Appendix 3-E
Description of Methods for Estimating Severity of Ill Effects to Juvenile Salmonids Resulting from Suspended Sediment Dose

Suspended sediment is the amount of particles suspended in the water column. It is measured in milligrams of suspended sediment per liter of water (mg/L) or in parts per million (ppm). High suspended sediment concentrations can negatively impact the cold water fishery by causing reduced feeding and growth rates, avoidance behavior, physiological stress, and death in salmonid species.

Over the past several years, methods and equipment for monitoring instream turbidity and suspended sediment concentrations and sediment load conditions have been refined to allow monitoring of remote locations, such as forested watersheds like Elk River. These methods involve the use of automated in-situ equipment for measuring stage and turbidity. A pump sampler is triggered to collect a water sample which is then analyzed in a laboratory for turbidity verification and suspended sediment concentration. Field staff make observations and measurements of stage, streamflow, and collect depth integrated samples over the streams depth and width for verification with the in-situ measurements. Through a series of data relationships the raw data is corrected and finalized to yield turbidity, stage, discharge, and suspended sediment concentration at time steps of ten (10) to fifteen (15) minutes.

Beginning in 2003, Palco, GDRCo, and Salmon Forever began monitoring for instream turbidity, suspended sediment concentration, and streamflow conditions. Figure 2.39 demonstrates the locations of the monitoring stations in Elk River. The Elk River monitoring station locations represent a range of drainage areas .
Data from these stations provide a measure of whether suspended sediment and turbidity levels in the Elk River watershed are supportive of salmonids, as discussed in the following sections. Specifically, staff evaluated the monitoring data collected in Elk River to evaluate the relative magnitude of ill effects on salmonids resulting from the measured suspended sediment and turbidity concentrations using a model developed by Newcomb and Jensen (1996). Note that data are not available for every station in every year of the analyses.

Severity of Ill Effects to Juvenile Salmonids

Newcombe and Jensen (1996) developed an empirical model which estimates the Severity of Ill Effects (SEV) Index, which represents the biological impacts to salmonids and other fish species, resulting from exposure to various suspended sediment concentrations and durations. This empirical model utilizes fisheries and suspended sediment research which correlate concentrations to an observed effect on the sampled population, such as salmonid avoidance of turbid waters, reduced feeding rates, reduced growth rates, or death. Newcombe and Jensen provide a

provides a very useful means of evaluating if exposure to the measured suspended sediment concentrations and durations have an adverse effect on salmonid beneficial uses in the Elk River watershed. It should be noted that the data sets used by the authors included a combination of turbidity and suspended sediment concentration all of which were all converted to suspended sediment concentration. Similarly, staff used the Elk River suspended sediment concentration data, also correlated to turbidity.

Table 1 presents the range of severity of ill-effects that fish experience upon exposure to excess suspended sediment, as indexed by Newcombe and Jensen .

Table 1. Severity Index describing severity of ill effects associated with excess suspended sediment, as presented in Table 1 of Newcombe and Jensen, 1996.

SEV	Description of Effect
	Nill Effect
0	No behavioral effects
	Behavioral Effects
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
	Sublethal Effects
4	Short-term reduction in feeding rates; Short-term reduction in feeding success
5	Minor physiological stress; Increase in rate of coughing; Increased respiration rate
6	Moderate physiological stress
7	Moderate habitat degradation
8	Indications of major physiological stress; Long-term reduction in feeding rate; Long-term reduction in feeding success; Poor condition
	Lethal and Paralethal Effects
9	Reduced growth rate; Delayed hatching; Reduced fish density
10	0-20% mortality; Increased predation; Moderate to severe habitat degradation
11	>20-40% mortality
12	>40-60% mortality
13	>60-80% mortality
14	>80-100% mortality

Newcomb and Jensen's meta-analysis used eighty (80) studies documenting the effects of suspended sediment on fish; the data associated with these studies were pooled to allow for an expanded database which the authors provide as Appendix Table A-1 in their report. The data were then grouped into six groups based upon four criteria: 1) taxonomy (salmonids and non-salmonids), 2) life stage (eggs, larvae, juveniles, and adults), 3) life history (estuarine versus freshwater and anadromous

species), and 3) particle size of sediment (fine (<75 micrometers (μm)) and course (75-250 μm). Each of the six groups of data were then evaluated by regressing the severity of ill-effects on suspended sediment dose (concentration and duration). The resulting predictive models take the form:

$$SEV = a + b \cdot \ln(Duration(hr)) + c \cdot \ln(Concentration(mg/L)),$$ where:

$$
\begin{aligned}
SEV &= \text{severity of ill effect} \\
a &= \text{Intercept} \\
b,c &= \text{slope coefficients}
\end{aligned}
$$

The coefficients *a, b,* and *c* vary depending on the data group. Most applicable in Elk River is the Group 3 model, "juvenile salmonids," as this model is predictive of the severity of ill effects on one of the most sensitive life stages of species of concern in Elk River. However, the Group 3 model included data for Arctic Graylings, a fish that does not occur in Elk River and evolved under more turbid conditions. In order to more closely model the conditions in Elk River, the data utilized in Group 3 by the authors were reevaluated by Regional Water Board staff to determine the appropriate coefficients corresponding to salmon and trout species (without inclusion of the Arctic Grayling). Using the "solver" feature of Excel staff solved the non-linear system for the values of the intercept and the two coefficients of the equation which minimized the sum of squared residuals of the observed versus predicted value for SEV. Because the data presented in Newcombe and Jensen demonstrate that Arctic Graylings are generally less sensitive than trout and salmonids, the effect of removing them from the equations is a small increase in severity of ill-effect experienced by the fish for a given concentration and duration.

The modified Model 3 thus takes the form:

$$SEV = 1.1184 + 0.8074 \cdot \ln(Duration(hr)) + 0.6814 \cdot \ln(Concentration(mg/L))$$

For the purpose of illustration of the difference the modification makes, Figure 2 compares the original Model 3 with the Modified Model 3. The result is that the same SEV value (SEV 6 in the example depicted) is achieved with a slightly shorter duration of a particular suspended sediment concentration. The effect is minimized with increasing suspended sediment concentrations.
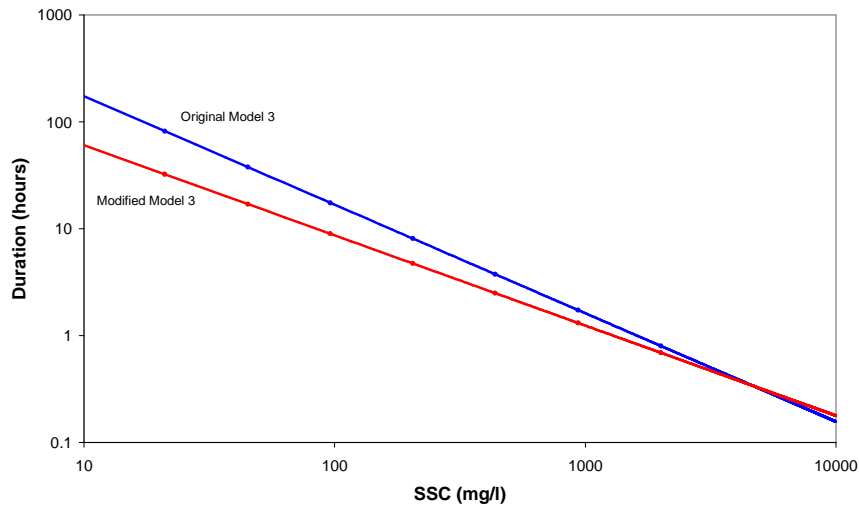
Figure 2.1 Comparison of original and modified Model 3 for the purposes of illustration.

The Elk River monitoring data were then evaluated with this predictive model to determine how juvenile salmonids are affected by current suspended sediment conditions in Elk River. Results are described in the Staff Report.