APPENDIX A

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TMDL Equation

The calculation of the total maximum daily load (TMDL) is intended by law and regulation to be the bedrock of a TMDL pollutant control program. While some pollutants and discharges lend themselves well to the calculation of a total maximum daily load and the enforcement of a program based on the calculation, the nonpoint source discharge of sediment presents some rather unique challenges. For example, the nonpoint source discharge of sediment is a natural process. Further, it is an erratic process, made somewhat unpredictable by the interaction of many uncontrollable factors such as: geology, soil structure, natural vegetative cover and type, slope, aspect, and climate. And, the nonpoint source discharge of sediment has a somewhat unpredictable effect on the instream environment. Factors such as stream gradient, substrate size and quality, presence of large woody debris, riparian zone structure, channel dimensions, rainfall intensity and rainfall duration each influence the degree to which excess sediment delivery will negatively alter a reach of stream, or not. Thus, the calculation of a TMDL for sediment, while possible, plays a less significant role in the overall control of sediment delivery under Section 303(d) of the Clean Water Act than such a calculation might for another pollutant. More significant for the control of sediment is the identification of potential and existing sediment delivery sites, the control of sediment delivery from those sites, and the implementation of non-erosive management practices for the long term.

Nonetheless, a TMDL calculation for sediment is provided, below. Rather, however, then the calculation of the *total maximum daily load*, this TMDL for sediment is expressed as a percent reduction in sediment delivery. A discussion of quantitative and qualitative margins of safety is also included.

The TMDL is not expressed as a rate of allowable sediment delivery (e.g., tons/mi^2/year) because:

- The current estimates are under-estimates;
- Tons/mi^2/yr represents an average condition rather than a real condition that exits on any given square mile of property or in any given year
- The actual discharge of sediment as tons/mi^2/yr would be impossible to reasonably monitor and regulate.

The TMDL is expressed as a percent sediment reduction because:

- It applies whatever the existing rate of sediment delivery
- It applies no matter what the range of existing sediment delivery rates
- It is easy to monitor and regulate once a baseline survey is conducted.

The percent reduction is calculated by the following process:

1. An estimate of the sources of sediment delivery (in tons/mi^2/day) in the Noyo River watershed from 1933 to 1999 is derived from aerial photograph assessment and GIS-based data analysis.

2. A theoretical link between sediment delivery and instream water quality is derived from the comparisons of 1933-1957 to 1979-1999 sediment delivery data.
3. Basin-wide estimates of sediment delivery reduction are developed via the theoretical link between sediment delivery and instream water quality (as above).
4. Estimates of the necessary Assessment Area-specific sediment delivery reductions are developed by comparing data from individual assessment areas to the estimated basin-wide reduction requirements.

Future adjustments to the estimated percent reductions could occur based on the development of more accurate: a) estimates of past and present sediment delivery, b) assessments of the relationships between sediment delivery and instream water quality, or c) any number of other improvements to the current data set.

1. Estimate of sediment delivery from 1933-1999

a. Current average sediment delivery rate (1979-1999)

The estimate of the current rate of sediment delivery due to management-related sources is given in Table 16 as 293 tons/mi^2/yr, based on the summation of the following:

- 6 tons/mi^2/yr for mass wasting due to the railroad
- 20 tons/mi^2/yr for mass wasting due to harvest areas
- 76 tons/mi^2/yr for mass wasting due to roads
- 175 tons/mi^2/yr for surface erosion due to roads
- 16 tons/mi^2/yr for surface erosion due to skid trails

b. Average natural background sediment delivery rate (1933-1999)

The estimate of the background sediment delivery rate from mass wasting, surface erosion and stream bank erosion is given in Table 16 as 366 tons/mi^2/yr, based on the summation of the following:

- 91 tons/mi^2/yr due to landsliding in the period of 1933-1999
- 75 tons/mi^2/yr due to surface erosion in the period of 1933-1999
- 200 tons/mi^2/yr due to stream bank erosion in the period of 1933-1999

2. Link between sediment delivery and instream water quality

Table 15 includes an estimate of the rate of sediment delivery during the period of 1933-1957 as follows:

- 558,000 tons for the period of 1933-1942
- 399,000 tons for the period of 1943-1952
- 385,000 tons for the period of 1953-1957

As such, the average rate of sediment delivery in the period of 1933-1957 was 475 tons/mi^2/yr [(558,000 + 399,000 + 385,000) tons/113 mi^2/25 yrs = 475 tons/mi^2/yr]. The period of 1933-1957 is the period in which sustainable populations of salmonids, coho salmon in particular, appear to have existed. The sediment delivery rate of this period is assumed to have posed no immediate threat to the success of salmonids. Indeed anecdotal evidence suggests that pools were deeper, gravels were unembedded, and the river had an abundance of large woody debris providing fish shelter and channel complexity. As such, achieving a sediment delivery comparable to that of this period is assumed, based on existing data, to be adequate (with respect to sediment) for the protection of salmonid populations, today. A 14% margin of safety is added to the overall sediment delivery reduction requirement to account for the uncertainty that the sediment-influenced habitat parameters of the 1933-1957 period then met the numeric targets described in Chapter V. A 14% margin of safety is viewed as appropriate because: 1) there is a small to moderate level of uncertainty with respect to the specific condition of aquatic habitat in the 1933-1957 period and 2) there is a small to moderate uncertainty with respect to the relative abundance of coho salmon in that period as compared to today.

3. Estimate of basin-wide reductions

As described above, the "desirable" rate of sediment delivery is estimated at 475 tons/mi^2/yr while the long-term average rate of sediment delivery due to natural background sources is estimated at 366 tons/mi^2/yr. As such, no more than a total of 109 tons/mi^2/yr of sediment delivery due to management-related sources is estimated as desirable [475 – 366 = 109].

The existing data indicates that 85% of the current management-related sediment delivery is coming from roads, either as mass wasting or surface erosion [(76 + 175)293 = 0.85]. (The existing data is insufficient to estimate fluvial erosion associated with roads. This issue is addressed below). As such targeting reductions in sediment delivery from roads appears warranted. To achieve an overall management-related sediment delivery rate of no more than 109 tons/mi^2/yr, a 73% reduction in sediment delivery from road-related sources is required [293 – (76 + 175)(x) = 109; x = (293 – 109)/(251) = 0.73]. Rounding this up to 75% provides an overall margin of safety of 4% [293 – (251)(0.75) = 105; 109-105/109 = 0.04]. The 4% margin of safety is included in the 14% margin of safety described above. The 4% margin of safety specifically addresses the uncertainty with respect to the proportional relationship as described by the estimated sediment delivery rates for individual year classes. While some of the early and later aerial photo sets are incomplete, the methods used to estimate sediment delivery in each year class are identical. A 4% margin of safety is viewed as appropriate since the uncertainty regarding this question is relatively small.

4. Estimates of Assessment Area-wide reductions

The estimates of the rates of management-related sediment delivery in individual assessment areas vary based on the kinds of management employed, the terrain and climate, and the available data. As such, the required reductions in each Assessment Area also vary.

Three factors are considered in the development of the following Assessment Area-specific sediment delivery reductions:

- *The proportion of the basin-wide sediment delivery from roads that is attributable to roads in a given Assessment Area.* The basin-wide estimate of current sediment delivery due to mass wasting from roads is 76 tons/mi^2/yr. A 75% reduction in this basin-wide rate results in a "desirable" basin-wide rate of no more than 19 tons/mi^2/yr. Similarly, the basin-wide estimate of the current sediment delivery due to surface erosion from roads is 175 tons/mi^2/yr r. A 75% reduction in this basin-wide rate results in a "desirable" basin-wide rate of no more than 44 tons/mi^2/yr. The following table summarizes the required road-related reductions resulting from the application of these target rates. The required percent reductions reflect the proportion of the overall mass wasting and surface erosion from roads which is attributable to roads in the individual Assessment Areas.

Table A1: Calculation of the necessary percent reduction in sediment delivery due to mass wasting and surface erosion from roads.

	Mass wasting from roads	Surface erosion from roads
Estimated "desirable" sediment delivery rate	≤19 tons/mi^2/yr	≤44 tons/mi^2/yr
Estimated current sediment delivery rate in HAA	106 tons/mi^2/yr	162 tons/mi^2/yr
Estimated current sediment delivery rate in NFAA	106 tons/mi^2/yr	182 tons/mi^2/yr
Estimated current sediment delivery rate in SFAA	18 tons/mi^2/yr	148 tons/mi^2/yr
Estimated current sediment delivery rate in MAA	76 tons/mi^2/yr	201 tons/mi^2/yr
Required percent reduction in HAA	82%	73%
Required percent reduction in NFAA	82%	76%
Requirement percent reduction in SFAA	0%	70%
Required percent reduction in MAA	75%	78%

- *The degree to which sediment delivery from railroad, harvest area, and skid trail sources are also significant.* On average, roads currently appear to be the greatest source of management-related sediment delivery. As such, it is appropriate to target roads for sediment control efforts. However, a margin of safety is required to address uncertainty regarding the degree to which the problem of sedimentation can be solved by reducing sediment from roads, alone. When looking at individual Assessment Areas, for example, other management-related sources of sediment may also be important contributors[1]. It is therefore appropriate to require control of those sources of sediment, in addition to road sources, that may also be significant.

  Estimated rates exceeding the basin-wide average by more than 25% are judged to be "elevated" and potentially significant. A 25% margin above the basin-wide average is viewed as appropriate because it describes those sediment delivery sites that are in the upper 75 percentile with respect to sediment delivery. By addressing the elevated railroad, harvest area and skid trail sources, implementation of the requirements

[1] Large woody debris and flow are also issues; but, they are not specifically addressed in the TMDL calculation. They are addressed as numeric and other targets. It is proposed that they be more fully addressed in the implementation plan, when it is developed.

ensures that landowners throughout the basin are treated equally. That is, no landowner will be allowed to discharge significantly more sediment from harvest areas, for example, than another landowner. Further, by addressing these other elevated management-related sources, a quantitative margin of safety is added to the TMDL.

These additional reduction requirements are applied as follows:

- The current basin-wide average rate of sediment delivery is estimated at 7 tons/mi^2/yr due to mass wasting from railroad sources, 20 tons/mi^2/yr due to mass wasting from harvest areas, and 16 tons/mi^2/yr due to surface erosion from skid trails.
- For the purposes of this assessment, an Assessment Area rate that is greater than these basin-wide rates by more than 25% is considered "elevated" and potentially significant.
- Therefore, railroad, harvest area, and skid trail sources in individual Assessment Areas for which the given estimate of current sediment delivery exceeds 9, 25, or 20 tons/mi^2/yr, respectively, must be reduced.

Table A2: Calculation of the necessary percent reductions in sediment delivery from "elevated" railroad, harvest area, and skid trail-related sources.

	Mass wasting from the railroad	Mass wasting from harvest areas	Surface erosion from skid trails
Estimated "elevated" sediment delivery rate	>9 tons/mi^2/yr	>25 tons/mi^2/yr	>20 tons/mi^2/yr
Estimated current sediment delivery rate in HAA	9 tons/mi^2/yr	8 tons/mi^2/yr	17 tons/mi^2/yr
Estimated current sediment delivery rate in NFAA	0 tons/mi^2/yr	5 tons/mi^2/yr	21 tons/mi^2/yr
Estimated current sediment delivery rate in SFAA	0 tons/mi^2/yr	5 tons/mi^2/yr	13 tons/mi^2/yr
Estimated current sediment delivery rate in MAA	12 tons/mi^2/yr	53 tons/mi^2/yr	13 tons/mi^2/yr
Required percent reduction in HAA	0%	0%	0%
Required percent reduction in NFAA	0%	0%	0%*
Required percent reduction in SFAA	0%	0%	0%
Required percent reduction in MAA	25%	53%	0%

*Surface erosion from skid trails in NFAA is currently estimated to exceed the assigned target by 5%. A reduction requirement of less than 10%, however, is judged to be difficult to implement, monitor and verify. As such, no reduction requirement for surface erosion from skid trails is included in NFAA.

The implementation of these additional sediment delivery reduction requirements has the following overall effect:

- Sediment delivery in tons/yr from HAA = (27.17)(9 + 8 + 19 + 44 + 17) = 2635.
- Sediment delivery in tons/yr from NFAA = (25.07)(0 + 5 + 19 + 44 + 17) = 2131.
- Sediment delivery in tons/yr from SFAA = (27.46)(0 + 5 + 18 + 44 + 13) = 2197.
- Sediment delivery in tons/yr from MAA = [33.3][12 – (12)(0.25) + 53 – (53)(0.53) + 19 + 44 + 13 = 3663.

- Sediment delivery in tons/mi^2/yr in the watershed overall = (2635 + 2131 + 2197 + 3663)/113 = 94

If the implementation of a 75% reduction in sediment delivery due to mass wasting and surface erosion from roads results in an estimated overall delivery rate of 105 tons/mi^2/yr (see above); and, the reduction in sediment delivery due to mass wasting from railroad sources and harvest areas in MAA results in an estimated overall delivery rate of 94 tons/mi^2/yr (see above); then, the additional reductions increase the margin of safety by 10% to 14%, overall [(109-94)/109 = 0.14]. The 10% margin of safety addresses the uncertainty with respect to the proportional relationship among source categories as described by estimated sediment delivery. While aerial photos were used as tools in estimating the areal extent of landslides and surface erosion potential, the estimation of sediment delivery rates due to landslides and surface erosion used different procedures. As such, the proportional relationship between road-related sediment delivery sources and other sources is contains uncertainty. An additional 10% margin of safety is viewed as appropriate because the uncertainty is small to moderate.

- *There is no reliable data regarding the rates of fluvial erosion from roads.* Fluvial erosion (primarily rills and gullies, including stream diversions and washed out culverts) is generally a significant component of the sediment budgets on the Northcoast (PWA, 1997). Unfortunately, the data available in the Noyo River watershed does not include estimates of the rates of fluvial erosion. Since the TMDL is expressed in percent reductions, however, a reduction in management-related fluvial erosion is included which will be applied after a baseline assessment of sediment delivery sources in the Noyo River watershed has been conducted. Because of the lack of available data, a conservative approach is appropriate. As such, the TMDL includes a 90% reduction in sediment delivery from management-related fluvial erosion sources. Including in the TMDL a reduction requirement for fluvial erosion sources adds a qualitative margin of safety

Margin of safety
Margins of safety are added to the TMDL equation to account for various uncertainties. A margin of safety can be either qualitative or quantitative. The uncertainties considered in the development of the TMDL calculation are described below, as well as the margins of safety included to address them.

Table A3: Margins of Safety

Uncertainty	Margin of Safety	Type of MOS
1. Degree to which the estimated sediment inputs provide an accurate basis for load allocations	Apply percent reductions instead of sediment volumes (or rates) as load allocations	Qualitative
2. Degree to which estimated sediment inputs reflect accurate proportional relationships among sediment delivery sources	Increase overall sediment delivery reduction requirements by 14%	Quantitative
3. Degree to which the rate of management-related sediment delivery estimated for the 1933-1957 period accurately reflect that which is protective of salmonids and their habitat	Apply percent reductions instead of sediment volumes (or rates) as load allocations. Increase the overall sediment delivery reduction requirements by 14%	Quantitative
4. Degree to which various unestimated sources of sediment are significant contributors	Require that 90% of all road-related sources of fluvial erosion be controlled. Require in-channel storage improvements through increases in large woody debris recruitment.	Qualitative