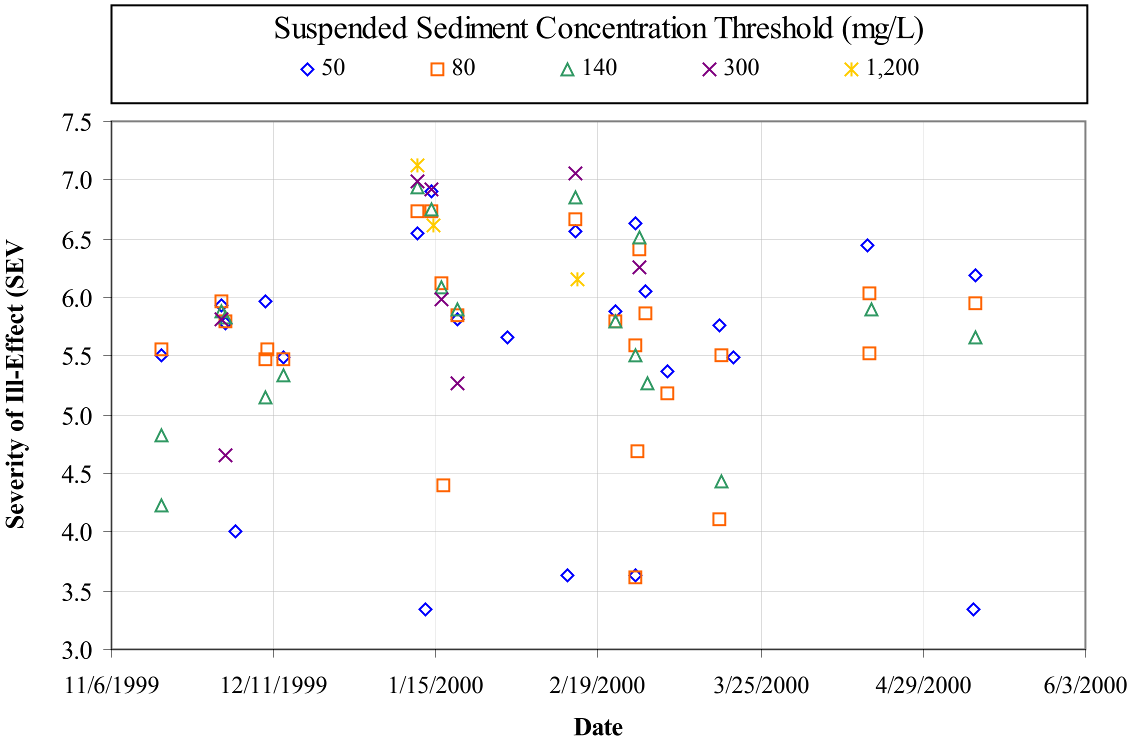

Figure 16. Temporal Variation of SEV, Underyearling Coho Salmon, HY 2000.

DISCUSSION

CONSTRUCTION OF A SEMI CONTINUOUS SUSPENDED SEDIMENT CONCENTRATION DATA SET

A power fit was used to prevent a negative intercept in the prediction of SSC from turbidity. Notice the large variance in the lowest turbidity range, 0 – 30 NTU for both HY 1999 and HY 2000 (see Figures 8 and 10), especially at turbidity 30 where SSC varies by almost 30 mg/L. This is likely due to many factors including anthropogenic influences in the stream, small precipitation events that barely increase flows, and measurement error. Notice also that a power function seemed appropriate on the lower range because the data exhibits some curvature (see Figures 8 and 10). Figure 17 reveals the large variation in residuals on the upper range linear regressions (101 – 700NTU).

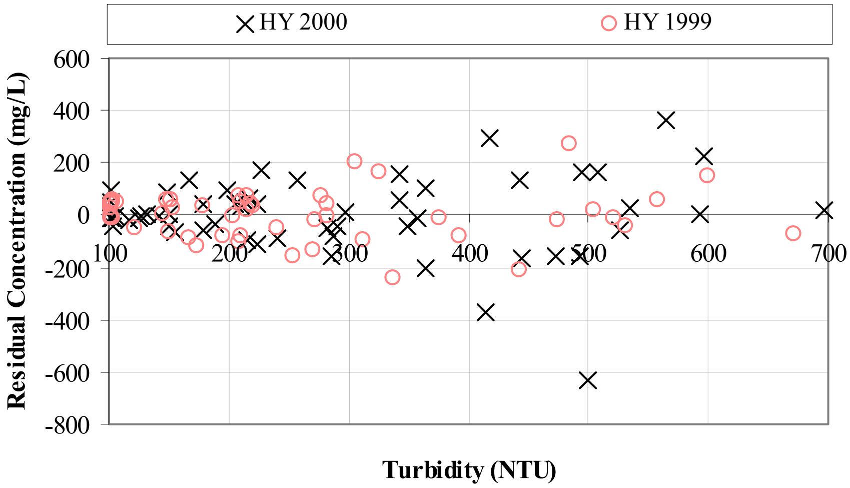

Figure 17. Plot of Residuals for Upper Turbidity Range (101 – 700NTU) Linear Regression Models.

Residual suspended sediment concentration standard deviation was on the order of ± 200 mg/L tended to increase with turbidity. This is likely due to a change in the particle size distribution in suspension, a physical process. From residual plot, variance seems to decrease as turbidity increases from 500NTU to 700NTU, but this is misleading because there are very few samples in this upper region, and samples are representative of only one or two storm events. These results support the assertion made by Lewis and Eads (*in press*) and Lewis (1996) that inferences of SSC from TURB are most accurate on an event basis.

Finally, notice that the regression parameters for the lower range between HY 1999 and HY 2000 are quite similar (see Table 4), which is encouraging because the relationship between both hydrologic years tends to be consistent. The linear regressions between HY 1999 and HY 2000 for the upper range are less similar; however, such a change in magnitude of slope and intercept is expected given the amount of variation in this range, 101 – 700NTU (see Figures 9 and 10).

CALIBRATION OF NEWCOMBE AND JENSEN (1996) MODEL TO JUVENILE AND UNDERYEARLING COHO SALMON

Data for juvenile and underyearling coho salmon were separated and different parameters were regressed for both life stages. The regression parameters (see Table 5) do not differ significantly which was unexpected because underyearling coho salmon were shown to be less responsive to sediment doses than juvenile coho salmon (Servizi and Martens, 1992). Also when considering the variation in juvenile coho salmon data (Figure 12), grouping underyearling and juvenile data does not seem unreasonable. Though the parameters in Table 5 appeared to be similar, the model predicted a characteristically different biological impact for juvenile and underyearling coho salmon. These results are discussed in the next subsection, MODEL APPLICATION: PREDICTING THRESHOLD OF BIOLOGICAL RESPONSE.

One of the major conclusions made by Newcombe and Jensen (1996) in developing the SEV model (Equation 1), was that the model tended to under-predict the lethal effects threshold. This was definitely the case for both the calibrated juvenile and underyearling coho salmon models (Figure 12). As predicted SEV tends to increase, observed SEV begins to increase exponentially with increasing rates of observed mortality. In other words the mathematical model (Equation 1) is conservative in estimating mortality; if the model were to predict an SEV of 12, then mortality is highly likely.

Figure 12 also shows that the observed data have portions of constant observed SEV with increasing predicted SEV. This result is marked by the row of three observations at an observed SEV of 4 and 6 for juvenile and underyearling coho salmon, respectively. The use of a discrete ranking scheme in determining the rank of severity of ill-effect (see Tables 1, 2, and 3) likely contribute to this effect, though it may also be a function of actual biological thresholds of tolerance to SSC. Biological response is highly complex, depends on many factors making it highly nonlinear, and is difficult to quantify. Further research is needed to identify these thresholds of biological response in terms of suspended sediment concentration and duration of exposure for target species.

MODEL APPLICATION: PREDICTING THRESHOLD OF BIOLOGICAL RESPONSE

The Newcombe and Jensen (1996) model predicted a mean SEV of 6 ± 1 for both juvenile and underyearling coho salmon and for both hydrologic years. An SEV of 6 ± 1 corresponds to the sublethal threshold effects category. The relatively small standard deviation and consistency among suspended sediment thresholds applied decreases the uncertainty of this assessment of biological impact.

The apparent consistency in SEV model output for each threshold suspended sediment concentration (50, 80, 140, 300, and 1200 mg/L) was unexpected. The thresholds were originally selected with the intent to target the three threshold impacts shown in Table 6. However, SEV values were fairly similar among SSC thresholds, the majority ranging between 5 and 7 (**APPENDIX D**). For this reason all SEV values for each species age class and hydrologic year were combined to produce the descriptive statistics presented in Table 7. If the SEV output is separated further by SSC threshold, the mean SEV tends to increase on average, with increasing SSC threshold (see Figure 18). These results suggest that higher suspended sediment concentration, even over short durations, lead to larger magnitude values of SEV, and thus have more of an impact on juvenile and underyearling coho salmon.

The maximum SEV for juvenile and underyearling coho salmon were also similar in magnitude, but the circumstances producing the maximum SEV values were quite different. The maximum predicted juvenile coho SEV was 7.4, occurring with suspended sediment concentration of 50mg/L for approximately 72 hours (1/14/2000 00:45 to 1/17/2000 01:00). In this instance, the maximum SEV resulted from the lowest threshold SSC (50 mg/L) over a long period of time (3 days). Discharge and SSC over this time period are shown in Figure 19. The dashed horizontal line at the bottom of the figure delineates the 50 mg/L threshold occurring over the period shown.

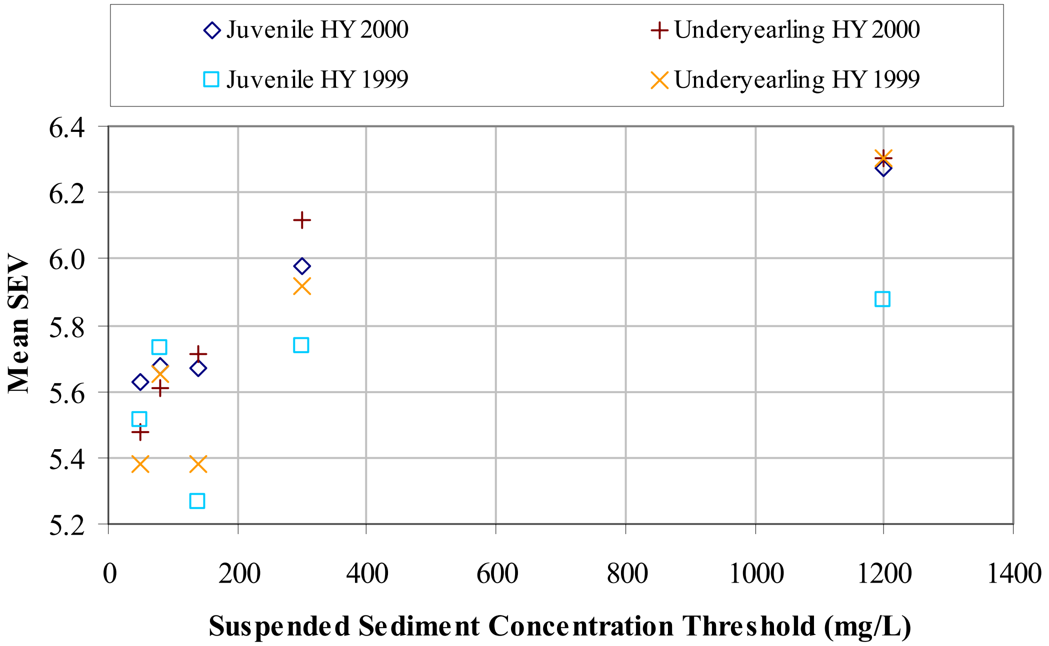

Figure 18. Mean SEV and Suspended Sediment Concentration Threshold, Grouped by Species Age Class and Hydrologic Year.

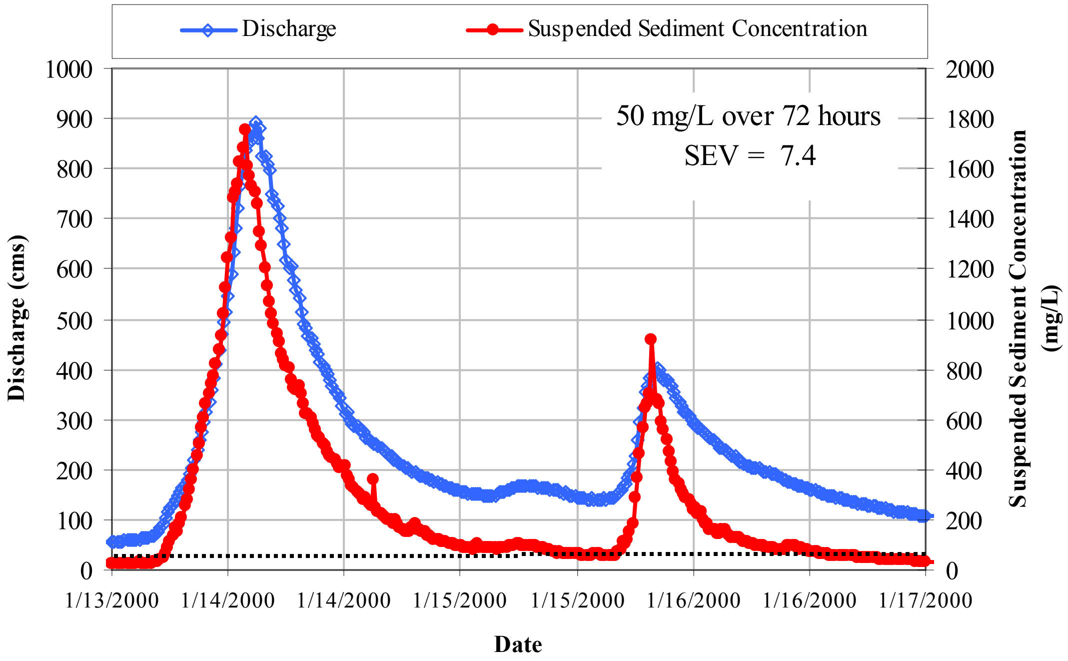

Figure 19. Discharge and Suspended Sediment Concentration, Freshwater Creek, 1/13/2000 – 1/17/2000.

The maximum predicted SEV for underyearling coho was 7.1 occurring with a SSC of 1,200 mg/L over an 8 hr period (1/11/2000 00:30 – 1/11/2000 08:15). In this case, a large magnitude SSC (1,200 mg/L) over a brief period in time (8 hrs) caused the maximum SEV. Figure 20 shows the variation in discharge and SSC, which resulted in an SEV of 7.1 for underyearling coho salmon. From these characteristic differences in maximum predicted SEV, one could infer that underyearling coho salmon are less tolerant of high SSC thresholds for short periods as compared with juvenile coho salmon, and visa versa. In this instance, the SEV model was able to predict sensitivity differences between underyearling and juvenile coho salmon.

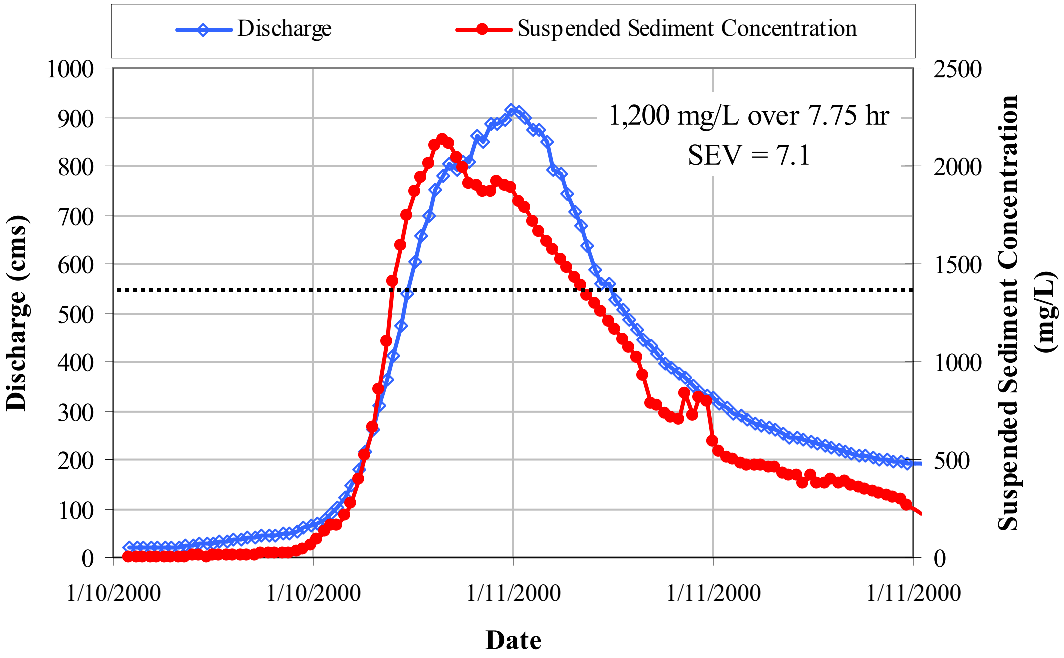

Figure 20. Discharge and Suspended Sediment Concentration, Freshwater Creek, 1/13/2000 – 1/17/2000.

Timing of biological impact is also important to assess an overall impact on coho salmon in Freshwater Creek because the Newcombe and Jensen (1996) model does not account for species recovery and impacts are not cumulative. Figures 13, 14, 15, and 16 show the variation in magnitude of SEV over both hydrologic years for juvenile and underyearling coho salmon. The largest SEV and most dense scatter of SEV clearly occur in winter months (December to February). In the above discussion both the maximum observed SEV for juvenile and underyearling coho salmon resulted from elevated discharge in storm events. Notice also that the storms causing the maximum SEV for underyearling coho (Figure 20) occurred directly after the maximum observed SEV for juvenile coho (Figure 19). Essentially both age classes of coho salmon were given little time to recover between storms. If species are not given enough time to recover and feed, then biomass is highly likely to be reduced, which will negatively impact the chances for smolt survival (Bilton et al., 1982). More research is needed to quantify the relationship between biomass and percent survivorship of coho salmon in Freshwater Creek.

CONCLUSIONS AND RECOMMENDATIONS

The Newcombe and Jensen model (1996) predicted a mean SEV of 6 ± 1 for both juvenile and underyearling coho salmon for both hydrologic years which corresponds to the sublethal effects category. The sublethal effects category includes minor to moderate physiological stress and moderate habitat degradation (Newcombe and Jensen, 1996). The model results tend to infer that coho salmon are stressed biologically in Freshwater Creek, but that suspended sediment concentration is not likely to be causing species mortality.

Maximum SEV values were 7.4 and 7.1 for juvenile and underyearling coho salmon, respectively. The circumstances causing the maximum SEV for both age classes of coho salmon were quite different: for juveniles, maximum SEV occurred with a low magnitude SSC threshold (50mg/L) over a long period of time (72hr), and for underyearlings, maximum SEV occurred with a high magnitude SSC threshold (1,200mg/L) over a brief time period (8hr).

A closer look at the time periods causing the maximum SEV values revealed that both instances occurred sequentially within a five-day period in January 2000. By plotting SEV sequentially in time (Figures 13, 14, 15, and 16) the most severe impacts to juvenile and underyearling coho occurred in winter months. In the winter, storm events cause continual pulses of sediment and maintain SSC levels over long periods of time. As storm events become more sporadic, lower suspended sediment concentrations over longer time periods still resulted in the sublethal effects classification (for example see Figure 16). As discussed in the **LITERATURE REVIEW**, extended periods of relatively low SSC can cause significant reductions in biomass and size of juvenile coho salmon. A reduction in size may reduce the chance of smolt survival. More research is needed to establish thresholds of size and survivorship, which can then be linked to available research on suspended sediment concentration and duration effects with respect to size and biomass of juvenile salmon species. Since the Newcombe and Jensen (1996) model does not account for species recovery or cumulative effects, appropriate recovery time for exposure of target salmon species to SSC thresholds would be extremely useful in assessing biological impact from the model results.

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APPENDIX A

REGRESSION SPREADSHEET, 0 – 100NTU TURBIDITY RANGE, HY 1999

Optimization					
Model	*SSC* = b[TURB]^{m}*				
b	0.03				
m	1.85				
Objective	24558.89				

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	(SSC* - SSC)^2
1	15	1.481	4.276	-2.795	7.81
2	15	1.717	4.276	-2.559	6.55
3	20	0.841	7.283	-6.441	41.49
4	20	4.898	7.283	-2.385	5.69
5	20	6.027	7.283	-1.256	1.58
6	20	8.061	7.283	0.778	0.61
7	21	5.242	7.971	-2.729	7.45
8	21	6.146	7.971	-1.825	3.33
9	23	6.348	9.432	-3.084	9.51
10	24	5.766	10.205	-4.439	19.71
11	24	7.755	10.205	-2.450	6.00
12	24	19.000	10.205	8.795	77.35
13	25	8.158	11.006	-2.848	8.11
14	26	9.963	11.835	-1.872	3.50
15	27	19.110	12.691	6.419	41.21
16	28	6.536	13.574	-7.038	49.54
17	29	0.756	14.485	-13.729	188.48
18	29	2.161	14.485	-12.324	151.88
19	29	2.518	14.485	-11.967	143.21
20	29	3.564	14.485	-10.921	119.27
21	29	7.089	14.485	-7.396	54.70
22	29	7.576	14.485	-6.909	47.73
23	29	12.770	14.485	-1.715	2.94
24	29	14.880	14.485	0.395	0.16
25	29	24.160	14.485	9.675	93.61
26	30	0.420	15.423	-15.003	225.08
27	30	6.165	15.423	-9.258	85.71
28	30	9.859	15.423	-5.564	30.96
29	30	10.190	15.423	-5.233	27.38

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	$(SSC^* - SSC)^2$
30	30	11.490	15.423	-3.933	15.47
31	30	11.820	15.423	-3.603	12.98
32	30	14.010	15.423	-1.413	2.00
33	30	14.380	15.423	-1.043	1.09
34	30	14.710	15.423	-0.713	0.51
35	30	15.220	15.423	-0.203	0.04
36	30	17.330	15.423	1.907	3.64
37	30	17.860	15.423	2.437	5.94
38	30	19.110	15.423	3.687	13.60
39	30	20.350	15.423	4.927	24.28
40	30	24.040	15.423	8.617	74.26
41	30	27.850	15.423	12.427	154.43
42	31	5.083	16.388	-11.305	127.80
43	33	10.600	18.398	-7.798	60.81
44	33	11.130	18.398	-7.268	52.82
45	42	20.850	28.747	-7.897	62.36
46	42	26.250	28.747	-2.497	6.24
47	45	24.020	32.662	-8.642	74.69
48	45	25.480	32.662	-7.182	51.58
49	46	32.350	34.018	-1.668	2.78
50	47	15.860	35.399	-19.539	381.78
51	49	34.510	38.237	-3.727	13.89
52	49	46.790	38.237	8.553	73.15
53	50	42.610	39.694	2.916	8.50
54	51	43.220	41.176	2.044	4.18
55	57	41.160	50.587	-9.427	88.86
56	59	51.230	53.920	-2.690	7.24
57	59	52.860	53.920	-1.060	1.12
58	60	50.270	55.624	-5.354	28.66
59	60	53.490	55.624	-2.134	4.55
60	61	43.310	57.352	-14.042	197.17
61	61	51.020	57.352	-6.332	40.09
62	61	54.020	57.352	-3.332	11.10
63	61	60.070	57.352	2.718	7.39
64	61	70.940	57.352	13.588	184.64
65	61	71.020	57.352	13.668	186.82
66	62	45.210	59.104	-13.894	193.03
67	62	45.720	59.104	-13.384	179.12

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	$(SSC^* - SSC)^2$
68	62	49.800	59.104	-9.304	86.56
69	62	56.290	59.104	-2.814	7.92
70	62	71.240	59.104	12.136	147.29
71	62	77.540	59.104	18.436	339.90
72	62	87.070	59.104	27.966	782.11
73	62	98.390	59.104	39.286	1543.41
74	77	75.440	88.259	-12.819	164.32
75	77	96.270	88.259	8.011	64.18
76	78	83.730	90.392	-6.662	44.38
77	81	91.620	96.931	-5.311	28.20
78	82	87.450	99.157	-11.707	137.05
79	82	172.000	99.157	72.843	5306.12
80	83	122.800	101.406	21.394	457.69
81	84	127.500	103.679	23.821	567.44
82	85	104.000	105.975	-1.975	3.90
83	85	166.100	105.975	60.125	3615.06
84	86	89.310	108.293	-18.983	360.37
85	86	105.500	108.293	-2.793	7.80
86	86	108.800	108.293	0.507	0.26
87	87	110.800	110.635	0.165	0.03
88	88	94.780	113.000	-18.220	331.98
89	91	106.700	120.233	-13.533	183.13
90	91	118.000	120.233	-2.233	4.98
91	92	117.500	122.689	-5.189	26.93
92	96	123.600	132.743	-9.143	83.60
93	97	157.800	135.314	22.486	505.64
94	99	63.590	140.522	-76.932	5918.53
95	99	145.100	140.522	4.578	20.96

REGRESSION SPREADSHEET, 101 – 700NTU TURBIDITY RANGE, HY 1999

Optimization					
Model	*SSC* = m[TURB] + b*				
m	3.03		R^2 =	0.9589	
b	-178.52				
Objective	439845.54				

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	(SSC* - SSC)^2
96	101	154.600	127.803	26.797	718.07
97	101	168.900	127.803	41.097	1688.94
98	101	180.600	127.803	52.797	2787.50
99	102	118.600	130.836	-12.236	149.72
100	102	127.800	130.836	-3.036	9.22
101	103	123.800	133.869	-10.069	101.39
102	103	184.400	133.869	50.531	2553.37
103	103	190.900	133.869	57.031	3252.53
104	106	194.800	142.968	51.832	2686.57
105	122	140.300	191.495	-51.195	2620.89
106	145	263.500	261.252	2.248	5.05
107	148	329.400	270.351	59.049	3486.83
108	150	210.400	276.416	-66.016	4358.17
109	152	338.400	282.482	55.918	3126.79
110	152	341.100	282.482	58.618	3436.03
111	153	310.800	285.515	25.285	639.32
112	167	242.100	327.976	-85.876	7374.71
113	174	227.500	349.207	-121.707	14812.50
114	178	396.300	361.338	34.962	1222.32
115	195	329.000	412.898	-83.898	7038.87
116	204	435.100	440.194	-5.094	25.95
117	208	349.100	452.326	-103.226	10655.61
118	208	527.600	452.326	75.274	5666.18
119	210	375.600	458.392	-82.792	6854.49
120	210	508.800	458.392	50.408	2540.98
121	215	545.200	473.556	71.644	5132.80
122	216	493.300	476.589	16.711	279.24
123	218	522.400	482.655	39.745	1579.65
124	220	524.500	488.721	35.779	1280.13
125	240	497.600	549.380	-51.780	2681.12

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	$(SSC^* - SSC)^2$
126	253	431.000	588.808	-157.808	24903.22
127	271	510.700	643.400	-132.700	17609.33
128	272	630.500	646.433	-15.933	253.86
129	277	736.400	661.598	74.802	5595.39
130	282	669.000	676.762	-7.762	60.25
131	282	720.100	676.762	43.338	1878.16
132	306	952.100	749.552	202.548	41025.51
133	312	673.600	767.750	-94.150	8864.22
134	326	971.400	810.211	161.189	25981.93
135	338	604.200	846.606	-242.406	58760.66
136	375	949.700	958.824	-9.124	83.25
137	393	931.500	1013.417	-81.917	6710.35
138	442	953.000	1162.030	-209.030	43693.53
139	475	1242.000	1262.116	-20.116	404.67
140	485	1561.000	1292.446	268.554	72121.44
141	504	1368.000	1350.071	17.929	321.44
142	521	1389.000	1401.631	-12.631	159.54
143	531	1391.000	1431.960	-40.960	1677.73
144	558	1567.000	1513.849	53.151	2825.03
145	599	1788.000	1638.199	149.801	22440.38
146	671	1781.000	1856.569	-75.569	5710.72

REGRESSION SPREADSHEET, 1 – 100NTU TURBIDITY RANGE, HY 2000

Optimization					
Model	$SSC^* = b[TURB]^m$				
b	0.0229				
m	1.948				
Objective	62296.04				

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	$(SSC^* - SSC)^2$
1	3	0.399	0.195	0.204	0.04
2	12	13.650	2.898	10.752	115.61
3	13	7.554	3.387	4.167	17.37
4	13	15.870	3.387	12.483	155.84
5	15	1.541	4.475	-2.934	8.61
6	15	2.453	4.475	-2.022	4.09
7	15	2.474	4.475	-2.001	4.01
8	15	10.420	4.475	5.945	35.34
9	16	2.198	5.075	-2.877	8.28
10	16	2.220	5.075	-2.855	8.15
11	16	4.880	5.075	-0.195	0.04
12	16	6.919	5.075	1.844	3.40
13	16	7.880	5.075	2.805	7.87
14	17	3.423	5.711	-2.288	5.24
15	18	1.956	6.384	-4.428	19.61
16	18	2.580	6.384	-3.804	14.47
17	19	1.584	7.093	-5.509	30.35
18	20	2.735	7.838	-5.103	26.05
19	20	2.762	7.838	-5.076	25.77
20	20	2.770	7.838	-5.068	25.69
21	20	4.868	7.838	-2.970	8.82
22	20	4.873	7.838	-2.965	8.79
23	20	4.890	7.838	-2.948	8.69
24	20	6.643	7.838	-1.195	1.43
25	20	17.580	7.838	9.742	94.90
26	21	6.388	8.620	-2.232	4.98
27	21	7.072	8.620	-1.548	2.40
28	21	7.916	8.620	-0.704	0.50
29	21	9.346	8.620	0.726	0.53
30	21	12.460	8.620	3.840	14.74

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	(SSC* - SSC)^2
31	21	15.510	8.620	6.890	47.47
32	21	17.410	8.620	8.790	77.26
33	21	17.910	8.620	9.290	86.30
34	22	4.068	9.438	-5.370	28.83
35	22	5.650	9.438	-3.788	14.35
36	22	6.354	9.438	-3.084	9.51
37	22	8.878	9.438	-0.560	0.31
38	22	17.350	9.438	7.912	62.60
39	23	4.342	10.292	-5.950	35.40
40	23	5.382	10.292	-4.910	24.10
41	23	10.580	10.292	0.288	0.08
42	23	12.790	10.292	2.498	6.24
43	23	12.890	10.292	2.598	6.75
44	23	14.540	10.292	4.248	18.05
45	23	15.670	10.292	5.378	28.93
46	24	3.376	11.181	-7.805	60.92
47	24	7.014	11.181	-4.167	17.37
48	24	23.350	11.181	12.169	148.08
49	26	3.676	13.068	-9.392	88.21
50	26	7.350	13.068	-5.718	32.70
51	26	8.006	13.068	-5.062	25.62
52	26	10.640	13.068	-2.428	5.89
53	26	10.740	13.068	-2.328	5.42
54	26	13.720	13.068	0.652	0.43
55	26	16.440	13.068	3.372	11.37
56	27	3.192	14.065	-10.873	118.22
57	27	3.244	14.065	-10.821	117.09
58	27	4.401	14.065	-9.664	93.39
59	27	10.670	14.065	-3.395	11.53
60	28	5.466	15.098	-9.632	92.77
61	28	9.404	15.098	-5.694	32.42
62	28	30.410	15.098	15.312	234.47
63	29	11.550	16.166	-4.616	21.31
64	29	11.900	16.166	-4.266	18.20
65	29	27.280	16.166	11.114	123.53
66	30	4.890	17.269	-12.379	153.25
67	30	6.294	17.269	-10.975	120.46
68	30	7.404	17.269	-9.865	97.33

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	$(SSC^* - SSC)^2$
69	30	7.658	17.269	-9.611	92.38
70	30	12.320	17.269	-4.949	24.50
71	30	12.740	17.269	-4.529	20.52
72	30	13.600	17.269	-3.669	13.47
73	30	13.950	17.269	-3.319	11.02
74	30	15.280	17.269	-1.989	3.96
75	30	16.410	17.269	-0.859	0.74
76	30	16.840	17.269	-0.429	0.18
77	30	17.360	17.269	0.091	0.01
78	30	18.000	17.269	0.731	0.53
79	30	19.070	17.269	1.801	3.24
80	30	19.750	17.269	2.481	6.15
81	30	20.910	17.269	3.641	13.25
82	30	23.050	17.269	5.781	33.41
83	30	24.560	17.269	7.291	53.15
84	35	27.920	23.318	4.602	21.17
85	37	16.930	25.985	-9.055	81.98
86	37	23.130	25.985	-2.855	8.15
87	39	46.950	28.791	18.159	329.75
88	44	13.580	36.418	-22.838	521.56
89	44	31.980	36.418	-4.438	19.69
90	45	12.980	38.048	-25.068	628.38
91	46	37.830	39.712	-1.882	3.54
92	51	43.290	48.554	-5.264	27.71
93	51	46.680	48.554	-1.874	3.51
94	52	50.230	50.426	-0.196	0.04
95	54	172.600	54.273	118.327	14001.36
96	55	51.540	56.248	-4.708	22.16
97	56	54.780	58.257	-3.477	12.09
98	57	71.630	60.301	11.329	128.34
99	58	67.430	62.379	5.051	25.51
100	58	68.280	62.379	5.901	34.82
101	59	60.680	64.491	-3.811	14.53
102	60	15.110	66.638	-51.528	2655.14
103	60	58.000	66.638	-8.638	74.62
104	60	62.030	66.638	-4.608	21.23
105	60	78.220	66.638	11.582	134.14
106	60	86.150	66.638	19.512	380.72

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	$(SSC^* - SSC)^2$
107	60	96.980	66.638	30.342	920.64
108	61	34.020	68.819	-34.799	1210.95
109	61	34.940	68.819	-33.879	1147.77
110	61	48.640	68.819	-20.179	407.18
111	61	71.290	68.819	2.471	6.11
112	61	81.370	68.819	12.551	157.53
113	61	97.660	68.819	28.841	831.82
114	62	45.130	71.034	-25.904	671.00
115	62	58.160	71.034	-12.874	165.73
116	62	67.740	71.034	-3.294	10.85
117	62	97.470	71.034	26.436	698.88
118	70	82.030	89.979	-7.949	63.19
119	76	129.600	105.614	23.986	575.34
120	77	80.960	108.338	-27.378	749.55
121	77	87.050	108.338	-21.288	453.18
122	78	108.500	111.096	-2.596	6.74
123	81	133.700	119.572	14.128	199.61
124	82	118.700	122.464	-3.764	14.17
125	82	119.200	122.464	-3.264	10.66
126	82	176.400	122.464	53.936	2909.07
127	83	91.970	125.391	-33.421	1116.93
128	84	167.800	128.350	39.450	1556.27
129	86	114.300	134.371	-20.071	402.84
130	86	217.700	134.371	83.329	6943.73
131	88	87.040	140.526	-53.486	2860.72
132	88	120.200	140.526	-20.326	413.14
133	88	146.500	140.526	5.974	35.69
134	93	115.500	156.499	-40.999	1680.91
135	94	150.400	159.794	-9.394	88.24
136	94	151.600	159.794	-8.194	67.14
137	94	189.800	159.794	30.006	900.37
138	95	177.600	163.122	14.478	209.61
139	95	244.000	163.122	80.878	6541.21
140	97	198.900	169.879	29.021	842.21
141	98	163.800	173.308	-9.508	90.39
142	99	128.400	176.769	-48.369	2339.60
143	100	127.300	180.265	-52.965	2805.24
144	100	185.500	180.265	5.235	27.41

REGRESSION SPREADSHEET, 101 – 700NTU TURBIDITY RANGE, HY 2000

Optimization					
Model	*SSC* = m[TURB] + b*				
m	3.35		R^2 =	0.9271	
b	-195.57				
Objective	1214359.52				

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	(SSC* - SSC)^2
145	101	190.400	142.605	47.795	2284.35
146	101	236.100	142.605	93.495	8741.30
147	102	132.800	145.953	-13.153	173.01
148	103	110.200	149.302	-39.102	1528.94
149	103	135.500	149.302	-13.802	190.48
150	105	148.700	155.998	-7.298	53.26
151	117	179.400	196.177	-16.777	281.47
152	125	212.500	222.963	-10.463	109.48
153	126	219.300	226.311	-7.011	49.16
154	131	245.900	243.053	2.847	8.11
155	142	276.500	279.883	-3.383	11.45
156	149	387.200	303.321	83.879	7035.65
157	150	262.900	306.669	-43.769	1915.77
158	150	311.000	306.669	4.331	18.75
159	155	255.600	323.411	-67.811	4598.29
160	167	497.500	363.590	133.910	17931.96
161	178	341.300	400.421	-59.121	3495.24
162	179	444.900	403.769	41.131	1691.78
163	188	399.100	433.903	-34.803	1211.25
164	198	560.200	467.386	92.814	8614.52
165	206	533.600	494.172	39.428	1554.60
166	211	548.200	510.913	37.287	1390.33
167	214	567.100	520.958	46.142	2129.12
168	215	425.500	524.306	-98.806	9762.60
169	217	592.200	531.002	61.198	3745.15
170	224	444.100	554.440	-110.340	12174.94
171	224	594.500	554.440	40.060	1604.79
172	227	735.700	564.485	171.215	29314.61
173	240	518.000	608.012	-90.012	8102.19
174	257	795.400	664.932	130.468	17021.78

Sample	turbidity	SSC	SSC*	(SSC* - SSC)	$(SSC^* - SSC)^2$
175	282	696.500	748.639	-52.139	2718.45
176	286	605.800	762.032	-156.232	24408.37
177	287	681.600	765.380	-83.780	7019.09
178	290	729.500	775.425	-45.925	2109.09
179	298	810.100	802.211	7.889	62.24
180	342	1007.000	949.534	57.466	3302.35
181	343	1108.000	952.882	155.118	24061.54
182	349	930.100	972.972	-42.872	1837.98
183	357	988.100	999.758	-11.658	135.90
184	364	823.100	1023.195	-200.095	40038.19
185	364	1127.000	1023.195	103.805	10775.38
186	414	816.100	1190.608	-374.508	140256.30
187	417	1491.000	1200.653	290.347	84301.48
188	443	1422.000	1287.707	134.293	18034.50
189	445	1132.000	1294.404	-162.404	26375.03
190	473	1232.000	1388.155	-156.155	24384.37
191	492	1296.000	1451.772	-155.772	24264.84
192	494	1626.000	1458.468	167.532	28066.88
193	500	850.300	1478.558	-628.258	394707.83
194	508	1669.000	1505.344	163.656	26783.35
195	527	1512.000	1568.961	-56.961	3244.51
196	535	1620.000	1595.747	24.253	588.23
197	565	2056.000	1696.194	359.806	129460.23
198	593	1797.000	1789.945	7.055	49.77
199	596	2024.000	1799.990	224.010	50180.48
200	696	2156.000	2134.815	21.185	448.79

APPENDIX B

FORTRAN PROCESSING ROUTINE

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program thold

!________________________________________________________________
!Ben Bray Senior Design Project
!Fall 2000
!
!= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
! Program Description
! ------- -----------
! This program is used to determine time intervals over which a
!  user specified suspended sediment threshold is exceeded.  This
!  program was designed specifically to take advantage of data
!  taken at Freshwater Creek, during smapling periods of 15 min.
!  Input files must be comma delimited format where:
!
!            date,time,hour,turbidity,estimated sus. sed. conc.
!            mm/dd/yyyy,hh:mm,tttt,sssss.sss
!  Where:
!   m    -        month
!   d    -        day
!   y    -        year
!   h    -        hour
!   m    -        minute
!   t    -        turbidity
!   s  -   suspended sediment concentration
!
!         Ouput is a table listing start date/time and end date/time
!   days and hours the threshold was exceeded in tab delimited
!   format.
!
!= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
!  Variables
!  ---------
!   in_file        -        Character variable for input file name
!   out_file       -        Character variable for output file name
!   response       -        Character variable used to store user response
!                           to querry
!   eps            -         Double precision varaible, parameter set to
!                           0.0009 used to test for threshold conidition
!   sc             -        Double precision variable storing the threshold
!                           suspended sediment concentration (mg/L) input
!                           by user.
!   ssc            -        Double precision variable storing the current
```

```
!                           suspended sediment concentration being
!                          processed
!   hours         -        Double precision varaible to store hours
!                          threshold sc was exceeded
!   days          -        Double precision varaible to tore the number
!                          of days the threshold sc was exceeded
!   ttime         -        Integer array used to store current time where:
!         ttime(1):        month
!         ttime(2):        day
!         ttime(3):        year
!         ttime(4):        hour
!         ttime(5):        seconds
!   stime         -        Integer array used to store start time of
!                          current threshold interval where:
!         stime(1):        month
!         stime(2):        day
!         stime(3):        year
!         stime(4):        hour
!         stime(5):        seconds
!   tlast         -        Integer array used to store start time of
!                          current threshold interval where:
!         tlast(1):        month
!         tlast(2):        day
!         tlast(3):        year
!         tlast(4):        hour
!         tlast(5):        seconds
!   i             -        Integer do loop control variable
!   tally         -        Integer variable used to tally the number of intervals
!                          the threshold sc is exceeded
!   istat_1       -        Integer variable used to detect end of file during read
!   flag          -        Logical variable to signal decision based on user
!                          response to querry
!   t_up          -        Logical variable used to signal that threshold is not
!                          exceeded
!   t_in          -        Logical variable used to signal that threshold has been
!                          exceeded
!
!++++ AUTHOR: BEN S. BRAY ========= 12/22/2000 -------------------------- HSUERE
!---------------------------------------------------------------------------

implicit none
character (len=20)::in_file,out_file
character (len=1)::response
double precision, parameter::eps=0.0009
double precision::sc,ssc
double precision::hours,days
```

```
integer, dimension(5)::ttime,stime,tlast
integer::i,tally,istat_1
logical::flag,t_up,t_in

!=====================================================================
!== PROGRAM INTRODUCTION ==============================================
!=====================================================================

write(*,'(A)')"WELCOME to the SEV threshold program..."

do
 write(*,*)
 write(*,'(A)')"To run this program you must have a standard .csv file"
 write(*,'(A)')"  from MS EXCEL.  The input to this program is a "
 write(*,'(A)')"  threshold suspended sediment value.  The output of this"
 write(*,'(A)')"  program is the start and end dates when the suspended "
 write(*,'(A)')"  sediment threshold was exceeded along with the length "
 write(*,'(A)')"  of time in days and hours the threshold was exceeded. "
 write(*,'(A)')"  Output format is written in tab-delimited columns."

 write(*,'(A)',advance="no")"Do you want to continue with processing? (Y or N):"
 read(*,'(A1)')response
 do
  if(response == "Y" .or. response == "y" .or. response == "n" &
     .or. response == "N") exit
  write(*,'(A)')"Invalid respnse! Enter Y or N"
 end do

 if (response == "N" .or. response == "n") exit

!=====================================================================
!== INPUT & OUTPUT INFORMATION ========================================
!=====================================================================

 ! Prompt user for input file name
 write(*,'(A)',advance="no")"Please enter the input file name:"
 read(*,*)in_file

 ! Prompt user for turbidity threshold
 write(*,*)
 write(*,'(A)',advance="no")"ENTER SSC threshold value:"
 read(*,*)sc

 ! Alert user about output file name
 out_file="thresh.txt"
 i = 1
```

```
flag = .false.
i=index(out_file, " ") - 1
do
 if (out_file(i:i) == " ") then
  flag = .true.
 end if
 if(flag) exit
 i = i+1
end do
i = i-1

write(*,*)
write(*,'(A,A)')"Output file will be named: ",out_file(1:i)
write(*,'(A)')"Any file with this name will be over-written!"
do
 write(*,'(A)',advance="no")"Do you want to rename output file? (Y or N):"
 read(*,'(A1)')response
 if(response == "Y" .or. response == "y") then
  write(*,'(A)',advance="no")"Enter output file name: "
  read(*,'(A20)')out_file
  exit
 else if (response == "N" .or. response == "n")then
  exit
 else
  write(*,'(A)')"Invalid respnse! Enter Y or N"
 end if
end do


!===============================================================
!== PROCESSING =================================================
!===============================================================

! Begin processing by opening input and output files
do
 open(22,file=in_file,iostat=istat_1)
 if (istat_1 == 0) exit
 write(*,*)
 write(*,*)
 write(*,'(A)')"*************************"
 write(*,'(A)')"Cannot open input file!"
 write(*,'(A)')"*************************"
 write(*,'(A)')
 write(*,'(A)')"Make sure the .csv file is in the same directory as "
 write(*,'(A)')"this exectutable before restarting this program."
 stop
```

```
end do
open(32,file=out_file)

! Write header information to output file
write(32,'(A10,7x,A8,10x,A11)')"START date","END date","CONSECUTIVE"
write(32,'(35x,A4,4x,A5)')"days","hours"

! Skip the first line of the .csv file containing header information
read(22,*)

! Initialize logical variables before entering processing loop
t_up = .true.
t_in = .false.
ttime = 0

do

 ! Set  tlast to ttime before reading in the next input line
 tlast = ttime

 ! Read the data line until the end of the file is reached
 read(22,'(2(I2,1x),I4,2(1x,I2),T23,F8.3)',iostat=istat_1) &
         ttime(1),ttime(2),ttime(3),ttime(4),ttime(5),ssc

 ! Check for turbidity threshold exceedence
 if((ssc-sc) > eps .and. t_up) then

  ! Set flags, initialize the tally and set the start time
  t_up = .false.
  t_in = .true.
  tally = 0
  stime = ttime

 ! Else if threshold has already been exceeded...
 else if (t_in) then

  ! Check to see if turbidity has dropped below threshold level
  if ((ssc-sc) < eps) then

   ! Calculate hours and days based on 15-min interval tally
         hours=dble(tally)/4.0d0
   days=hours/24

   ! If
   if (tally > 1) then
    ! Write output to out_file
```

```
          write(32,'(2(2(I2.2,A1),I4.4,2(A1,I2.2),1x),F5.2,1x,F8.2)')stime(1),"/", &
           stime(2),"/",stime(3)," ",stime(4),":",stime(5),tlast(1),"/", &
           tlast(2),"/",tlast(3)," ",tlast(4),":",tlast(5),days,hours
   end if

         ! Reset processing varriables
         tally = 0
         days = 0.0d0
         hours = 0.0d0
         t_up = .true.
         t_in = .false.

  ! Otherwise we are still in a threshold interval; increment tally
  else
   tally = tally+1
  end if
 end if

 ! If the end of the .csv file has been reached exit processing loop
 if (istat_1 < 0) exit

end do

! Close output file
close(32)

! Prompt user for another run
do
 write(*,*)
 write(*,*)
 write(*,'(A)',advance="no")"Do you want to do another SSC ", &
                   "threshold? (Y or N):"
 read(*,'(A1)')response
 if(response == "Y" .or. response == "y" .or. response == "n" &
    .or. response == "N") exit
 write(*,'(A)')"Invalid respnse! Enter Y or N"
end do

! Close input file
close(22)

! Prompt user for another processing run
if (response == "N" .or. response == "n") exit

end do
```

```
!=========================================================
!== TERMINATION MESSAGE =====================================
!=========================================================

! Write termination message
write(*,*)
write(*,*)
write(*,'(A)')"~~~~~~~~~~~~~~~~~~~~~~~~~~~~"
write(*,'(A)')"~~  PROGRAM TERMINATED  ~~"
write(*,'(A)')"~~  ------- ----------  ~~"
write(*,'(A)')"~~~~~~~~~~~~~~~~~~~~~~~~~~~~"

stop
end program thold
```

Sample Input File (first 10 lines, HY 1999)

```
date,time,turb,estssc
01/13/1999,18:00,0004,0000.370
01/13/1999,18:15,0003,0000.218
01/13/1999,18:30,0004,0000.370
01/13/1999,18:45,0004,0000.370
01/13/1999,19:00,0005,0000.560
01/13/1999,19:15,0003,0000.218
01/13/1999,19:30,0004,0000.370
01/13/1999,19:45,0005,0000.560
01/13/1999,20:00,0004,0000.370
```

Sample Output File (SSC threshold of 300 mg/L, HY 1999)

```
START date       END date         CONSECUTIVE
                                  days   hours
01/17/1999 18:15 01/18/1999 03:15 0.38    9.00
01/22/1999 17:00 01/23/1999 01:15 0.34    8.25
02/06/1999 08:45 02/06/1999 21:00 0.51   12.25
02/07/1999 05:15 02/07/1999 13:30 0.34    8.25
02/09/1999 02:00 02/09/1999 06:15 0.18    4.25
03/24/1999 09:15 03/25/1999 01:15 0.67   16.00
03/25/1999 01:45 03/25/1999 02:15 0.02    0.50
04/05/1999 20:45 04/05/1999 21:30 0.03    0.75
05/03/1999 07:30 05/03/1999 10:15 0.11    2.75
```

APPENDIX C

Dates of Exceedence, 50 mg/L Threshold, HY 1999

START	date	END	date	CONSECUTIVE	
				days	hours
1/15/1999	0:30	1/15/1999	2:15	0.07	1.75
1/15/1999	3:00	1/15/1999	18:00	0.63	15.0
1/15/1999	22:30	1/16/1999	12:00	0.56	13.5
1/17/1999	17:15	1/18/1999	23:30	1.26	30.25
1/19/1999	9:00	1/19/1999	21:45	0.53	12.75
1/20/1999	22:15	1/21/1999	3:30	0.22	5.25
1/22/1999	14:30	1/24/1999	4:00	1.56	37.5
2/06/1999	8:15	2/08/1999	11:00	2.11	50.75
2/08/1999	13:45	2/08/1999	14:45	0.04	1.0
2/08/1999	15:15	2/08/1999	15:45	0.02	0.5
2/08/1999	17:15	2/10/1999	4:15	1.46	35.0
2/13/1999	20:00	2/14/1999	3:30	0.31	7.5
2/16/1999	21:30	2/16/1999	22:15	0.03	0.75
2/16/1999	23:00	2/17/1999	7:00	0.33	8.0
2/18/1999	9:45	2/18/1999	23:15	0.56	13.5
2/23/1999	4:45	2/23/1999	16:00	0.47	11.25
2/24/1999	18:00	2/26/1999	0:00	1.25	30.0
2/28/1999	9:15	3/01/1999	1:15	0.67	16.0
3/02/1999	22:30	3/03/1999	1:45	0.14	3.25
3/09/1999	1:15	3/09/1999	8:00	0.28	6.75
3/09/1999	14:30	3/09/1999	21:00	0.27	6.5
3/14/1999	4:00	3/14/1999	22:30	0.77	18.5
3/24/1999	4:30	3/25/1999	19:30	1.63	39.0
3/30/1999	14:15	3/31/1999	22:30	1.34	32.25
4/05/1999	19:30	4/06/1999	2:15	0.28	6.75
4/08/1999	2:15	4/08/1999	2:45	0.02	0.5
5/03/1999	5:15	5/04/1999	0:30	0.80	19.25

Dates of Exceedence, 80 mg/L Threshold, HY 1999

START date		END date		CONSECUTIVE	
				days	hours
1/15/1999	4:00	1/15/1999	9:30	0.23	5.5
1/16/1999	1:15	1/16/1999	7:30	0.26	6.25
1/17/1999	17:15	1/18/1999	14:00	0.86	20.75
1/19/1999	9:15	1/19/1999	16:30	0.3	7.25
1/20/1999	23:15	1/21/1999	0:45	0.06	1.5
1/22/1999	15:00	1/23/1999	21:15	1.26	30.25
2/06/1999	8:30	2/08/1999	2:30	1.75	42.0
2/08/1999	22:30	2/09/1999	19:45	0.89	21.25
2/17/1999	0:00	2/17/1999	4:00	0.17	4.0
2/18/1999	11:30	2/18/1999	18:15	0.28	6.75
2/23/1999	5:30	2/23/1999	13:15	0.32	7.75
2/24/1999	18:45	2/25/1999	17:30	0.95	22.75
2/28/1999	10:15	2/28/1999	12:45	0.1	2.5
2/28/1999	18:00	2/28/1999	22:00	0.17	4.0
3/14/1999	5:00	3/14/1999	17:15	0.51	12.25
3/24/1999	5:00	3/25/1999	12:30	1.31	31.5
3/30/1999	14:30	3/31/1999	14:30	1.0	24.0
3/31/1999	16:00	3/31/1999	17:00	0.04	1.0
4/05/1999	19:45	4/06/1999	0:30	0.2	4.75
5/03/1999	5:30	5/03/1999	17:00	0.48	11.5

DATES OF EXCEEDENCE, 140 MG/L THRESHOLD, HY 1999

START	date	END	date	CONSECUTIVE	
				days	hours
1/16/1999	3:00	1/16/1999	4:30	0.06	1.5
1/17/1999	17:45	1/18/1999	9:15	0.65	15.5
1/22/1999	15:45	1/23/1999	7:15	0.65	15.5
1/23/1999	10:30	1/23/1999	12:15	0.07	1.75
2/06/1999	8:45	2/07/1999	18:45	1.42	34.0
2/09/1999	0:15	2/09/1999	10:00	0.41	9.75
2/18/1999	13:30	2/18/1999	15:15	0.07	1.75
2/23/1999	8:15	2/23/1999	10:30	0.09	2.25
2/24/1999	20:00	2/25/1999	2:45	0.28	6.75
2/25/1999	8:30	2/25/1999	9:00	0.02	0.5
2/25/1999	9:30	2/25/1999	12:30	0.13	3.0
2/28/1999	19:00	2/28/1999	19:45	0.03	0.75
3/14/1999	8:45	3/14/1999	12:00	0.14	3.25
3/24/1999	6:30	3/25/1999	6:45	1.01	24.25
3/30/1999	17:30	3/30/1999	18:30	0.04	1.0
4/05/1999	20:30	4/05/1999	22:45	0.09	2.25
5/03/1999	6:45	5/03/1999	12:30	0.24	5.75

DATES OF EXCEEDENCE, 300 MG/L THRESHOLD, HY 1999

START	date	END	date	CONSECUTIVE	
				days	hours
1/17/1999	18:15	1/18/1999	3:15	0.38	9.0
1/22/1999	17:00	1/23/1999	1:15	0.34	8.25
2/06/1999	8:45	2/06/1999	21:00	0.51	12.25
2/07/1999	5:15	2/07/1999	13:30	0.34	8.25
2/09/1999	2:00	2/09/1999	6:15	0.18	4.25
3/24/1999	9:15	3/25/1999	1:15	0.67	16.0
3/25/1999	1:45	3/25/1999	2:15	0.02	0.5
4/05/1999	20:45	4/05/1999	21:30	0.03	0.75
5/03/1999	7:30	5/03/1999	10:15	0.11	2.75

DATES OF EXCEEDENCE, 1,200 MG/L THRESHOLD, HY 1999

START	date	END	date	CONSECUTIVE	
				days	hours

1/17/1999	19:45	1/17/1999	21:45	0.08	2.0
2/6/1999	11:15	2/6/1999	14:15	0.13	3.0

Dates of Exceedence, 50 mg/L Threshold, HY 2000

START date		END date		CONSECUTIVE	
				days	hours
11/16/1999	14:00	11/17/1999	0:15	0.43	10.25
11/29/1999	16:15	11/30/1999	10:45	0.77	18.5
11/30/1999	13:45	12/1/1999	4:45	0.63	15
12/2/1999	12:30	12/2/1999	13:45	0.05	1.25
12/9/1999	3:15	12/9/1999	22:30	0.8	19.25
12/12/1999	21:30	12/13/1999	7:30	0.42	10
1/10/2000	21:30	1/12/2000	17:45	1.84	44.25
1/12/2000	21:30	1/12/2000	22:00	0.02	0.5
1/14/2000	0:45	1/17/2000	1:00	3.01	72.25
1/19/2000	15:15	1/20/2000	7:00	0.66	15.75
1/30/2000	13:45	1/31/2000	2:30	0.53	12.75
2/12/2000	6:30	2/12/2000	7:15	0.03	0.75
2/14/2000	0:15	2/15/2000	20:45	1.85	44.5
2/22/2000	14:15	2/23/2000	7:30	0.72	17.25
2/26/2000	18:45	2/26/2000	19:30	0.03	0.75
2/26/2000	20:45	2/28/2000	22:15	2.06	49.5
2/29/2000	1:30	2/29/2000	23:30	0.92	22
3/4/2000	17:45	3/5/2000	2:15	0.35	8.5
3/16/2000	5:00	3/16/2000	19:45	0.61	14.75
3/19/2000	1:00	3/19/2000	11:00	0.42	10
4/17/2000	4:00	4/18/2000	17:30	1.56	37.5
5/10/2000	1:30	5/10/2000	2:00	0.02	0.5
5/10/2000	3:30	5/11/2000	6:00	1.1	26.5

Dates of Exceedence, 80 mg/L Threshold, HY 2000

START	date	END	date	CONSECUTIVE	
				days	hours
11/16/1999	14:00	11/16/1999	21:30	0.31	7.5
11/29/1999	16:15	11/30/1999	5:30	0.55	13.25
11/30/1999	14:30	12/1/1999	1:00	0.44	10.5
12/9/1999	3:30	12/9/1999	10:15	0.28	6.75
12/9/1999	11:00	12/9/1999	18:30	0.31	7.5
12/12/1999	22:15	12/13/1999	5:00	0.28	6.75
1/10/2000	21:45	1/12/2000	12:30	1.61	38.75
1/14/2000	1:00	1/15/2000	16:15	1.64	39.25
1/15/2000	23:45	1/16/2000	16:15	0.69	16.5
1/16/2000	16:45	1/16/2000	18:15	0.06	1.5
1/19/2000	15:30	1/20/2000	2:45	0.47	11.25
2/14/2000	0:30	2/15/2000	12:00	1.48	35.5
2/22/2000	16:15	2/23/2000	2:45	0.44	10.5
2/26/2000	18:45	2/26/2000	19:15	0.02	0.5
2/26/2000	21:15	2/27/2000	5:15	0.33	8
2/27/2000	10:45	2/27/2000	13:00	0.09	2.25
2/27/2000	15:30	2/28/2000	16:15	1.03	24.75
2/29/2000	5:30	2/29/2000	17:00	0.48	11.5
3/4/2000	18:30	3/4/2000	23:00	0.19	4.5
3/16/2000	5:30	3/16/2000	6:30	0.04	1
3/16/2000	8:00	3/16/2000	15:00	0.29	7
4/17/2000	6:30	4/17/2000	13:45	0.3	7.25
4/17/2000	14:45	4/18/2000	5:30	0.61	14.75
5/10/2000	3:45	5/10/2000	16:45	0.54	13

DATES OF EXCEEDENCE, 140 MG/L THRESHOLD, HY 2000

START	date	END	date	CONSECUTIVE	
				days	hours
11/16/1999	14:15	11/16/1999	15:00	0.03	0.75
11/16/1999	15:45	11/16/1999	17:30	0.07	1.75
11/29/1999	18:45	11/30/1999	2:15	0.31	7.5
11/30/1999	15:30	11/30/1999	22:30	0.29	7
12/9/1999	4:15	12/9/1999	7:00	0.11	2.75
12/12/1999	22:45	12/13/1999	2:15	0.15	3.5
1/10/2000	22:15	1/12/2000	7:30	1.39	33.25
1/14/2000	1:45	1/15/2000	3:30	1.07	25.75
1/16/2000	0:45	1/16/2000	10:45	0.42	10
1/19/2000	16:15	1/19/2000	0:00	0.32	7.75
2/14/2000	1:15	2/15/2000	6:30	1.22	29.25
2/22/2000	17:00	2/22/2000	23:45	0.28	6.75
2/26/2000	22:00	2/27/2000	2:30	0.19	4.5
2/27/2000	16:30	2/28/2000	11:00	0.77	18.5
2/29/2000	10:15	2/29/2000	13:30	0.14	3.25
3/16/2000	11:00	3/16/2000	12:00	0.04	1
4/17/2000	16:45	4/18/2000	0:30	0.32	7.75
5/10/2000	6:00	5/10/2000	11:30	0.23	5.5

Dates of Exceedence, 300 mg/L Threshold, HY 2000

START	date	END	date	CONSECUTIVE	
				days	hours
11/29/1999	19:15	11/29/1999	23:00	0.16	3.75
11/30/1999	17:45	11/30/1999	18:30	0.03	0.75
1/10/2000	23:15	1/11/2000	18:30	0.8	19.25
1/14/2000	3:15	1/14/2000	20:45	0.73	17.5
1/16/2000	1:30	1/16/2000	6:15	0.2	4.75
1/19/2000	17:30	1/19/2000	19:15	0.07	1.75
2/14/2000	2:15	2/14/2000	23:30	0.89	21.25
2/27/2000	22:15	2/28/2000	5:15	0.29	7

Dates of Exceedence, 1,200 mg/L Threshold, HY 2000

START	date	END	date	CONSECUTIVE	
				days	hours
1/11/2000	0:30	1/11/2000	8:15	0.32	7.75
1/14/2000	7:15	1/14/2000	11:00	0.16	3.75
2/14/2000	12:00	2/14/2000	14:00	0.08	2

APPENDIX D

SEV SPREADSHEET CALCULATION, HY 1999

Start	End	SSC	Duration	Severity of Ill-Effect	
date time	date time	(mg/L)	(hr)	J	U
1/15/1999 0:30	1/15/1999 2:15	50	1.75	4.13	4.24
1/15/1999 3:00	1/15/1999 18:00	50	15.0	5.99	5.78
1/15/1999 22:30	1/16/1999 12:00	50	13.5	5.90	5.70
1/17/1999 17:15	1/18/1999 23:30	50	30.25	6.60	6.28
1/19/1999 9:00	1/19/1999 21:45	50	12.75	5.85	5.66
1/20/1999 22:15	1/21/1999 3:30	50	5.25	5.09	5.03
1/22/1999 14:30	1/24/1999 4:00	50	37.5	6.79	6.44
2/6/1999 8:15	2/8/1999 11:00	50	50.75	7.05	6.65
2/8/1999 13:45	2/8/1999 14:45	50	1.0	3.65	3.84
2/8/1999 15:15	2/8/1999 15:45	50	0.5	3.05	3.35
2/8/1999 17:15	2/10/1999 4:15	50	35.0	6.73	6.39
2/13/1999 20:00	2/14/1999 3:30	50	7.5	5.39	5.28
2/16/1999 21:30	2/16/1999 22:15	50	0.75	3.40	3.64
2/16/1999 23:00	2/17/1999 7:00	50	8.0	5.45	5.33
2/18/1999 9:45	2/18/1999 23:15	50	13.5	5.90	5.70
2/23/1999 4:45	2/23/1999 16:00	50	11.25	5.75	5.57
2/24/1999 18:00	2/26/1999 0:00	50	30.0	6.59	6.28
2/28/1999 9:15	3/1/1999 1:15	50	16.0	6.05	5.83
3/2/1999 22:30	3/3/1999 1:45	50	3.25	4.67	4.69
3/9/1999 1:15	3/9/1999 8:00	50	6.75	5.30	5.21
3/9/1999 14:30	3/9/1999 21:00	50	6.5	5.27	5.18
3/14/1999 4:00	3/14/1999 22:30	50	18.5	6.18	5.93
3/24/1999 4:30	3/25/1999 19:30	50	39.0	6.82	6.46
3/30/1999 14:15	3/31/1999 22:30	50	32.25	6.66	6.33
4/5/1999 19:30	4/6/1999 2:15	50	6.75	5.30	5.21
4/8/1999 2:15	4/8/1999 2:45	50	0.5	3.05	3.35
5/3/1999 5:15	5/4/1999 0:30	50	19.25	6.21	5.96
1/15/1999 4:00	1/15/1999 9:30	80	5.5	5.34	5.33
1/16/1999 1:15	1/16/1999 7:30	80	6.25	5.45	5.42
1/17/1999 17:15	1/18/1999 14:00	80	20.75	6.49	6.28
1/19/1999 9:15	1/19/1999 16:30	80	7.25	5.58	5.53
1/20/1999 23:15	1/21/1999 0:45	80	1.5	4.21	4.40
1/22/1999 15:00	1/23/1999 21:15	80	30.25	6.82	6.55
2/6/1999 8:30	2/8/1999 2:30	80	42.0	7.10	6.79
2/8/1999 22:30	2/9/1999 19:45	80	21.25	6.51	6.30

Start date time	End date time	SSC (mg/L)	Duration (hr)	Severity of Ill-Effect	
				J	U
2/17/1999 0:00	2/17/1999 4:00	80	4.0	5.06	5.10
2/18/1999 11:30	2/18/1999 18:15	80	6.75	5.52	5.48
2/23/1999 5:30	2/23/1999 13:15	80	7.75	5.64	5.58
2/24/1999 18:45	2/25/1999 17:30	80	22.75	6.57	6.35
2/28/1999 10:15	2/28/1999 12:45	80	2.5	4.66	4.77
2/28/1999 18:00	2/28/1999 22:00	80	4.0	5.06	5.10
3/14/1999 5:00	3/14/1999 17:15	80	12.25	6.03	5.90
3/24/1999 5:00	3/25/1999 12:30	80	31.5	6.85	6.58
3/30/1999 14:30	3/31/1999 14:30	80	24.0	6.62	6.39
3/31/1999 16:00	3/31/1999 17:00	80	1.0	3.86	4.11
4/5/1999 19:45	4/6/1999 0:30	80	4.75	5.21	5.23
5/3/1999 5:30	5/3/1999 17:00	80	11.5	5.98	5.86
1/16/1999 3:00	1/16/1999 4:30	140	1.5	4.47	4.72
1/17/1999 17:45	1/18/1999 9:15	140	15.5	6.49	6.39
1/22/1999 15:45	1/23/1999 7:15	140	15.5	6.49	6.39
1/23/1999 10:30	1/23/1999 12:15	140	1.75	4.60	4.83
2/6/1999 8:45	2/7/1999 18:45	140	34.0	7.17	6.95
2/9/1999 0:15	2/9/1999 10:00	140	9.75	6.09	6.06
2/18/1999 13:30	2/18/1999 15:15	140	1.75	4.60	4.83
2/23/1999 8:15	2/23/1999 10:30	140	2.25	4.82	5.01
2/24/1999 20:00	2/25/1999 2:45	140	6.75	5.77	5.80
2/25/1999 8:30	2/25/1999 9:00	140	0.5	3.52	3.94
2/25/1999 9:30	2/25/1999 12:30	140	3.0	5.07	5.22
2/28/1999 19:00	2/28/1999 19:45	140	0.75	3.87	4.23
3/14/1999 8:45	3/14/1999 12:00	140	3.25	5.14	5.27
3/24/1999 6:30	3/25/1999 6:45	140	24.25	6.88	6.71
3/30/1999 17:30	3/30/1999 18:30	140	1.0	4.12	4.43
4/5/1999 20:30	4/5/1999 22:45	140	2.25	4.82	5.01
5/3/1999 6:45	5/3/1999 12:30	140	5.75	5.63	5.68
1/17/1999 18:15	1/18/1999 3:15	300	9.0	6.37	6.44
1/22/1999 17:00	1/23/1999 1:15	300	8.25	6.29	6.38
2/6/1999 8:45	2/6/1999 21:00	300	12.25	6.64	6.66
2/7/1999 5:15	2/7/1999 13:30	300	8.25	6.29	6.38
2/9/1999 2:00	2/9/1999 6:15	300	4.25	5.72	5.90
3/24/1999 9:15	3/25/1999 1:15	300	16.0	6.87	6.85
3/25/1999 1:45	3/25/1999 2:15	300	0.5	3.87	4.37
4/5/1999 20:45	4/5/1999 21:30	300	0.75	4.22	4.66

Start	End	SSC	Duration	Severity of Ill-Effect	
date time	date time	(mg/L)	(hr)	J	U
5/3/1999 7:30	5/3/1999 10:15	300	2.75	5.34	5.59
1/17/1999 19:45	1/17/1999 21:45	1200	2.0	5.70	6.16
2/6/1999 11:15	2/6/1999 14:15	1200	3.0	6.05	6.45

SEV Spreadsheet Calculation, HY 2000

Start	End	SSC	Duration	Severity of Ill-Effect	
date time	date time	(mg/L)	(hr)	J	U
11/16/1999 14:00	11/17/1999 0:15	50	10.25	5.66	5.51
11/29/1999 16:15	11/30/1999 10:45	50	18.5	6.18	5.93
11/30/1999 13:45	12/1/1999 4:45	50	15.0	5.99	5.78
12/2/1999 12:30	12/2/1999 13:45	50	1.25	3.84	4.00
12/9/1999 3:15	12/9/1999 22:30	50	19.25	6.21	5.96
12/12/1999 21:30	12/13/1999 7:30	50	10.0	5.64	5.49
1/10/2000 21:30	1/12/2000 17:45	50	44.25	6.93	6.55
1/12/2000 21:30	1/12/2000 22:00	50	0.5	3.05	3.35
1/14/2000 0:45	1/17/2000 1:00	50	72.25	7.356	6.90
1/19/2000 15:15	1/20/2000 7:00	50	15.75	6.04	5.81
1/30/2000 13:45	1/31/2000 2:30	50	12.75	5.85	5.66
2/12/2000 6:30	2/12/2000 7:15	50	0.75	3.40	3.64
2/14/2000 0:15	2/15/2000 20:45	50	44.5	6.94	6.56
2/22/2000 14:15	2/23/2000 7:30	50	17.25	6.12	5.88
2/26/2000 18:45	2/26/2000 19:30	50	0.75	3.40	3.64
2/26/2000 20:45	2/28/2000 22:15	50	49.5	7.03	6.63
2/29/2000 1:30	2/29/2000 23:30	50	22.0	6.33	6.05
3/4/2000 17:45	3/5/2000 2:15	50	8.5	5.50	5.37
3/16/2000 5:00	3/16/2000 19:45	50	14.75	5.98	5.77
3/19/2000 1:00	3/19/2000 11:00	50	10.0	5.64	5.49
4/17/2000 4:00	4/18/2000 17:30	50	37.5	6.79	6.44
5/10/2000 1:30	5/10/2000 2:00	50	0.5	3.05	3.35
5/10/2000 3:30	5/11/2000 6:00	50	26.5	6.49	6.19
11/16/1999 14:00	11/16/1999 21:30	80	7.5	5.61	5.55
11/29/1999 16:15	11/30/1999 5:30	80	13.25	6.10	5.96
11/30/1999 14:30	12/1/1999 1:00	80	10.5	5.90	5.79
12/9/1999 3:30	12/9/1999 10:15	80	6.75	5.52	5.48
12/9/1999 11:00	12/9/1999 18:30	80	7.5	5.61	5.55
12/12/1999 22:15	12/13/1999 5:00	80	6.75	5.52	5.48
1/10/2000 21:45	1/12/2000 12:30	80	38.75	7.03	6.73
1/14/2000 1:00	1/15/2000 16:15	80	39.25	7.04	6.74
1/15/2000 23:45	1/16/2000 16:15	80	16.5	6.29	6.12
1/16/2000 16:45	1/16/2000 18:15	80	1.5	4.21	4.40
1/19/2000 15:30	1/20/2000 2:45	80	11.25	5.96	5.84
2/14/2000 0:30	2/15/2000 12:00	80	35.5	6.95	6.67
2/22/2000 16:15	2/23/2000 2:45	80	10.5	5.90	5.79

Start	End	SSC	Duration	Severity of Ill-Effect	
date time	date time	(mg/L)	(hr)	J	U
2/26/2000 18:45	2/26/2000 19:15	80	0.5	3.26	3.62
2/26/2000 21:15	2/27/2000 5:15	80	8.0	5.66	5.60
2/27/2000 10:45	2/27/2000 13:00	80	2.25	4.57	4.69
2/27/2000 15:30	2/28/2000 16:15	80	24.75	6.64	6.41
2/29/2000 5:30	2/29/2000 17:00	80	11.5	5.98	5.86
3/4/2000 18:30	3/4/2000 23:00	80	4.5	5.17	5.19
3/16/2000 5:30	3/16/2000 6:30	80	1.0	3.86	4.11
3/16/2000 8:00	3/16/2000 15:00	80	7.0	5.55	5.50
4/17/2000 6:30	4/17/2000 13:45	80	7.25	5.58	5.53
4/17/2000 14:45	4/18/2000 5:30	80	14.75	6.19	6.04
5/10/2000 3:45	5/10/2000 16:45	80	13.0	6.08	5.95
11/16/1999 14:15	11/16/1999 15:00	140	0.75	3.87	4.23
11/16/1999 15:45	11/16/1999 17:30	140	1.75	4.60	4.83
11/29/1999 18:45	11/30/1999 2:15	140	7.5	5.86	5.87
11/30/1999 15:30	11/30/1999 22:30	140	7.0	5.80	5.82
12/9/1999 4:15	12/9/1999 7:00	140	2.75	5.00	5.16
12/12/1999 22:45	12/13/1999 2:15	140	3.5	5.20	5.33
1/10/2000 22:15	1/12/2000 7:30	140	33.25	7.15	6.94
1/14/2000 1:45	1/15/2000 3:30	140	25.75	6.93	6.76
1/16/2000 0:45	1/16/2000 10:45	140	10.0	6.11	6.08
1/19/2000 16:15	1/19/2000 0:00	140	7.75	5.89	5.90
2/14/2000 1:15	2/15/2000 6:30	140	29.25	7.04	6.85
2/22/2000 17:00	2/22/2000 23:45	140	6.75	5.77	5.80
2/26/2000 22:00	2/27/2000 2:30	140	4.5	5.42	5.51
2/27/2000 16:30	2/28/2000 11:00	140	18.5	6.65	6.52
2/29/2000 10:15	2/29/2000 13:30	140	3.25	5.14	5.27
3/16/2000 11:00	3/16/2000 12:00	140	1.0	4.12	4.43
4/17/2000 16:45	4/18/2000 0:30	140	7.75	5.89	5.90
5/10/2000 6:00	5/10/2000 11:30	140	5.5	5.60	5.65
11/29/1999 19:15	11/29/1999 23:00	300	3.75	5.61	5.81
11/30/1999 17:45	11/30/1999 18:30	300	0.75	4.22	4.66
1/10/2000 23:15	1/11/2000 18:30	300	19.25	7.03	6.98
1/14/2000 3:15	1/14/2000 20:45	300	17.5	6.95	6.92
1/16/2000 1:30	1/16/2000 6:15	300	4.75	5.82	5.98
1/19/2000 17:30	1/19/2000 19:15	300	1.75	4.95	5.27
2/14/2000 2:15	2/14/2000 23:30	300	21.25	7.11	7.05
2/27/2000 22:15	2/28/2000 5:15	300	7.0	6.15	6.26

Start	End	SSC	Duration	Severity of Ill-Effect	
date time	date time	(mg/L)	(hr)	J	U
1/11/2000 0:30	1/11/2000 8:15	1200	7.75	6.87	7.13
1/14/2000 7:15	1/14/2000 11:00	1200	3.75	6.24	6.61
2/14/2000 12:00	2/14/2000 14:00	1200	2.0	5.70	6.16