Appendix A: Regression Equations for Flow and Suspended Sediment Estimates

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Regression Equations and Flow Synthesis Information

A.1 Regression Equations to Estimate Sediment Loading

Regression equations were developed by DRI primarily using instantaneous flow values recorded at the time of suspended sediment concentration (SSC) sampling. Instantaneous values were obtained from USGS records where gauging stations existed, or were measured at the time of sampling (as described in DRI 2001). Two circumstances warranted the substitution of average daily flows for instantaneous flows. In the first case, fouling of flow gages by debris or some other manner corrupted instantaneous discharge records. In these instances, the USGS estimated average daily flow at the station. Second were the cases where instantaneous flow values were not logged at the time of sampling. However, DRI examined rating curves developed for Farad from both the average daily and instantaneous flow records, and found that the general good agreement between the rating curves validated the substitution (DRI, 2001; Kuchnicki, 2001).

Regression equations were developed according to the following process:

1. calculating instantaneous suspended sediment flux (Q_s) by multiplying instantaneous water discharge Q_i by the corresponding SSC values (mass/volume) and a units conversion factor K;
2. transforming Q_i and Q_s into log units;
3. performing ordinary least squares regression (OLS) of $log\ Q_s$ on $log\ Q_i$.

This process resulted in the following subwatershed-specific regression equations shown in Table A-1.

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Table A-1. Regression Equations Expressing the Relationship Between Flow and Suspended Sediment Load (DRI, 2001, Appendix D; Kuchnicki, 2001).

Subwatershed	N	R^2	Regression equation	Range of flows (cfs)	
				Low	High
Bear	27	0.76	log y = 1.67(logQ)-2.99	1	160
Squaw	32	0.94	log y = 1.93(logQ)-3.26	6	661
Donner	36	0.80	log y = 1.78(logQ)-3.31	8	456
Trout	31	0.63	log y = 1.30(logQ)-2.05	<1	59
Martis	34	0.89	log y = 1.24(logQ)-2.05	1	108
Juniper	17	0.91	log y = 1.76(logQ)-2.40	1	35
Little Truckee	19	0.80	log y = .84(logQ)-1.62	<1	757
Prosser	21	0.70	log y = 1.39(logQ)-2.59	23	279
Gray	22	0.95	log y = 2.44(logQ)-3.58	8	73
Bronco	19	0.88	log y = 1.91(logQ)-2.82	6	45
Farad	362	0.78	log y = 1.59(logQ)-3.44	48	8230

Notes: N = number of SSC samples
y = load in tons/day
Q = flow in cubic feet per second (cfs)

A.2 Regression Equations to Synthesize Flow Records for Bear, Trout and Juniper Creeks

Hydrographs were generated for ungauged tributaries by correlating available measurements of discharge to flow records of gauged tributaries. Gauged tributaries were initially selected on the basis of proximity and similarity of watershed characteristics. Instantaneous and/or daily average flow values were then compared between the watersheds to test for a significant relationship. If the regression demonstrated that a significant flow relation existed between the watersheds, the flow record contained in the gauged watershed was used to generate one for the ungauged tributary (Kuchnicki, 2001). Table A-2 shows the equations developed for Bear, Trout and Juniper creeks.

Table A-2. Flow correlations between tributaries (DRI, 2001).

Sub-watershed				Flow Range (cfs)	
(y)	(x)	N	Regression equation	Low	High
Bear	Blackwood (x_1) Ward (x_2)	33	Qy = 0.84 (Qx_1)-.36 (Qx_2) - 1.58	2.1	192
Trout	Sagehen	26	Qy= 0.24 (Qx) + 2.6563	2.8	228
Juniper	Bronco	11	Qy = 0.66 (Qx)	<1	35

Notes:

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y = the dependent variable (value to be calculated) and x equals the independent variable.
N = the number of measurements
Q = flow in cubic feet per second
cfs = cubic feet per second

A.3 Explanation of Synthesized Flow Record for Bronco Creek

Although DRI (2001) developed a regression equation for Bronco Creek as well, when Water Board staff attempted to use this equation to estimate loads based on water years, the regression did not yield reasonable estimates, suggesting a possible math or typographical error in the equation. Therefore, Water Board staff developed a synthesized flow record for Bronco Creek for water year 2003-2004 using an alternative method. The mean daily flows reported by the USGS for Bronco and Sagehen Creeks for the calendar years 1994-1997 were compared. Sagehen Creek was chosen due to its similarity in watershed size. A scaling factor (flow at Sagehen divided by the flow at Bronco) was calculated for each day of the five years paired flow measurements were available. An average scaling factor was then calculated for each day of the year. The average daily scaling factor was then applied to the daily flow record at Sagehen for the water year 2003-2004.

Due to the large amount of data, the flow record is not included. Flow records and estimated scaling factors are available upon request.

Appendix B: Load Duration Curves for the Truckee River and Major Subwatersheds

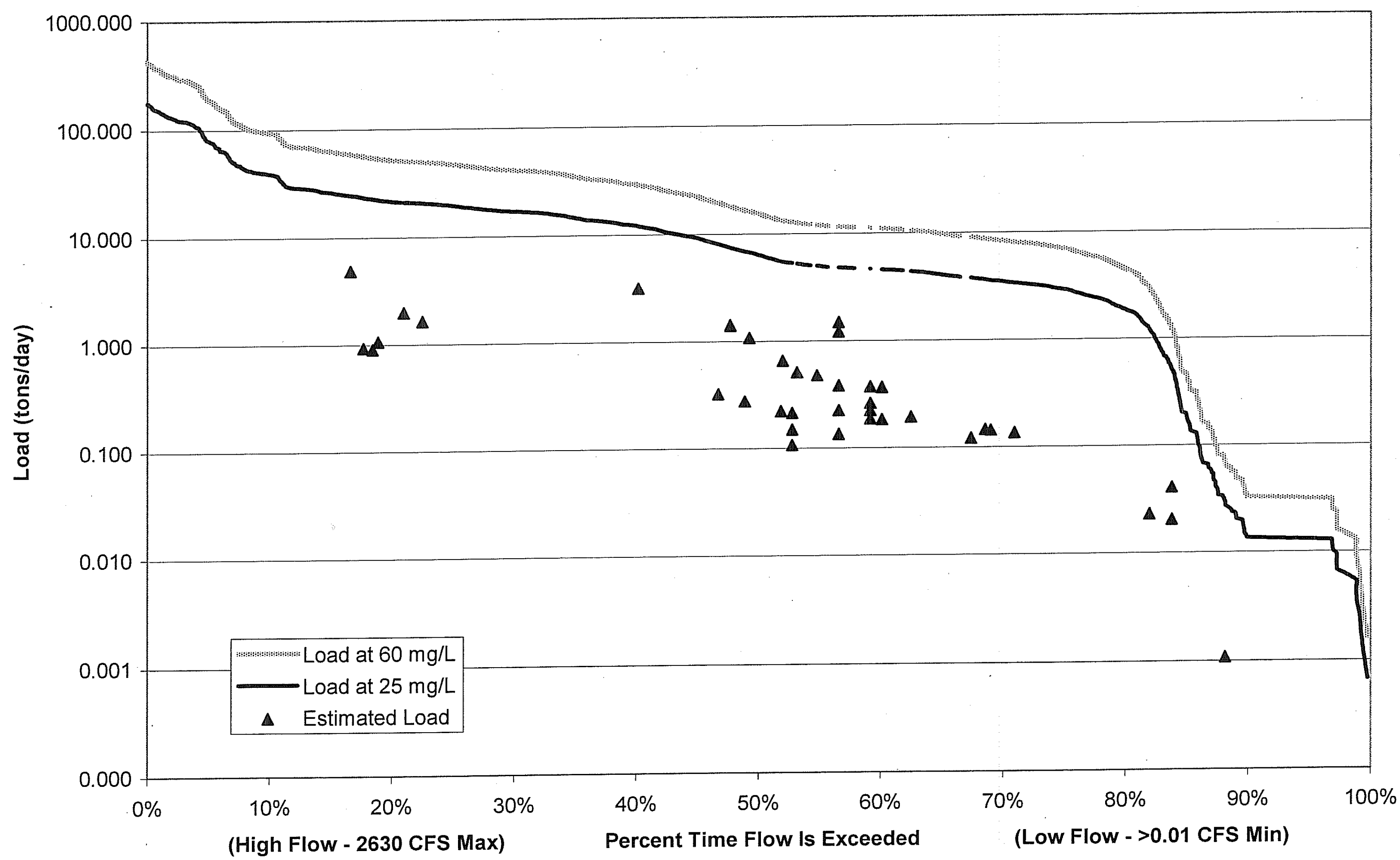
Truckee River Sites:

Truckee River at Tahoe City
Truckee River near Truckee
Truckee River at Farad

Subwatersheds:

Bear Creek
Squaw Creek
Donner Creek
Trout Creek
Martis Creek
Prosser Creek
Little Truckee River
Juniper Creek
Gray Creek
Bronco Creek

Truckee River at Tahoe City Load Duration Curve



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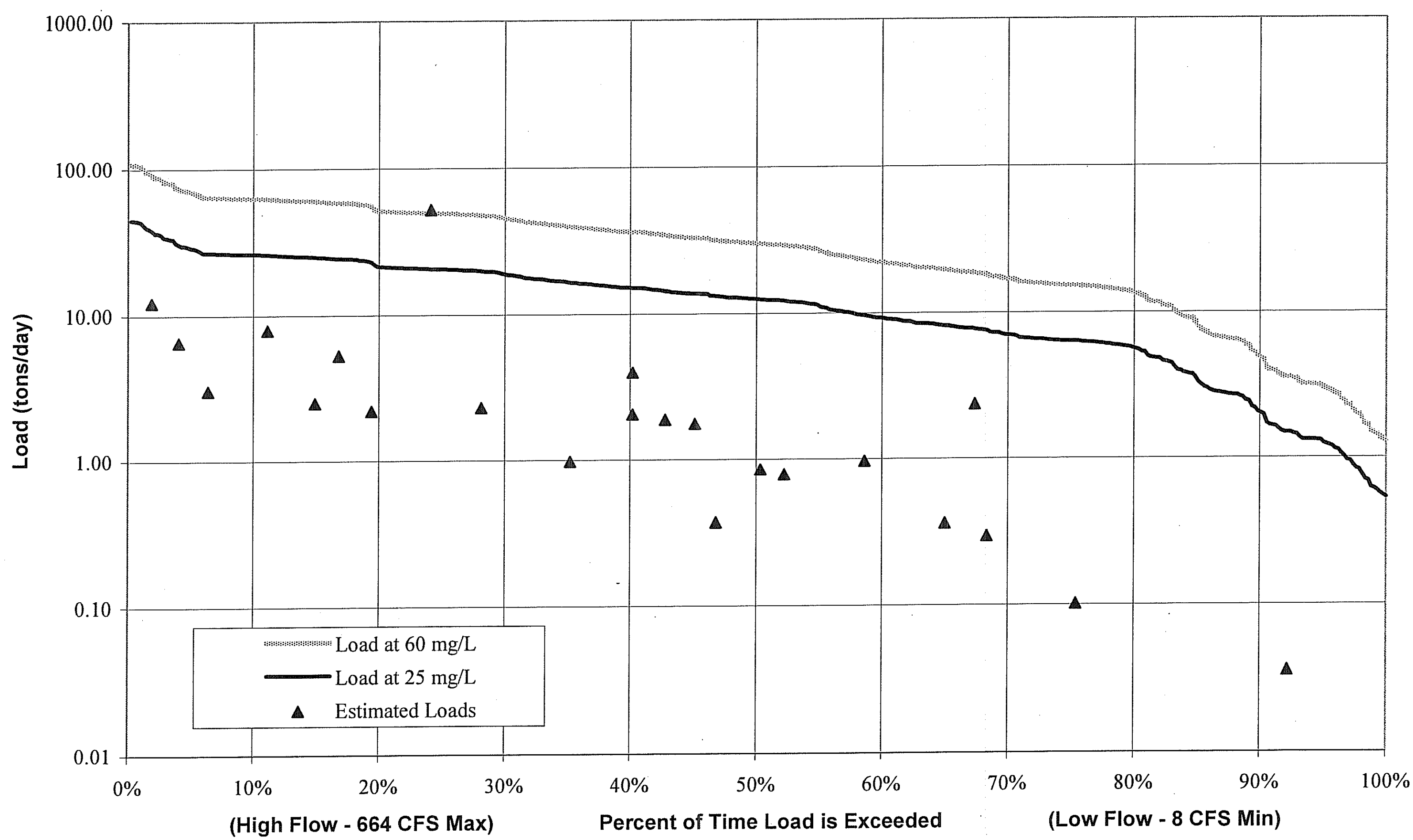
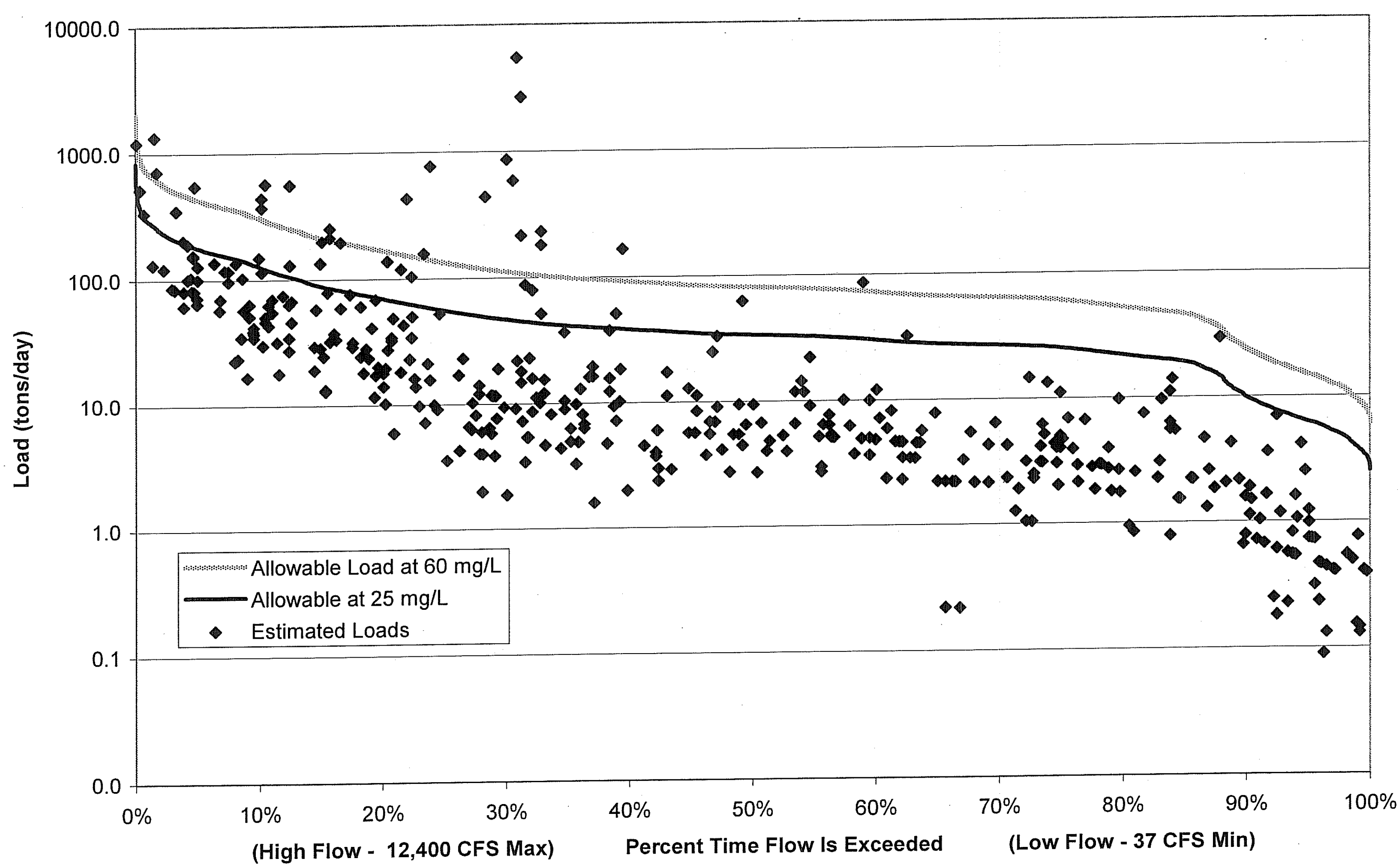
Truckee River Near Truckee Load Duration Curve



Truckee River at Farad Load Duration Curve



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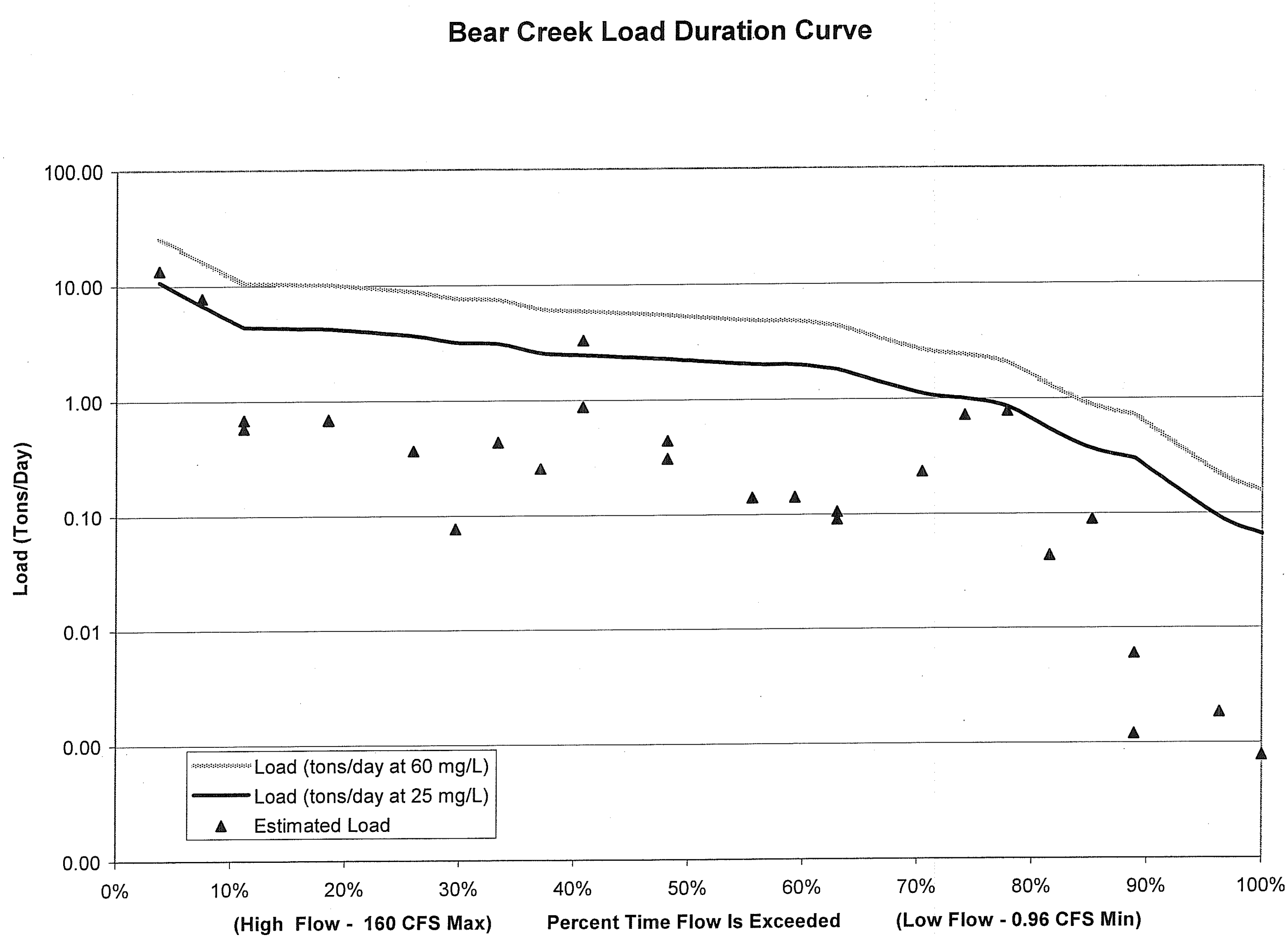
Bear Creek Load Duration Curve
100.00
10.00
1.00
0.10
0.01
0.00
0.00
Load (Tons/Day)
Load (tons/day at 60 mg/L)
Load (tons/day at 25 mg/L)
Estimated Load
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
(High Flow - 160 CFS Max)
Percent Time Flow Is Exceeded
(Low Flow - 0.96 CFS Min)

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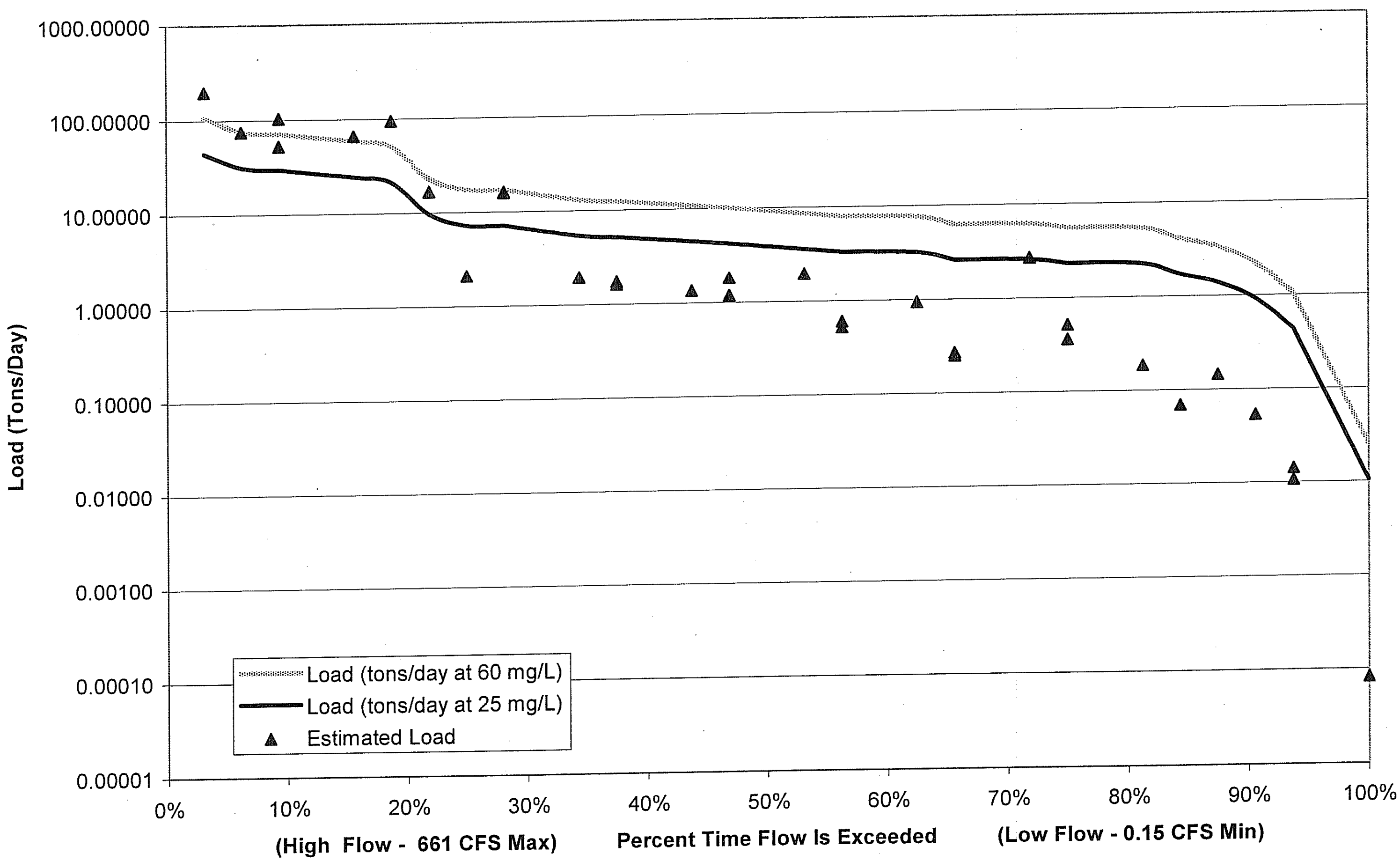
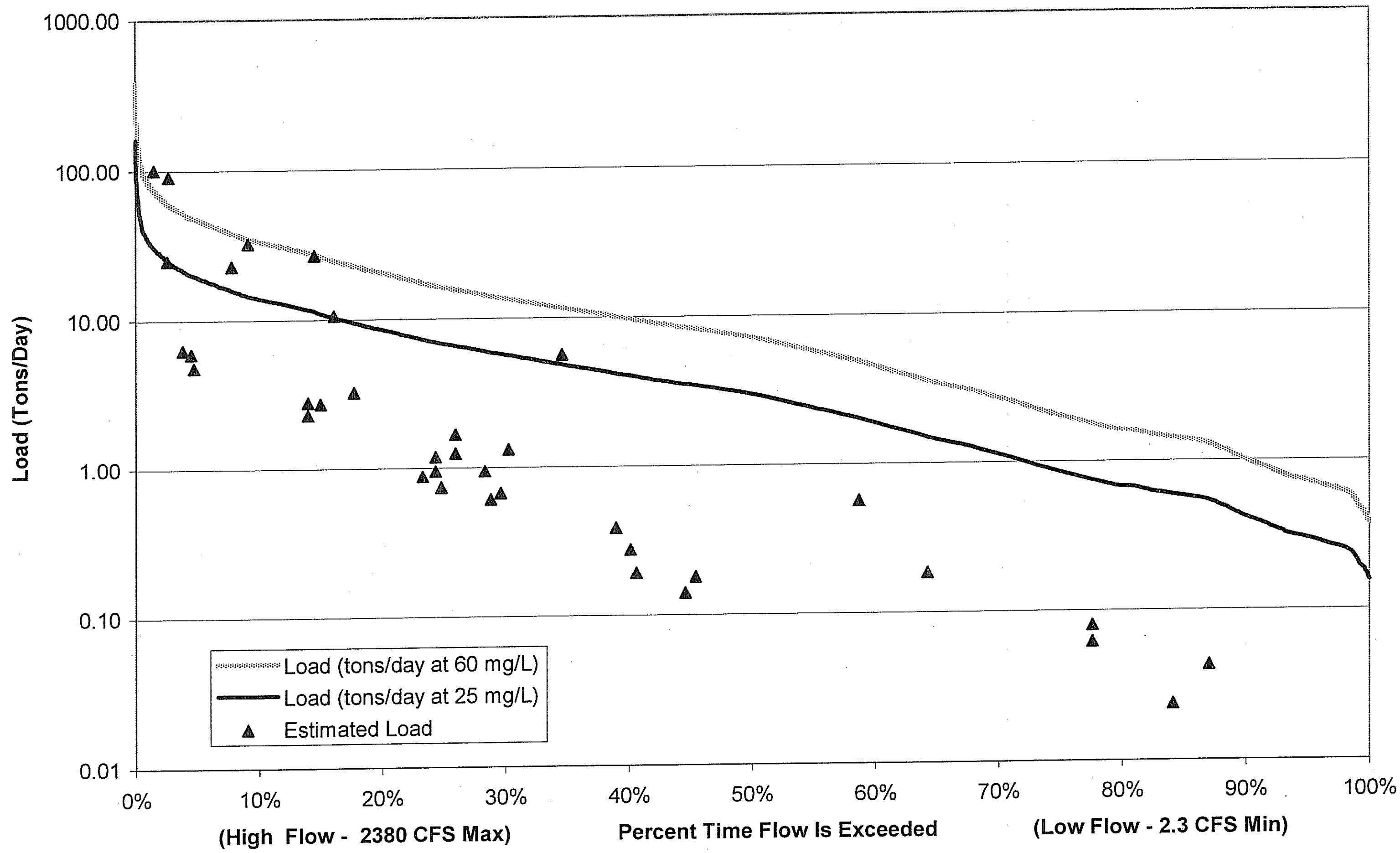
Squaw Creek Load Duration Curve



Donner Creek Load Duration Curve



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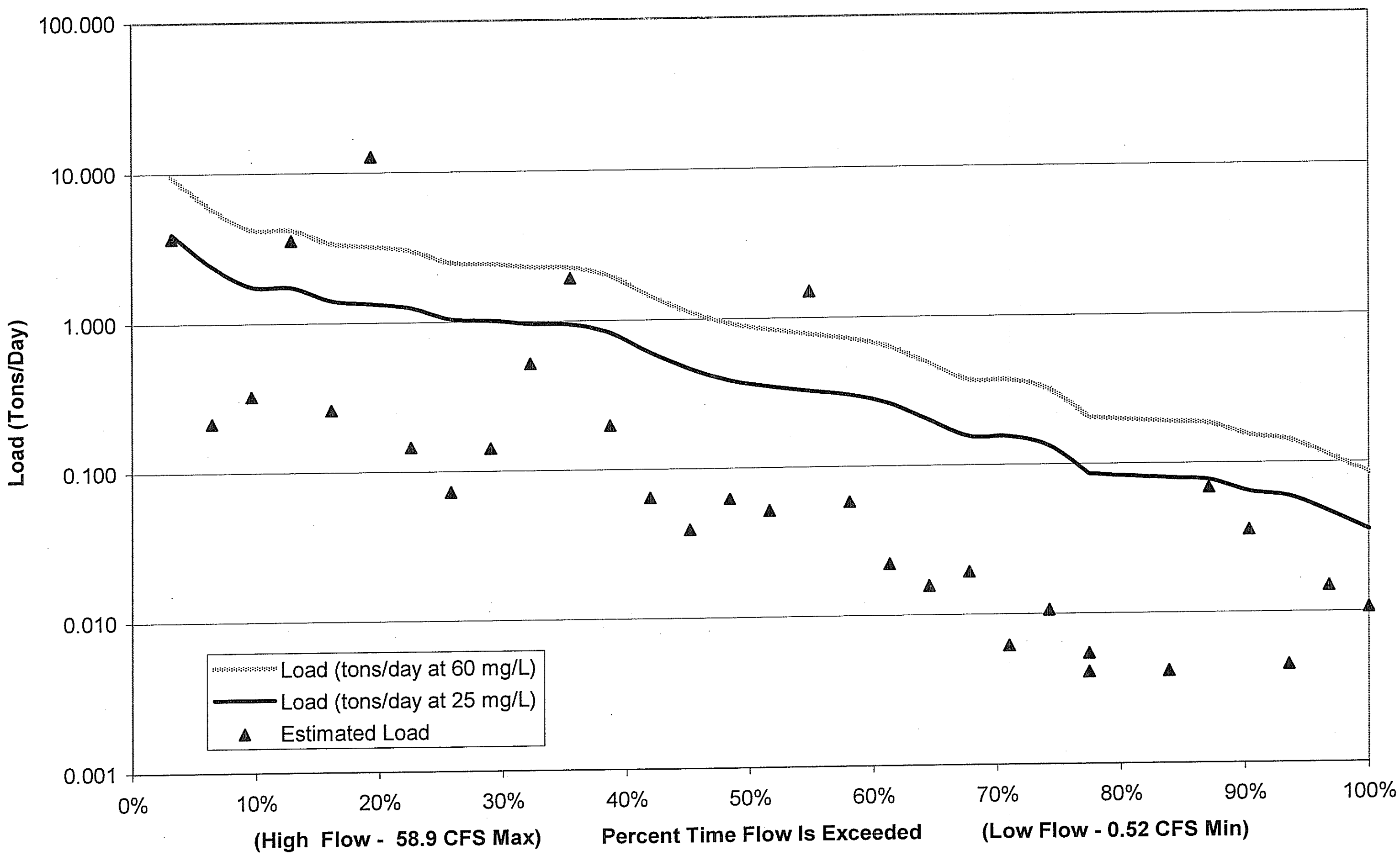
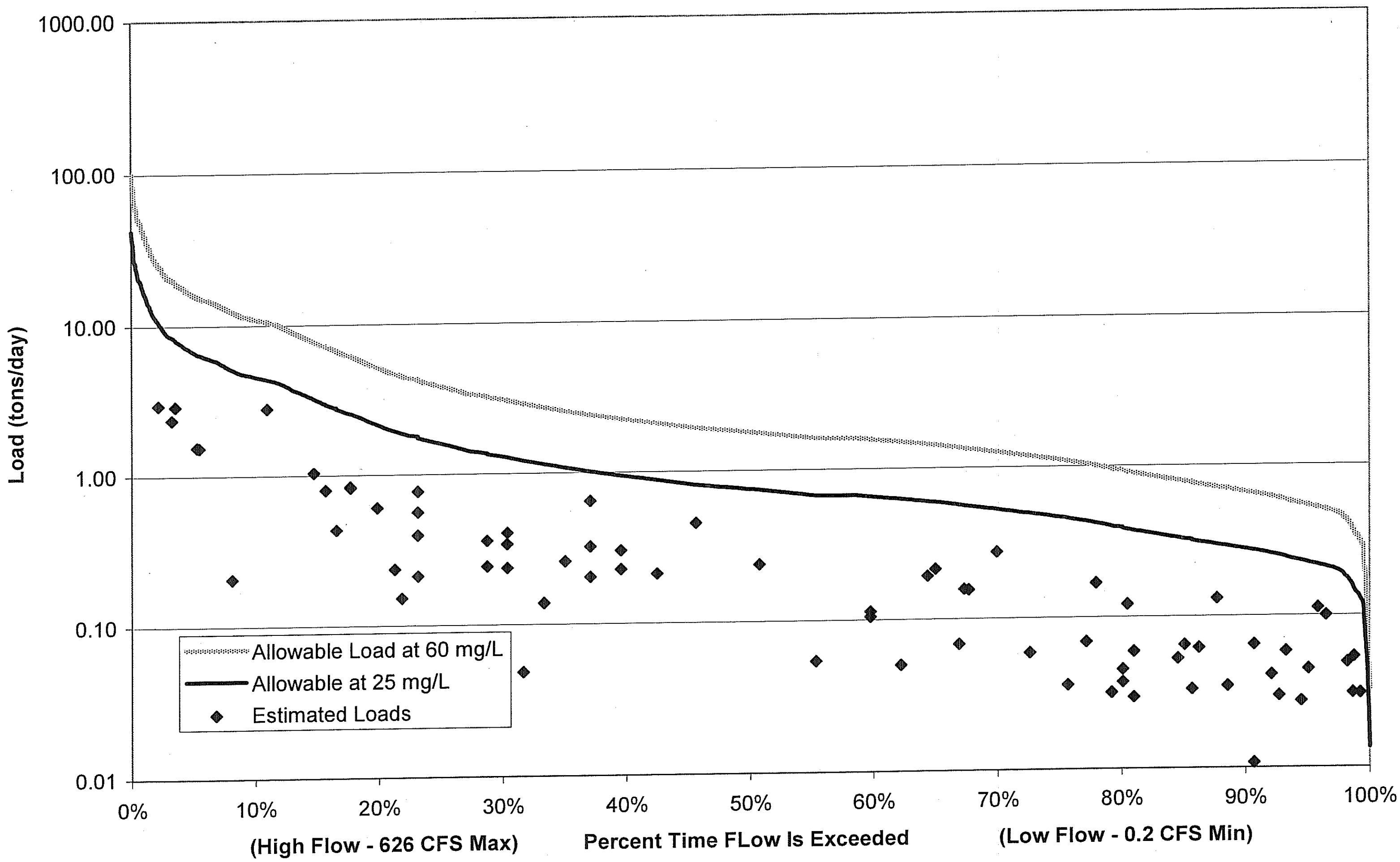
Trout Creek Load Duration Curve



Martis Creek Load Duration Curve



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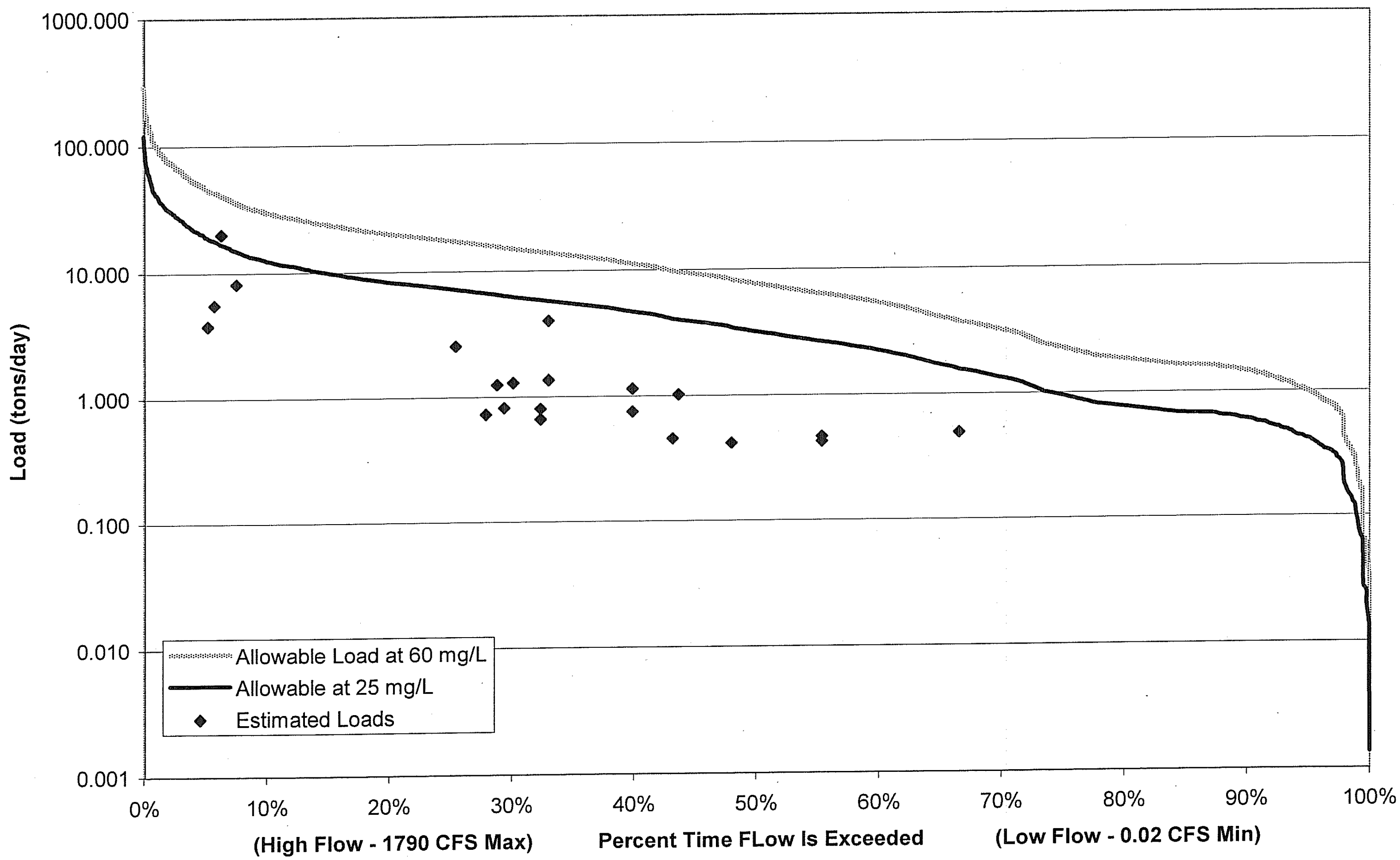
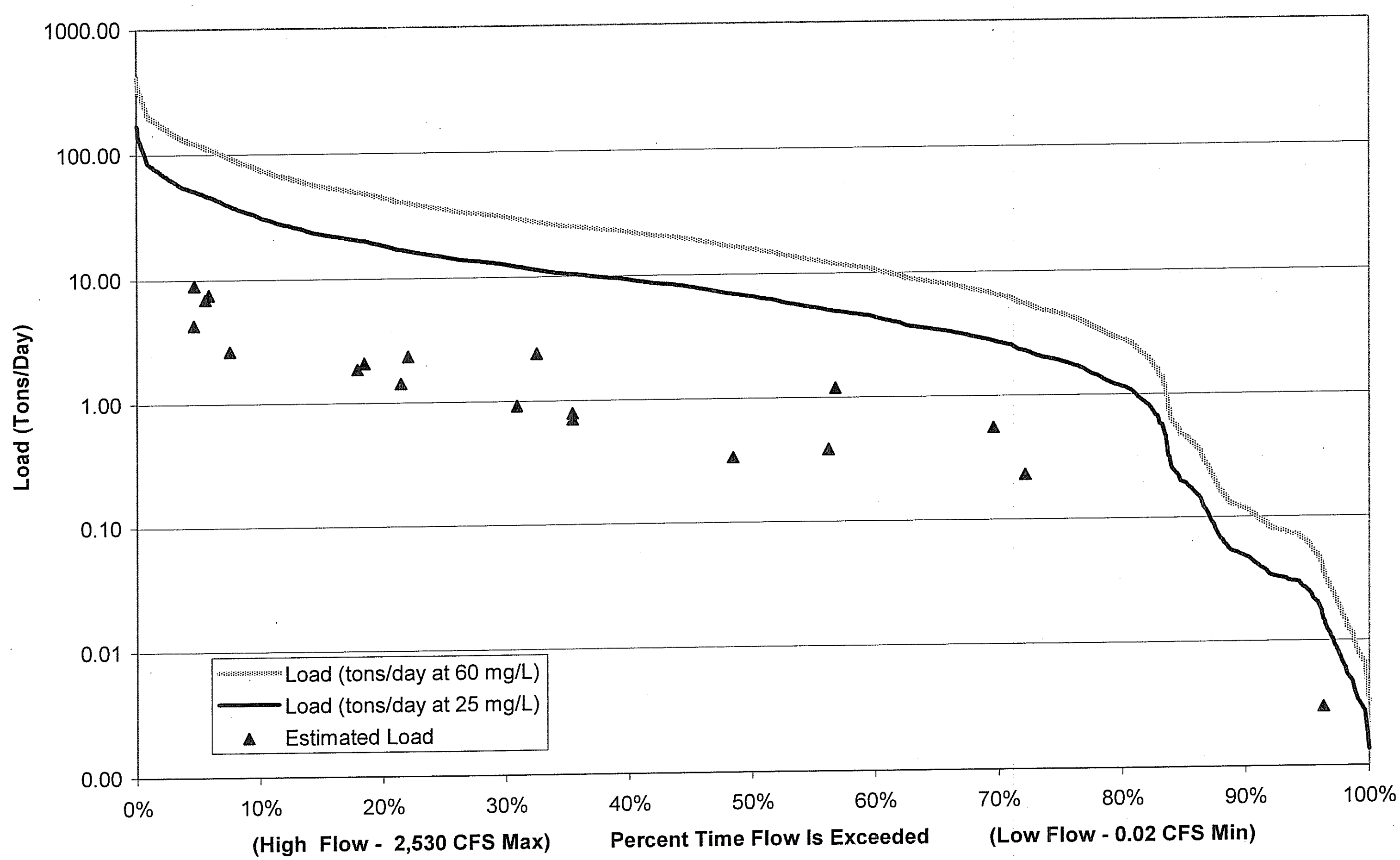
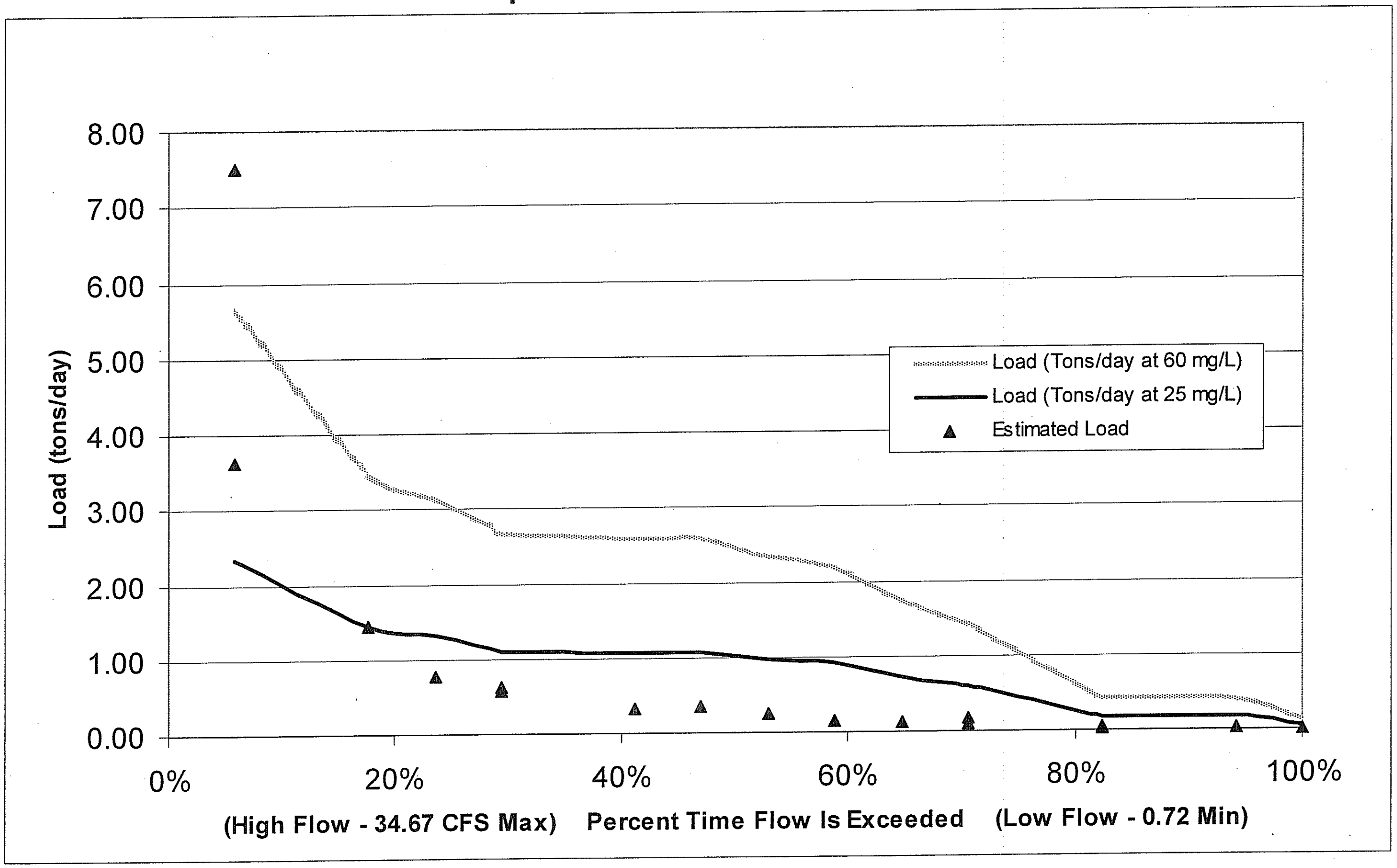
Prosser Creek Load Duration Curve



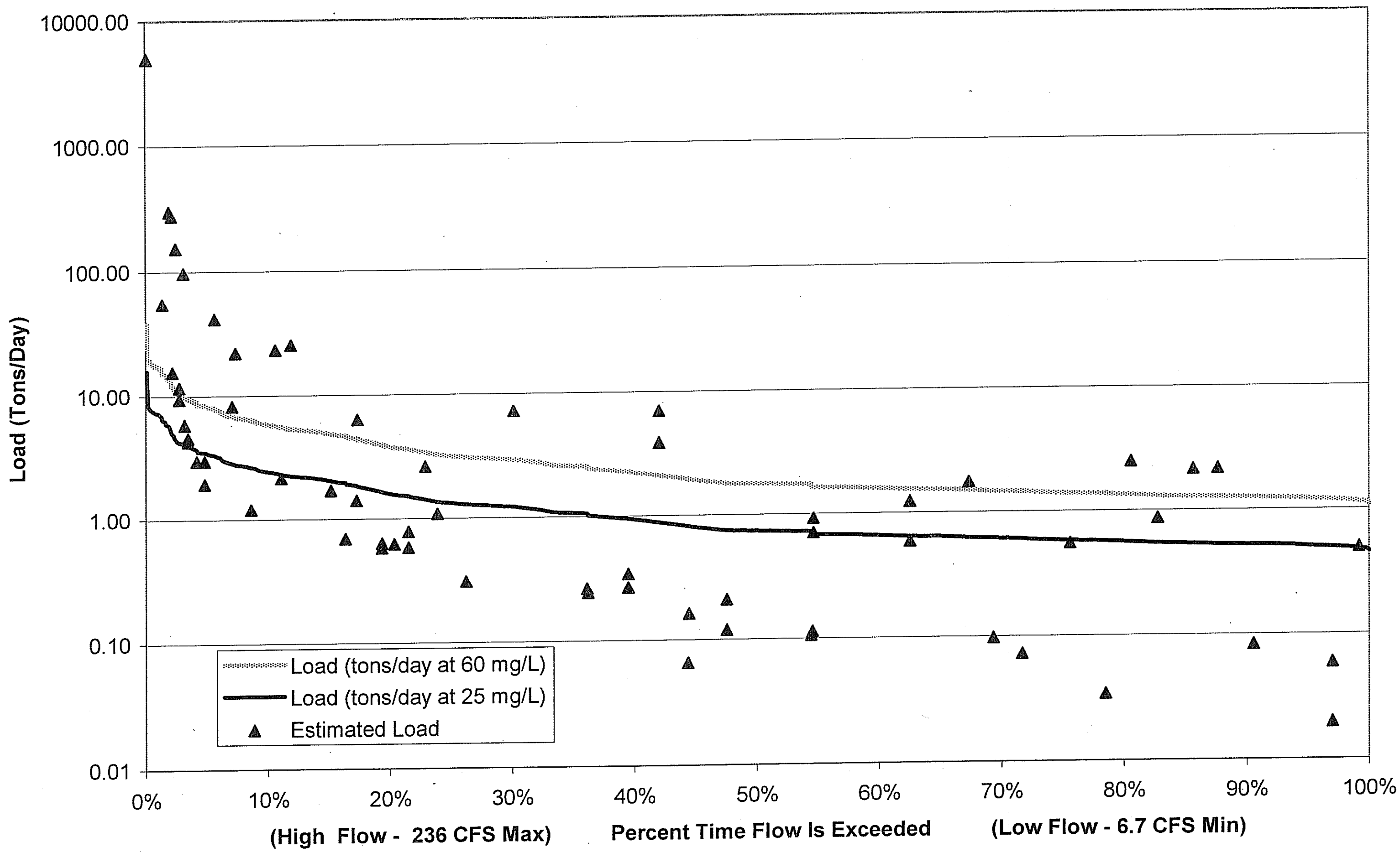
Little Truckee River Load Duration Curve



Juniper Creek Load Duration Curve



Gray Creek Load Duration Curve



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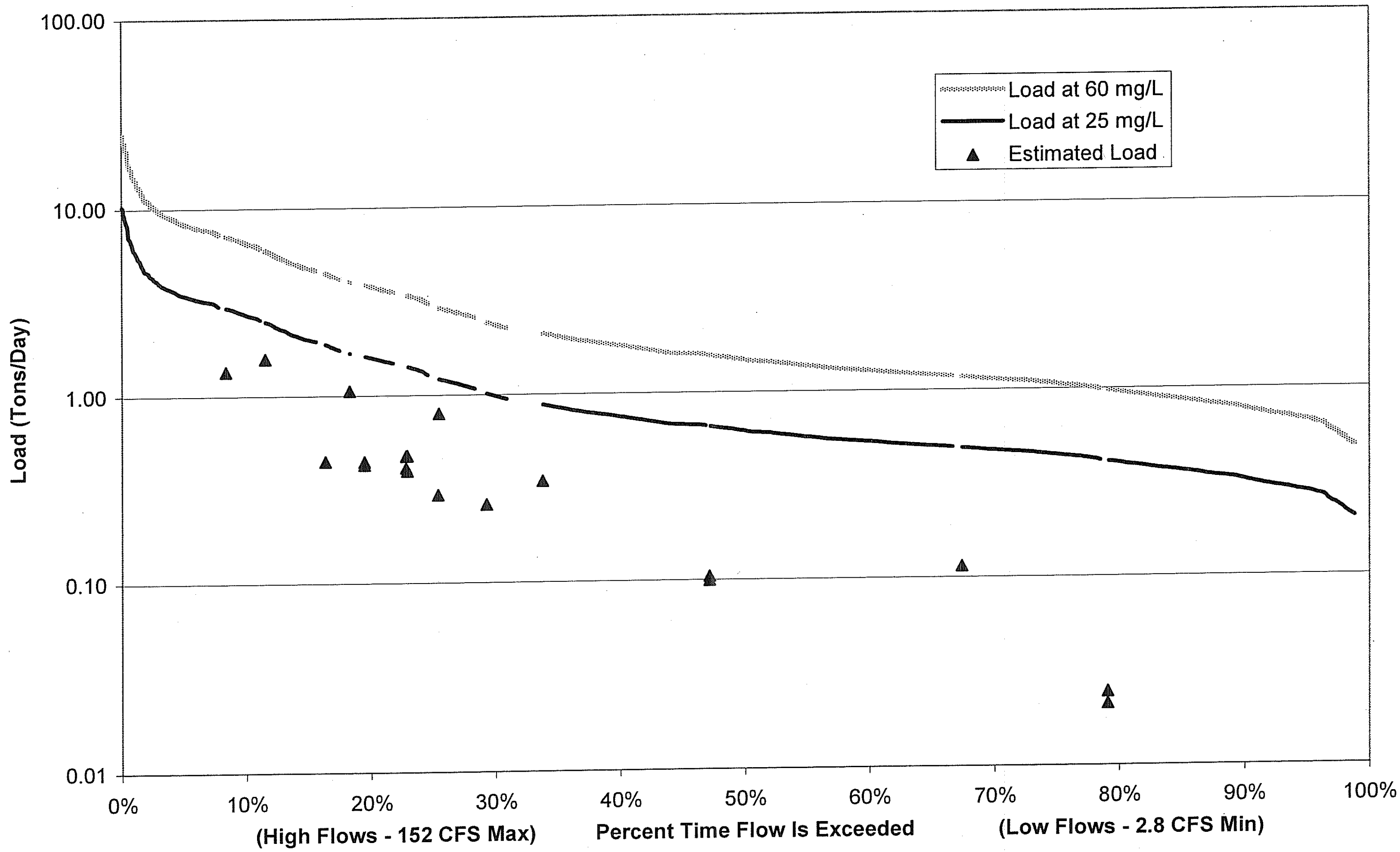
Bronco Creek Load Duration Curve



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Appendix C: Suspended Sediment Literature Review

Literature Review on Suspended Sediment Criteria

In evaluating suspended sediment levels necessary to protect aquatic life in the Truckee River, numerous studies, water quality objectives and numeric targets for suspended sediment and solids were reviewed.

The European Inland Fisheries Advisory Commission (EIFAC, 1964 in Idaho Department of Environmental Quality (IDEQ), 2003; Miller, 1998; Newcombe, 1997) suggested the following standards for protection of salmonids and other fish:

Concentration	Effect
<25 mg/L	No effect
25-80 mg/L	Slight effect on production
80-400 mg/L	Significant reduction in fisheries
>400 mg/L	Poor fisheries

Similar ranges of TSS concentrations were suggested by the National Academy of Sciences (1973 in IDEQ, 2003; Miller, 1998) to protect aquatic communities:

Concentration	Level of Protection
<25 mg/L	High level of protection
25 - 80 mg/L	Moderate protection
80 - 400 mg/L	Low level of protection
>400 mg/L	Very Low level of protection

USEPA guidance documents have classified impairment of aquatic habitat or organisms due to TSS as follows (Mills *et al.*, 1985, in IDEQ, 2003):

Concentration	Impairment Status
< 10 mg/L	impairment improbable
< 100 mg/L	impairment potential
> 100 mg/L	impairment probable

Newcombe and Jensen (1996, in USEPA, 2003; Miller, 1998; Newcombe, 1997) summarized the acute and chronic effects of suspended sediment on a variety of fish species, and used these data to develop a quantitative assessment of risk and impact to aquatic life. They described four categories of "severity of ill effects" associated with various combination of suspended sediment concentration and durations, beginning with no effects and progressively worsening through behavioral effects (e.g., alarm reaction, avoidance response), sublethal effects (e.g., short-term reduction in feeding rates, physiological stress), and paralethal to lethal effects (e.g., reduced growth rate, percent mortality).

Staff of the North Coast Regional Quality Control Water Board (NCRWQCB), in a memo on potential turbidity and suspended sediment water quality objectives, suggested that water quality objectives for suspended sediment should to correspond to a Newcombe and Jensen "Severity Index" of 4. Effects associated with this Severity Index are "short-term reduction in feeding rates and/or feeding success." However, NCRWQCB staff note that regional studies show that pristine and near-pristine streams are unable to meet the concentration-duration thresholds in Newcombe and Jensen (Klein, 2001, in NCRWQCB, 2001). Due to these and other uncertainties (lack of site-specific data, lack of data on chronic effects), the NCRWQCB did not recommend a dose-based suspended sediment objective.

Other reviewers also note that caution must be used when applying Newcombe and Jensen's models to assess the effects of low concentrations of suspended sediments over protracted time periods (Canada Department of Fisheries and Oceans, 2000; IDEQ, 2003). Concentrations as low as 5 mg/L for only 1 day would have behavioral effects on all species and life stages according to the models. This result appears to be somewhat inconsistent with other work (e.g., EIFAC, 1964, Miller et al., 1985, NAS, 1983). Further, meaningful assessment of Newcombe and Jensen's models requires SSC sampling (or an established sediment surrogate such as turbidity) on at least a daily basis, making practical application of the models difficult. Data of this resolution are not available for the Truckee River, and it is unknown if daily sampling of SSC or a reliable surrogate may commence in the future. For these reasons, Water Board staff does not propose use of the Newcombe and Jensen approach to set a suspended sediment target for the Truckee River.

Several TMDLs have adopted numeric targets for suspended sediment. Miller (1998) used the Newcombe and Jensen charts as a basis for recommending suspended sediment targets in the lower Boise River (IDEQ, 1998). The targets were selected to protect aquatic communities in the lower Boise River, including rainbow and brown trout. TSS targets were expressed as geometric means not to exceed a 60-day chronic exposure of 50 mg/L or 14-day acute exposure of 80 mg/L.

The Central Coast Regional Water Quality Control Board (CCRWQCB, 2005) also used the Newcombe and Jensen models to establish a range of targets for the Pajaro River Sediment TMDL to protect steelhead trout. Target concentrations and associated durations to protect against sub-lethal effects ranged from 33 mg/L for 49 days and up to 1,807 mg/L for one day.

Joy and Patterson (1997) set TSS targets at 56 mg/L in tributaries and return drains in the Yakima River in Washington to protect the salmon fishery. In Idaho's Bear River basin, TMDL targets for suspended solids varied based on receiving water type and hydrologic regime (runoff versus base flow). For stream reaches that flow into other streams, TSS targets were 80 mg/L during runoff and 60 mg/L at base flow. Runoff and base flow targets for stream reaches that flow into lakes or reservoirs were 60 and 35 mg/L, respectively (Ecosystem Research Institute, 2006). These targets were based on

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the 1964 EIFAC recommendations to protect the basin's coldwater fishery and salmonid spawning.

TMDL targets for Utah's Bear River, Cub River, Worm Creek and Malad River are 90 mg/L for mainstem waters and 35 mg/L TSS for tributaries (Ecosystem Research Institute, 2006).

Most states have narrative water quality objectives for suspended sediment, but several have promulgated numeric criteria. The state of Nevada established water quality objectives for suspended solids for the Truckee River at Farad. They are intended to protect the aquatic life beneficial use, and mandate an average annual value of less than or equal to 15 mg/L, with a single value maximum of 25 mg/L. These objectives are tempered by Nevada's low flow/high flow policy, which states that during extreme flow events, water quality objectives may be exceeded.

Streams tributary to Lake Tahoe have an SSC objective of 60 mg/L, expressed as a 90th percentile value. This objective is equivalent to the Tahoe Regional Planning Agency's "environmental threshold carrying capacity" standard for suspended sediment.

Several other states also have suspended sediment water quality objectives:

- New Jersey has limits on suspended solids of 25 to 40 mg/L on specific streams (NJ Department of Environmental Protection, 2006)
- South Dakota has a TSS limit of less than 30 mg/L as a 30-day average, with a daily maximum of 53 mg/L. These limits are to protect coldwater fish propagation (Administrative Rules of South Dakota, Section 74:51:01:45)
- Hawaii has seasonal limits:
  Wet season limits are a geometric mean TSS of 20 mg/L, with no more than 10 percent exceeding 50 mg/L and no more than 2 percent exceeding 80 mg/L.
  Dry season limits are more stringent, with a geometric mean TSS of 10 mg/L, and no more than 10 percent exceeding 30 mg/L and no more than 2 percent exceeding 55 mg/L (Hawaii Administrative Rules, 2004)

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