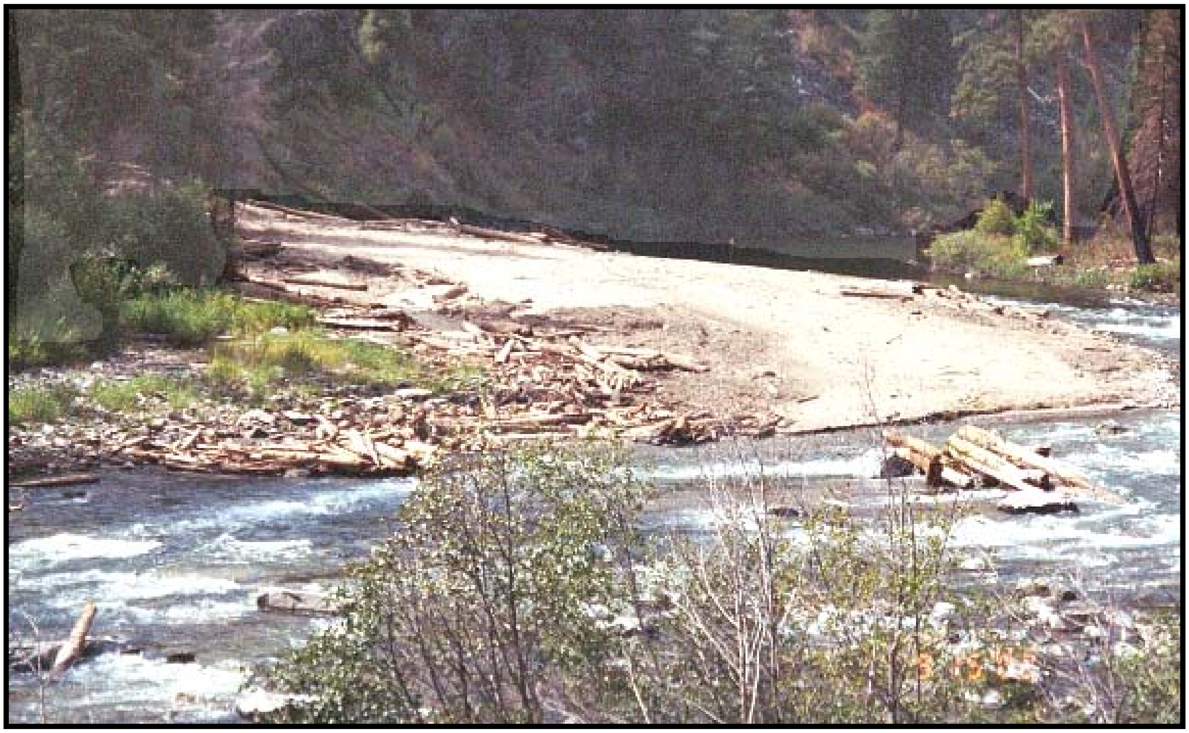
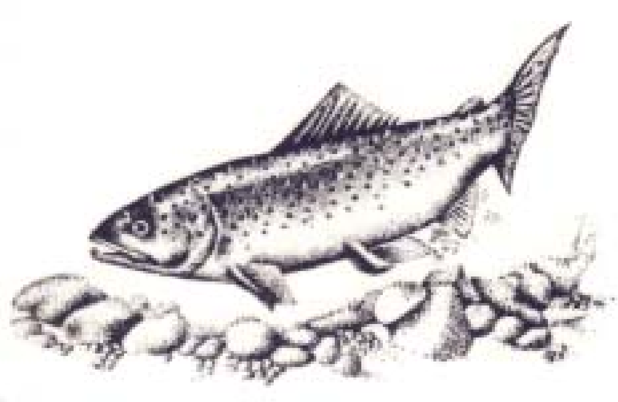
Guide to Selection of Sediment Targets for Use in Idaho TMDLs





Mike Rowe, Idaho Department of Environmental Quality
Don Essig, Idaho Department of Environmental Quality
Ben Jessup, Tetra Tech, Inc.

June, 2003

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Mike Rowe
Idaho Department of Environmental Quality
Pocatello, Idaho

Don Essig
Idaho Department of Environmental Quality
Boise, Idaho

Ben Jessup
Tetra Tech, Inc.
Montpelier, VT

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Executive Summary

Excessive fine sediment is the most common pollutant in impaired streams in Idaho. Total Maximum Daily Load (TMDL) plans prepared to address excessive fine sediment must comply with the existing narrative water quality standard for sediment, which states *"Sediment shall not exceed quantities ... which impair beneficial uses"* (IDAPA 58.01.02.200.08). While this aptly describes a goal, it does not describe objectives for TMDL plans and stream restorations. Through this report, the Idaho Department of Environmental Quality is suggesting appropriate water column and streambed measures for gauging attainment of the narrative sediment goal.

One of the important beneficial uses of Idaho streams is production of trout and salmon for ecological and recreational purposes. The effects of excessive fine sediment on the embryo, fry, juvenile and adult life stages of salmonids are well studied. Characteristics of the stream that change with increasing fine sediments and are known to affect salmonids and other aquatic biota are the best measures of sediment-caused impairment of beneficial uses. These characteristics and the threshold values that describe minimal degradation are the targets that are recommended in this report.

Water column and instream measures that were determined to be the best indicators of sediment related impairment of beneficial uses include light penetration, turbidity, total suspended solids and sediments, embeddedness, extent of streambed coverage by surface fines, percent subsurface fines in potential spawning gravels, riffle stability, and intergravel dissolved oxygen. The relationships between these measures and the aquatic biota are described in this paper, with special attention given to growth, survival, reproductive success, and habitat suitability of salmonids. Target levels for most measures are recommended based on generalized relationships found in the scientific literature and specific background conditions that exist in Idaho streams. The targets for turbidity and intergravel dissolved oxygen were established based on existing Idaho Water Quality Standards. Where data to describe sediment-biota relationships are lacking or highly variable or background conditions are highly variable, statewide numeric thresholds are inappropriate. For total suspended solids and sediments, embeddedness, and surface sediments, target levels should be established for each individual stream based on local reference sediment conditions. To provide a regional perspective of the recommended target levels, comparisons are made to standards adopted in neighboring states and provinces.

Acknowledgements

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1. Introduction

Sediment is the biggest water quality problem in Idaho streams. For over 90% of the streams on the state's 1998 303(d) list sediment was identified as a pollutant of concern. Between 1992 and 2003, 76% of the approved TMDLs in the state addressed sediments (DEQ 2003). Temperature is the second most frequently listed pollutant on the 303(d) list, at about half the frequency of sediment. Sediment can have direct effects on beneficial uses for salmonid spawning, cold and warm water aquatic life, and domestic, agricultural, and industrial water supplies. Water quality plans will be written to address these sediment concerns, including an estimation of a total maximum daily load (TMDL) for sediment. The TMDL is a limit on the quantity of sediment, which enters the stream from both natural and human-caused sources. This limit is to be set at a level such that water in the streams will meet state water quality standards. Idaho's water quality standard for sediment is narrative, "*Sediment shall not exceed quantities ... which impair beneficial uses*" (IDAPA 58.01.02.200.08). A narrative standard for sediment is necessary and desirable as it accommodates the vast range of sediment conditions that exist in nature. The primary beneficial use addressed in this paper is the propagation and maintenance of viable aquatic ecosystems, especially as they support salmonid fisheries.

With no fixed numeric criterion, a major challenge to preparing a TMDL for sediment is development of a numeric target that can be used to derive a load capacity. The target is a site-specific interpretation of the narrative sediment criterion based on an assessment of how sediment in a particular waterbody impairs beneficial use. The sediment targets are surrogate measures for beneficial use support. As such, they supplement a load or concentration goal used in a TMDL, providing a bridge over the uncertainty in the connection between sediment loading and support of beneficial uses.

The work of developing sediment criteria is ongoing. One of the first efforts by Idaho Department of Environmental Quality (DEQ) to address sediment concerns was Harvey's 1989 Technical Review of Sediment Criteria. He recommended four criteria as they relate to domestic water supply, salmonid spawning, and cold water aquatic life beneficial uses. Harvey's work was the basis for current state Water Quality Standards for intergravel dissolved oxygen for salmonid spawning and turbidity for both cold water aquatic life and domestic water supply.

Sediment-caused impairment can take many forms and be measured in a variety of ways. To assist planners responsible for writing TMDLs for Idaho streams, DEQ has explored measurements of sediment that may assist in setting targets and in gauging progress toward meeting water quality standards. Earlier recommendations (Harvey 1989) and the targets recommended in this document are site-specific and are not enforceable. The ultimate measure of sediment water quality standard attainment, and the only measure recognized in Idaho's water quality rules, is instream beneficial use support.

Sediments can be dichotomously classified in at least three overlapping ways - clean or contaminated, organic or inorganic, and suspended or bed material. This paper deals only with clean sediment, not sediment that is contaminated by toxic substances such as heavy metals. Organic solids are only a minor fraction of sediment in most Idaho streams, providing a vital source of food energy in many smaller streams. Organic matter can become abundant enough to cause water quality problems, typically below sewage outfalls where decay can depress dissolved oxygen levels. The distinction between inorganic and organic fractions is not always made in the monitoring or study of sediment. Inorganic sediment, the product of physical weathering of geologic materials, predominates as a water quality problem in Idaho and is the main focus of the studies referenced below. While we refer to both suspended solids and stream bed deposits collectively as sediment, clearly these solids act differently upon aquatic life depending on their location in the aquatic environment. This important distinction is affected by the balance between particle size and stream energy, and presents difficulty in both the measurement of sediment load and its relation to beneficial use support.

One of the fundamental questions regarding sediment in streams and its effect on biota is particle size. Particle size may be described as a fraction below some cutoff value, an average (median, mean, geometric mean) diameter, or most robustly as a frequency or cumulative frequency distribution. Chapman (1988) suggested, based on the work of Tappel and Bjornn (1983) and others, that two sizes of sediment be considered: fine sediment (< 0.85 mm) which is most responsible for suffocation and abrasion of salmonid eggs, and coarser sediment (< 9.5 mm) which can create a surficial barrier preventing salmonid fry emergence from the redd. Hunter (1973) reported a minimum substrate size of 6 mm for steelhead, rainbow trout, and cutthroat trout spawning areas. Particles less than 0.063 mm (silt and clay) remain suspended in flowing water and are largely the cause of turbidity and effects on visual feeding. Although it is often assumed that smaller substrates (e.g., fine sediment) are the overriding problem in streams, there are times when large size substrate (> 9.5 mm) can also be a problem (e.g. filling of pools with cobbles or deficit of spawning gravel). For most of the proposed streambed targets, sediment size of concern is fines less than 6.35 mm based on Burton and Harvey (1990). Fine sediments can cause impairment with either too much or too little in the system. The overwhelming problem in Idaho is excessive fine sediments.

In an ideal world, target levels to achieve sediment reduction would be developed for each stream. Not only will stream sediment conditions differ between, for example, ecoregions, conditions will also vary within reaches of the same stream, and over time. Sediment conditions, even in the absence of development (e.g., wilderness areas), are highly variable (Rosgen 1980, Nelson et al. 1997). It is important to remember that there is a range of conditions, a natural distribution, within a stream that is important to maintain (Russ Thurow, Forest Service, personal communication). Stochastic events (e.g., summer thunder storms) may create conditions in which sediment parameters exceed targets, even in pristine streams (Benda and Dunne 1997).

Nothing precludes the establishment of site-specific targets if enough information is available. Necessary information would include: sufficient sites throughout the stream drainage to ensure a representative sample; within year data covering both base flow, spring runoff, and episodic events; and between years data to cover a range of precipitation and spring runoff conditions. If site-specific data were not available, targets could be based on a relatively undisturbed stream similar to the study stream (i.e., a reference stream in a paired watershed). Sufficient data to establish site-specific sediment targets on individual Idaho streams seldom exist; however, there is enough similarity among Idaho streams that some statewide targets can be recommended.

Some authors would argue against establishment of any type of threshold, which, if not met, would be assumed to have certain and deleterious effects on aquatic biota. For example, Chapman and McLeod (1987) found no functional predictors for evaluating quantitative effects of sediment on the natural incubation, rearing, or wintering phases of salmonid life history in the northern Rocky Mountains. Chapman (1988) and Everest and others (1987) caution against applying results of laboratory studies to field conditions. These conclusions emphasize the need for writers of TMDLs to carefully consider available data when establishing sediment targets on streams.

Sediment targets for water column, streambed, and subsurface flow parameters are proposed. No targets are currently recommended for channel characteristics (e.g., residual pool volume, width/depth ratio). A brief summary of channel characteristics as they relate to sediment loading is presented in Appendix A.

Targets are considered for the following parameters:

Water Column parameters:
- Turbidity
- Light penetration
- Total suspended solids and suspended sediment

Streambed parameters:
- Embeddedness
- Surface sediment
- Subsurface sediment
- Riffle stability

Subsurface Flow parameter:
- Intergravel dissolved oxygen

The targets proposed for the above mentioned parameters are benchmarks, selected such that few, if any, deleterious effects are expected to occur. At levels beyond the target, there may or may not be deleterious effects depending on the parameter value and the particular site. The proposed targets should not be viewed as points to which streams with parameter levels better than the targets can be degraded. The State's anti-degradation rule requires streams that presently have conditions better than the proposed targets are maintained at those above par conditions.

It is not expected that every stream needs targets for all the parameters listed. On the other hand, in most cases, due to the inherent variability in the relation of sediment loads to target parameters and lag times in response, more than one target could be useful. For example, Lloyd (1987) suggested reasonable turbidity criteria could protect aquatic habitats from decreased light penetration, suspended sediments, and possibly heavy metals. Separate settleable solids or streambed standards could then be applied to protect aquatic habitats from the impacts of heavier sediments on benthic substrates. The choice of targets should be appropriate to the stream under study, as some streams may not lend themselves to a particular target (e.g., Riffle Stability Index in southeast Idaho streams).

There are several definitions (below), which help to clarify subsequent recommendations. It should also be noted that where concentration ranges and resultant biological effects are discussed for parameters such as turbidity or suspended solids, the lower end of the range is presented as a conservative effect threshold for use in recommending a target.

- Baseline background - the biological, chemical, or physical condition of waters measured at a point immediately upstream (upgradient) of the influence of an individual point source discharge or nonpoint source input;
- Natural background - naturally occurring background (i.e., expected historic value of the parameter for a given site absent any impact from human activity); and,
- Base flow - the value of the parameter when flows are low and relatively stable (i.e., neither on the rising nor falling limb of an annual runoff or storm event hydrograph).

2. Water Column Measures

There are valid reasons for considering the water column measures both individually and in relation to each other. Turbidity is a measure of light dispersion caused by particles suspended in a water column. Light penetration, turbidity, and suspended solids are therefore correlated, though the characteristics of the particles in suspension can change the degree of light dispersion or penetration. Larger particles can increase total suspended solids (TSS) without refracting light as much as the same quantity of smaller particles would. Lloyd (1987) concluded that turbidities of 25 and 95 NTU could be expected to impact fish communities through indirect effects of light extinction and the accommodating decrease in the production of plants and fish food. While effects of light penetration are usually associated solely with primary production, turbidity is also associated with elevated stress in fish, predatory efficiency, inducement of invertebrate drift, and suffocation of incubating salmonid embryos. TSS is perhaps the most direct measurement of sediment loads in the stream, and is treated in this paper in terms of its effects on fish, macroinvertebrates, and the aquatic habitat.

As turbidity and suspended solids increase, benthic macroinvertebrates tend to drift. They are especially prone to drift as the duration of the sediment pulse is lengthened (Shaw and Richardson 2001) and when suspended particles are smaller (Runde and Hellenthal 2000). Net-spinning caddisflies have been observed drifting in highly turbid suspended solids, while they will remain to be buried alive by less turbid suspended sediments (Runde and Hellenthal 2000). In a turbid water column, macroinvertebrates will be less visible to salmonid predators and have a better chance of survival (Vogel and Beauchamp 1999, Sweka and Hartman 2001, Shaw and Richardson 2001) while survival is also probable when overlying sediments are large (Runde and Hellenthal 2000).

Attempts have been made to predict TSS from turbidity, thereby avoiding the greater time and expense of measuring TSS. However, predictive models can be so sensitive to location and time period (Mack 1988) that the application may be limited to the current year and waterbody for each calibration effort. TSS and turbidity showed a strong positive relationship in nine urban/suburban Puget lowland streams (Packman et al. 1999). After log transformation, the coefficient of determination was 0.96, but confidence intervals around predicted TSS were large after back-transforming. In New Mexico TMDLs (e.g., Canyon Creek, Whitewater Creek, and Cordova Creek), the turbidity standard is converted to TSS by calibrating with local data so that the TSS values in units of mg/L can be converted to sediment loads in lbs/day.

Turbidity units (NTU) have been calibrated to approximate TSS measures using 40 mg/L kaolin clay to set a standard of 40 NTU, which should result in a TSS to turbidity slope of about 1.0 (Keyes and Radcliffe 2002). However, the calibration is not reliable for application in natural streams because the composition of suspended particles in streams rarely resembles the kaolin clay standard. Larger particles contribute weight to a TSS measurement, but will not scatter light as much as a similar weight of smaller particles.

2.1 Light Penetration

2.1.1 Biological background

Inorganic suspended materials reduce light penetration in a waterbody. This decreases the depth of the photic zone and reduces primary production leading to a decrease in the primary consumers that form the basis of fish diets (U. S. EPA 1986, Lloyd et al. 1987, Kiffney and Bull 2000, Rosemond et al. 2000). Benthic herbivores are also responsive to sediment accumulation in algal mats (Kiffney and Bull 2000), further reducing the abundance of these important grazers. In addition to negative effects on primary production and grazer abundance, reduced light can affect salmonid visual acuity by diminishing reaction distances (Vogel and Beauchamp 1999) and changing predatory efficiency.

In slow moving waters, suspended materials decrease light penetration while increasing absorption of solar energy near the surface. The heated upper layers tend to stratify the water column (NAS and NAE 1973), reducing the dispersion of dissolved oxygen and nutrients to the lower depths of the waterbody. In a study of the effect of clay on a New Zealand stream, Davies-Colley et al. (1992) suggested that restriction in light penetration into water may be a generally important mechanism by which fine inorganic solids damage streams.

2.1.2 Other states

No northwestern state had a specific light penetration standard. British Columbia has a clarity standard based on Secchi disk readings (>= 1.5 m [average of at least 5 readings over 30 days]).

2.1.3 Recommendation

We recommend that settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life. This standard is the same as recommended in the U. S. Environmental Protection Agency “Gold Book” (1986).

2.2 Turbidity

2.2.1 Biological background

Increased levels of turbidity dramatically reduce light penetration in both lakes and streams and are associated with decreased production and abundance of plant material (primary production), decreased abundance of food organisms (secondary production), decreased production and abundance of fish (Lloyd et al. 1987), decreased growth of fish (Sigler et al. 1984), and decreased predatory efficiency (Sweka and Hartman 2001). Benthic invertebrates tend to drift as turbidity increases (Runde and Hellenthal 2000, Shaw and Richardson 2001). Predatory salmonids also avoid highly turbid waters (Servizi and Martens 1992) and they do not benefit from increased drift associated with turbidity (Shaw and Richardson 2001) because sight distances and capture rates are reduced (Vogel and Beauchamp 1999). Servizi and Martens (1992) showed that coho salmon were relatively tolerant of low-turbidity suspended solids, but that behavioral responses match other studies when turbidity levels were considered.

Turbidity includes both organic and inorganic particles. The inorganic component of turbidity may be comprised of clay, silt, or other finely divided inorganic matter of less than 2 mm diameter (APHA et al. 1995). Plankton, microscopic organisms, and finely divided organic matter make up the organic component of turbidity. Generally speaking, the component of concern as it relates to physiological effects on fish and macroinvertebrates is the inorganic component.

Work on the effects of turbidity to aquatic fauna, especially salmonids, is extensive. Effects range from relatively benign indicators of stress to reduced growth and mortality (Table 1). Behavioral modification and secondary stress indicators occur at relatively low turbidity levels. Servizi and Martens (1992) noticed that blood sugar levels (a secondary indicator of stress) increased with turbidity at all levels tested and coughing increased significantly between 3 and 30 NTUs. Altered behavior, avoidance, and reduced feeding rates are generally noticed between 10 and 30 NTUs over the course of 24 hours. Reduced reaction distances are observed at even lower turbidities. A decrease in growth has been found in turbidities of 22 NTUs and reduced survival rates were seen in turbidities as low as 15 NTUs. Many of these studies were conducted in laboratory settings and/or with artificially induced turbidity. They mostly represent continuous (chronic) exposures. A turbidity of 30 NTU has been described as having a clarity such that when viewing a newspaper through a 6 inch column of water, the lines of print would be visible, but not legible.

Turbidity can affect primary producers by reducing light penetration and thus photosynthesis (Waters 1995). Lloyd (1987) concluded that in Alaska turbidities of 25 NTU or more could cause light extinction at too shallow a depth with an associated decrease in plant production, fish food, and fish. Modeling of a clear, shallow stream indicated that an increase of 5 NTU would decrease gross primary production by 3-13% while a 25 NTU increase would result in a 13-50% reduction. He also postulated that these levels of turbidity could be expected to interfere with sight feeding of fish, angler success, and aerial escapement surveys.

Table 1. Summary of effects on fish, periphyton, and invertebrates noted for turbidity ranges. Units of Nephelometric (NTU) and Jackson (JTU) turbidity units are roughly equivalent (U. S. EPA 1983a).

Effect	Organism	Turbidity range	Reference
Increased blood sugar levels	Juvenile coho	Linear correlation	Sevizi and Martens 1992
Increased coughing	Juvenile coho	3 - 30 NTU for 24 hours	Sevizi and Martens 1992
Altered behavior	Juvenile coho	10-60 NTU	Berg 1982; Berg and Northcote 1985
	Largemouth bass and green sunfish	14-16 JTU	Heimstra et al. 1969
Emigration/avoidance	Steelhead and coho	11-51 NTU	Sigler et al. 1984
	Juvenile coho and steelhead	22-265 NTU	Sigler 1980
	Juvenile coho	>37 NTU	Sevizi and Martens 1992
Reduced feeding rate	Juvenile coho	10-60 NTU	Berg 1982; Berg and Northcote 1985
	Brown trout	7.5 NTU	Bachman 1984
	Lahontan cutthroat trout and Lahontan redside shiner	3.5-25 NTU	Vinyard and Yuan 1996
Reduced reaction distance	Lake trout, rainbow trout, cutthroat trout	3.2 – 7.4 NTU	Vogel and Beauchamp 1999
	Brook trout	0 – 43 NTU	Sweka and Hartman 2001
Reduced growth	Juvenile coho and steelhead	22-113 NTU	Sigler 1980
	Juvenile coho and steelhead	as low as 25 NTU	Sigler et al. 1984
Reduced survival	Juvenile coho	15 – 27 JTU	Smith and Sykora 1976
Reduced primary production	Algae/periphyton	3 – 25 NTU	Lloyd et al. 1987
Reduced density	Benthic invertebrates	8.4 – 161 NTU	Quinn et al. 1992
Reduced feeding rate, food assimilation, and reproductive potential	*Daphnia pulex*	10 NTU	McCabe and O'Brien 1983

Both pelagic and benthic invertebrates are affected by turbidity. A turbidity level of 10 NTU caused significant declines in feeding rate, food assimilation, and reproductive potential of *Daphnia pulex* (McCabe and O'Brien 1983). In a New Zealand stream subjected to clay discharges from alluvial gold mining (range in mean of NTU from 8.4-161 following addition of clay), Quinn et al. (1992) found invertebrate densities were significantly lower at all downstream sites ranging from 9-45% (median 26%) of densities at matched upstream sites.

In addition to the periphyton, macroinvertebrate, and salmonid effects, warmwater fish are also affected by turbidity. Work on largemouth bass and green sunfish showed altered behavior at 14-16 JTU (Heimstra et al. 1969). In Georgia, the highest fish Index of Biotic Integrity (IBI) values were found in streams with low-flow turbidity values less than 6 NTU (Walters et al. 2001). IBI values were consistently lower in streams with low-flow turbidity values exceeding 8 NTU.

It is not uncommon for increased turbidity levels resulting from human activity to affect downstream aquatic life. From the above, effects of chronic exposure to increased turbidity are evident - reduced feeding, resulting in reduced growth if prolonged, and eventual avoidance. On the other hand there is evidence that short exposures to very high turbidities (100,000 ppm), have no lasting effect (Wallen 1951). A lack of response to episodes of increased sediment loading is not contradictory as tolerance to brief periods of high sediment levels is a trait essential to survival in an environment of spring freshets and capricious floods (Gammon 1970). Instream construction activities generate sediments in an amount that is unlikely to meet reasonable criteria that have been set according to effects of upland activities (Reid and Anderson 1998). Downstream of culvert removal activities in Idaho, turbidity levels peaked at 92 NTU above background though levels recovered to background often at night following cessation of construction activity, and at completion of the project (Wegner 1998). While brief spikes in turbidity may be benign, frequent episodes are not (Shaw and Richardson 2001).

2.2.2 Other states

Turbidity in Idaho should not be greater than 50 NTU instantaneous or 25 NTU for more than 10 consecutive days above baseline background (Idaho Department of Environmental Quality n.d.a.). This standard is similar to other state and province standards (Table 2). Most of the other entities also relate their standard to a baseline background except for Montana which relates its standard to a naturally occurring (natural background) turbidity level. Wyoming tiers its turbidity criteria by ecoregion. The Washington Department of Ecology in its TMDL for the Yakima River (Joy and Patterson 1997) set a turbidity target of 25 NTU for irrigation return drains and tributaries. Alaska’s applicable water quality criterion for propagation of aquatic wildlife states that turbidity may not exceed 25 NTU above natural conditions. Several TMDLs approved in California specify a target of <= 20% above naturally occurring background (see Appendix C).

Alberta’s turbidity guidelines for freshwater aquatic life include targets for both low flow (clear) and high flows, and turbid waters. The guideline for clear flow is a maximum increase of 8 NTU above background levels for any short-term exposure (e.g., 24-hour) and maximum increase of 2 NTU above background for long-term exposure (e.g., 24 hours to 30 days). For high flow or turbid waters, instantaneous increases should not exceed 8 NTU when background is 8-80 NTU, and no more than 10% of background when background is > 80 NTU (Alberta Environment 1999).

Eastern U.S. states have established standards for controlling erosion and sedimentation that can occur during disturbance of uplands (Keyes and Radcliffe 2002) and instream crossings (Reid and Anderson 1998). Examples of criteria for upland disturbances include: Alabama -

Table 2. Water quality standards related to sediment for states and provinces surrounding Idaho. Note that background refers to baseline background except for Montana.

State/ Province	Turbidity	Total Suspended Solids Or Settleable Solids	Intergravel Dissolved Oxygen	Remarks
Colorado				For embeddedness, surface sediments and sub-surface sediments: Attainment when – > 73% of reference, or > 58% of reference and biology > 50% of reference
Montana	varies according to stream classification A - no increase above naturally occurring turbidity A1 - no increase above naturally occurring turbidity except under short-term authorization B1 - no more than 5 NTU (instantaneous) above naturally occurring turbidity B2 & B3 - no more than 10 NTU (instantaneous) above naturally occurring turbidity C1 - no more than 5 NTU (instantaneous) above naturally occurring turbidity C2 & C3 - no more than 10 NTU (instantaneous) above naturally occurring turbidity I - no increase in naturally occurring turbidity which will impair beneficial uses	narrative only - no change above background which will, or is likely to, impair uses	For A-1, B-1, B-2, C-1, and C-2 classified waters, 1-day minimum (instantaneous) of 5.0 mg/l, 7-day mean >= 6.5 mg/l	Class A streams are used for drinking water Class B streams are suitable for drinking water B1 streams are coldwater streams B2 streams are marginally coldwater streams B3 streams are predominantly warmwater streams Class C streams are marginal for drinking water C1 streams are coldwater streams C2 streams are marginally coldwater streams C3 streams are predominantly warmwater streams Class I streams are presently impaired with goal of improving water quality to support uses

Table 2 (cont'd). Water quality standards related to sediment for states and provinces surrounding Idaho. Note that background refers to baseline background except for Montana.

State/ Province	Turbidity	Total Suspended Solids Or Settleable Solids	Intergravel Dissolved Oxygen	Remarks
Oregon	no more than a 10% cumulative increase relative to an immediately upstream control point	sediment has a narrative standard - not to exceed deposits deleterious to fish or aquatic life or injurious to public health	minimum spatial median of 6.0 mg/l for salmonid spawning streams	
Nevada	site specific for major water bodies based on the most restrictive beneficial use of the water body	TSS - 25 - 80 mg/l (instantaneous), generally coldwater 25 mg/l and warmwater 80 mg/l		Settleable Solids - narrative only - waters must be free of substances from controllable sources which settle in sufficient amounts to interfere with any beneficial use
Utah	varies according to stream classification Class 2A, 2B, 3A, & 3B watersheds - not to exceed 10 NTU (instantaneous) above background Class 3C & 3D watersheds - not to exceed 15 NTU (instantaneous) above background	narrative only - unlawful for any person to discharge or place any substance which produces undesirable physiological responses in desirable resident fish or aquatic life		Class 2A waters - protected for primary Class 2B waters - protected for secondary contact recreation Class 3A waters - protected for coldwater species of game fish and other cold water aquatic life Class 3B waters - protected for warmwater species of game fish and other warm water aquatic life Class 3C waters - protected for nongame fish and other aquatic life Class 3D waters - protected for waterfowl, shore birds, and other water-oriented wildlife not included above

Table 2 (cont'd). Water quality standards related to sediment for states and provinces surrounding Idaho. Note that background refers to baseline background except for Montana.

State/ Province	Turbidity	Total Suspended Solids Or Settleable Solids	Intergravel Dissolved Oxygen	Remarks
Washington	varies according to class of water body Class A A & A - not to exceed 5 NTU (instantaneous) over background if background is 50 NTU or less; if background is greater than 50 NTU cannot exceed a 10% increase (instantaneous) Class B & C - not to exceed 10 NTU (instantaneous) over background if background is 50 NTU or less; if background is greater than 50 NTU cannot exceed a 20% increase (instantaneous)	narrative only - no degradation which would interfere with or become injurious to existing beneficial uses		Class AA - extraordinary waters Class A - excellent waters Class B - good waters Class C - fair waters
Wyoming	varies according to stream classification Class 1& 2 watersheds with coldwater fisheries - not to exceed 10 NTU (instantaneous) above background Class 1& 2 watersheds with warmwater fisheries & Class 3 watersheds - not to exceed 15 NTU (instantaneous) above background	narrative only - no human-induced quantities which could result in significant degradation of habitat for aquatic life	For class 1, 2, and 3 waters, 1-day minimum (instantaneous) of 5.0 mg/l, 7-day mean >= 6 5 mg/l	Class 1 watersheds - outstanding waters Class 2 watersheds - non-class 1 watersheds that support game fish Class 3 watersheds - non-class 1 watersheds that support non-game fish
British Columbia	varies according to water use aquatic life - not to exceed 5 NTU (instantaneous) over background if background is 50 NTU or less; if background is greater than 50 NTU, cannot exceed a 10% increase (instantaneous)	varies according to water use aquatic life - not to exceed 10 mg/l (instantaneous) if background is 100 mg/l or less; if background is greater than 100 mg/l, cannot exceed a 10% increase (instantaneous)	instantaneous minimum of 6	Light Penetration: average minimum Secchi disk >= 1.5 m, taken over 30-day period (at least 5 samples) Subsurface Sediments: No significant accumulation by weight of particles <3mm

background + 50 NTU; Georgia - background + 10 NTU for trout streams, background + 25 NTU for non-trout streams; Florida - background + 29 NTU; North Carolina - Background + 10 NTU for trout streams, background + 50 NTU for non-trout streams; South Carolina - background + 10%; Tennessee - background + 50 NTU; and, Vermont - background + 10 NTU. Separate criteria for permitted instream activities consider a mixing zone or time period which are exempt from turbidity limitations (Table 3).

Eastern states have established standards for controlling erosion and sedimentation (Table 3) that can occur during disturbance of uplands (Keyes and Radcliffe 2002) and instream crossings (Reid and Anderson 1998). The instream criteria for permitted activities consider a mixing zone or time period which are exempt from turbidity limitations.

Table 3. Examples of turbidity criteria that account for upland and instream disturbances.

State	Turbidity restriction
Alabama	Upland: Background + 50 NTU
Florida	Upland: Background + 29 NTU Instream: Not to exceed 29 NTUs outside the 800 meter downstream mixing zone. Within the mixing zone, not to exceed 1000 NTUs for 12 consecutive hours, or 3000 NTUs for 3 consecutive hours.
Georgia	Upland: Background + 10 NTU for trout streams, background + 25 NTU for non-trout streams Instream: Post construction levels are not to exceed 20 NTUs
New Hampshire	Instream: Not to exceed 10 NTUs above background outside of a mixing zone. For watercourses greater than 10 ft wide, the mixing zone is 1000 ft. For those less than 10 ft wide, it is 500 ft.
New York	Instream: Not to exceed 10 NTUs outside of a 300 ft mixing zone.
North Carolina	Upland: Background + 10 NTU for trout streams, background + 50 NTU for non-trout streams
South Carolina	Upland: Background + 10%;
Tennessee	Upland: Background + 50 NTU
Vermont	Upland: Background + 10 NTU

2.2.3 Recommendation

We affirm the current Idaho water quality standard (Water Quality Standards and Wastewater Treatment Requirements 58.01.02.250.02.e) to protect cold water aquatic life, turbidity below any applicable mixing zone should not be greater than 50 NTU instantaneous or 25 NTU for more than 10 consecutive days above baseline background (Idaho Department of Environmental Quality n.d.a.). We feel that this standard is most applicable to periods of high flow whether during the time of annual runoff (i.e., spring for most Idaho streams) or episodic storm events.

Some evidence suggests that detrimental effects to biota can occur with turbidity as low as 10 NTU. Therefore, we recommend that chronic turbidity not exceed 10 NTU at summer base flow.

2.3 Total Suspended Solids and Suspended Sediment

Total suspended solids (TSS) and suspended sediment are sampled and analyzed differently, and therefore often give different results for the same waterbody. The target addressed here regards TSS, not suspended sediment. Protocols for measuring TSS as recommended by the U.S. EPA are included in Appendix B, where a comparison to the suspended sediment analytical method (of the USGS) is also given. Direct measurement of TSS is limited by standard equipment to particle sizes of 2.0 mm or less. This is smaller than the range of fines considered in surface or subsurface sediments (up to 6.4 mm), but is more representative of the particles actually found in suspension. Larkin and Slaney (1996) found that deposition in sediment traps was highly correlated with suspended sediment, suggesting that total suspended solids could be related to surface and subsurface sedimentation measures.

2.3.1 Biological background

Much information is available on the effects of total suspended solids (TSS) and suspended sediment on aquatic fauna, particularly fish. Direct acute effects of suspended sediment on adult fish may not be observed until concentrations reach thousands to tens of thousands of mg/L (Waters 1995, Everest et al. 1987, Newport and Moyer 1974, Wallen 1951, Lake and Hinch 1999). However, the effects of sediment are dependent on the duration (Newcombe and MacDonald 1991) and frequency (Shaw and Richardson 2001) of exposure as much as concentration, so concentration measures must be considered over time to be meaningful. Most researchers report greater sensitivity of younger fish, particularly sac fry, with increased mortality evident at concentrations on the order of a thousand mg/L or less (Anderson et al. 1996, Newcombe and MacDonald 1991). Responses to lower concentrations are largely behavioral (avoidance, reduced feeding, coughing, seeking refuge) which can lead to reduced growth if exposure is frequent or persistent. As noted by Gammon (1970), loss of fisheries due to avoidance or failed reproduction is as real as direct mortality, the cause makes little difference to the fisherman (or the fish community).

A significant relationship has been documented between suspended sediment duration (concentration x days) and percent egg-to-fry survival of rainbow trout (Slaney et al. 1977). Survival dropped below 30% at about 1000 mg/L-day, and approached zero at about 2000 mg/L-day. The relationship between suspended sediment duration and percent fines by weight in the gravel of simulated redds was also found to be significant. Arctic grayling sac fry exposed to suspended sediment averaging 750 mg/L over a 96-hour period experienced nearly four times the mortality of a control group exposed to suspended sediment averaging 105 mg/L (Reynolds et al. 1989). Bachmann (1958) observed a cessation of feeding in cutthroat trout exposed to a suspended sediment concentration of 35 mg/L over a 2-hour period.

In a study of sub-lethal responses to low-turbidity (large particle) suspended sediments, blood sugar levels (a secondary indicator of stress) were found to increase at low levels of short duration (Servizi and Martens 1992). Coughing frequency increased significantly between 2 and 240 mg/L in a 24-hour exposure. Avoidance behavior climbed steadily with increasing TSS, but was inconsistent until levels reached more than 4000 mg/L in 96 hours. These relatively high levels of suspended solids may be attributed to the composition of the particles (240 mg/L was equivalent to approximately 30 NTU). Thus, higher concentrations of larger suspended sediments may not be as disruptive of normal salmonid behavior as are smaller suspended sediments associated with higher turbidities. Fish IBI values were consistently low in Georgia streams with low-flow TSS values exceeding 8 mg/L (Walters et al. 2001). The highest IBI values were found in streams with low-flow TSS values less than 6 mg/L.

Human activities in and around waterbodies often result in varied sediment input during the active phase of a project. Stream restoration activities in bull trout habitat of the Middle Kootenai River (MT) were monitored for TSS before, during, and after instream disturbances for culvert removals and road repair (Wegner 1998). Instream disturbance had an obvious effect on downstream TSS values. With pre-construction values below 20 mg/L, peak values during the construction phase reached as high as 1,574 mg/L. Return to pre-construction levels took two to three days after construction activity stopped. Another example described by Wegner (1998) showed that TSS values never peaked above 16 mg/L when measured 1000 feet below the construction activity. Incidentally, these instream activities were considered necessary for the long-term rehabilitation of bull trout habitat, which, from the perspective of USFS hydrologists, outweighed any short-term impacts. Wegner found that variability in sediment production could be partially attributed to the diligence of equipment operators in reducing sediment sources during disturbances.

Newcombe and Jensen (1996) developed concentration:duration charts based on the effects (e.g., behavioral, sublethal, para-lethal, lethal) of the two parameters on the life stages of various fish. Miller used the Newcombe and Jensen charts in his development of recommendations for suspended sediment targets in the lower Boise River (IDEQ 1998a). Miller's TSS targets of geometric means not to exceed a 60-day chronic exposure of 50 mg/L or 14-day acute exposure of 80 mg/L were adopted for the lower Boise River TMDL.

Discretion must be used when applying Newcombe and Jensen's models. For the models, Severity of Effect was categorized into nil (< behavioral or 0); nil or behavioral (< sublethal or 3); and nil, behavioral, or sublethal (< lethal or 8). The duration which met the Severity of Effect at various concentrations was then calculated using the model formulas. Table 4 shows durations for sub-lethal effects at various concentrations. 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).

Table 4. Duration (days) for a sub-lethal Severity of Effect for concentrations (mg/L) of suspended sediment based on models from Newcombe and Jensen (1996). Behavioral effects were predicted to occur in less than 1 day at all concentrations (not shown).

	Duration[1]				
Suspended Sediment Concentration	**Salmonids**			**Salmonids & Non-salmonids**	**Non-salmonids**
	Juveniles & Adults	**Adults**	**Juveniles**	**Eggs & Larvae**	**Adults**
5	541	1841	252	1	5
10	233	613	124	1	4
25	76	143	49	1	3
50	33	48	24	1	2
80	19	23	15	1	2
100	14	16	12	1	2

[1] Duration (days)=(EXP((Effect-a-(c*LN(SS))/b))/24

Information is not quite as abundant on the effects of suspended sediment on macroinvertebrates. Rosenberg and Wiens (1978) exposed benthic invertebrates to 8 mg/L of suspended sediment for 5 hours and observed increased rate of drift. They found that invertebrates most sensitive to sediment, i.e., those species which drifted almost immediately after the sediment addition, included important salmonid prey (Plecoptera and Ephemeroptera). Populations of Ephemeroptera disappeared when exposed to greater than 29 mg/L of suspended sediment for 30 days (M. P. Vivier, personal communication in Alabaster and Lloyd [1982]). Macroinvertebrate drift tends to increase with longer repeated pulses (Shaw and Richardson 2001) and with smaller particle sizes (Runde and Hellenthal 2000). The filter feeding zooplankton *Daphnia pulex* displayed a reduced capacity to assimilate food when exposed to 24 mg/L of suspended sediment for only 15 minutes (McCabe and O'Brien 1983).

Higher levels of total suspended solids affect primary production, not only by reducing light penetration but also through abrasion. Lewis (1973) observed severe abrasive damage to the leaves of the aquatic moss *Eurhynchium riparioides* after 3 weeks of exposure to 100 mg/L of coal-dust.

Several groups have categorized concentrations of total suspended solids based on their effect on the aquatic environment, primarily fish (Table 5). The European Inland Fisheries Advisory Commission (EIFAC 1964) in their review of suspended solids in relation to fisheries concluded that concentrations less than 25 ppm have no harmful effect on fisheries; concentrations of 25-80 ppm will have some effect but it is possible to maintain good to moderate fisheries; concentrations of 80-400 ppm are unlikely to support good fisheries; and, concentrations greater than 400 ppm will at best result in poor fisheries. Gammon (1970) felt that the suspended solids criteria proposed by EIFAC may be too liberal for fish populations in the U. S. (Lloyd 1987). Others who agreed with EIFAC proposed criteria for high (0-25 mg/L) and moderate (26-80 mg/L) protection include Alabaster (1972), NAS and NAE (1973), and Alabaster and Lloyd (1980). Newport and Moyer (1974) recommended high protection at 0-25 mg/L and moderate protection at 26-100 mg/L. Wilber (1969, 1983) was slightly more liberal on high protection at 0-30 mg/L and moderate protection at 30-85 mg/L. Hill (1974) was much more conservative recommending a high protection range of 0-10 mg/L as was DFO (1983) in their recommendation of 0 mg/L for high protection. DFO also proposed a limitation of 1-100 mg/L for moderate protection. The U. S. Environmental Protection Agency (Mills et al. 1985) has classified impairment of aquatic habitat or organisms by TSS as: concentrations less than 10 mg/L - improbable; concentrations greater than 10 mg/L and less than 100 mg/L - potential; and concentrations greater than 100 mg/L - probable. Suspended sediment effects linked with high, moderate, or low habitat conditions for endangered species were developed by Clearwater and Nez Perce National Forests and Cottonwood (Idaho) area BLM (Matrix 1998). High levels of habitat conditions on these federal lands were associated with suspended sediment levels >= 25 mg/L for up to 10 days and >= 80 mg/L for up to 5 days in a year. Habitat conditions were low with >= 25 mg/L for more than 31 days or >= 80 mg/L for more than 11 days in a year. Intermediate levels were considered moderate habitat conditions.

2.3.2 Other States

No state or province has a standard or target for suspended sediment but several address total suspended solids (Table 2). Nevada has a standard of 25-80 mg/L with coldwater streams generally using the 25 mg/L standard and warmwater streams generally having an 80 mg/L standard (Adele Basham, Nevada Division of Environmental Protection, personal communication). Utah in their water quality management plan for the lower Bear River (Ecosystem Research Institute 1995) adopted two TSS targets - 35 mg/L or 90 mg/L - based on a 75th percentile concentration from historic TSS sampling. The Washington Department of Ecology in its TMDL for the Yakima River (Joy and Patterson 1997) set a TSS target of 56 mg/L for irrigation return drains and tributaries. For the Umatilla River (OR) sediment TMDL the target was set at <= 80 mg/L or the TSS value locally calibrated to a turbidity of 30 NTU (ODEQ 2001). In the Deep Creek (MT) TMDL, the target for TSS was related to discharge, where the slope of the regression of TSS on discharge was expected to be 0.26 or better (Endicott and McMahon 1996). Both the Gualala River and Trinity River TMDLs (CA) specified only decreasing trends in suspended sediments (U.S. EPA 2001a, U.S. EPA 2001b). Alberta water quality guidelines recommend suspended solids not exceed 10 mg/L above background for both acute and chronic conditions (Alberta Environment 1999).

Table 5. Suggested levels of TSS (mg/L) for categorizing fish habitat conditions.

Habitat Effects			
Least effects, High protection, Best conditions	**Some effects, Moderate protection, Moderate conditions**	**Definite effects, Low protection, Poor conditions**	**Citation**
< 25	25-80	>80	EIFAC 1964
< 25	26-80	>80	Alabaster 1972, NAS and NAE 1973, and Alabaster and Lloyd 1980
< 25	26-100	>100	Newport and Moyer 1974
<30	30-85	>83	Wilber 1969, 1983
<10			Hill 1974
0	1-100	>100	DFO 1983
<10	10 - 100	>100	Mills et al. 1985
>= 25 for <= 10 days and >= 80 for <=5 days in a year	>=25 for 11 - 30 days and >=80 for <=10 days in a year	>= 25 for > 31 days or >= 80 for >=11 days in a year	Matrix 1998

In British Columbia, the ambient water quality guidelines state that expectations for suspended sediments should be related to background conditions. When background levels are at or below 25 mg/L, induced suspended sediment concentrations should not exceed background levels by more than 25 mg/L during any 24-hour period (hourly sampling preferred) or by more than 5 mg/L for inputs that last between 24 hours and 30 days (daily sampling preferred). With turbid background conditions (25 - 250 mg/L), induced suspended sediment concentrations should not exceed background levels by more than 25 mg/L at any time. When background exceeds 250 mg/L, suspended sediments should not be increased by more than 10% of the measured background level at any one time.

2.3.3 Recommendation

We propose no specific targets for total suspended solids. The effects of sediment are dependent on concentration and duration of exposure. We recognize that there can be effects on biota at concentrations of total suspended solids above 25 mg/L, and many papers recommend a long-term exposure of not greater than 80 mg/l to maintain a good fish community (EIFAC 1964, NAS and NAE 1973). Any recommendations regarding concentration or duration would be difficult to generalize for the entire state because of differences in seasonal flows, episodic flows, geology, and hydrography. Site-, season-, and flow-specific targets should be developed using data collected from appropriate reference streams or upstream sites. To allow for spikes in TSS that may occur with spring runoff or episodic storm events, targets should represent averages per unit time (e.g., Total Suspended Solids not to exceed an average of 50 mg/L over a 28-day period). The TMDL writer would be well advised to consider these effects when establishing TSS targets.

3. Streambed Measures

The proportion of fine sediments among stream substrate components can affect salmonids in several ways. Spawning trout may have more difficulty building redds if sufficient quantity of appropriate sized gravel has been displaced, cemented, or buried by fine sediment deposits. When gravels are cleaned of fine sediments and eggs deposited, later intrusion of fine sediments into the redd can reduce egg and alevin survival. If gravels become clogged with fine sediments permeability is reduced and the resulting decrease in flow provides less oxygen to and removes less waste from incubating eggs. Fine sediments that clog interstitial spaces of a redd can physically block emergence of alevins. In addition, substrates that have interstitial spaces filled with fine sediments are poorer habitat for newly emerged salmonid fry and for invertebrate prey.

Surface fines and embeddedness are similar ways of measuring the suitability of stream substrates for invertebrate and salmonid habitation. Embeddedness measures the degree to which cobbles and large gravels are buried because of fine sediment deposition. Surface fines describe the percentage of streambed area with exposed fine sediments. Streambeds can be partially embedded without having fines exposed. There also can be exposed fines in some part of the streambed without embeddedness in others. The measures are related, but are not directly comparable. With either measure it is important to assess areas used by fish for spawning, e.g. riffles and pool tail outs.

The Wolman pebble count method yields not only percent surface fines, but also allows calculation of the median substrate size (d50), which has been used as a sediment target. The number of counts that represent fine sediment influence the median of the distribution, but other variables that are not related to fine sediment supply also determine the d50, such as underlying geology. A target regarding d50 may best be left as “improving trends”, though several TMDLs in California specify a threshold for the mean (>=69 mm) and minimum (>=37 mm) for multiple samples (see Appendix C). The geometric mean particle size of Yellowstone cutthroat trout spawning areas in Pine Creek, Idaho averaged 16.6 mm (Thurow and King 1994).

While surface fines and embeddedness are more apparent to the human observer, and thus easy to measure, it is subsurface or depth fines which really alter suitability of spawning habitats. The amount of subsurface fine sediments as measured at the head of riffles in likely spawning areas can be an indication of redd site suitability, conditions for egg survival and alevin emergence in the constructed redd, and habitat quality for emerged fry and prey. However, redd construction can actually change the ambient streambed by removing fine sediments and re-shaping the topography to induce water infiltration (Kondolf 2000). Subsurface sediments are measured by driving a metal cylinder into the streambed, carefully removing the sediment, and working the sample through a series of sieves to determine the particle size distribution. Exacting measurement requires in situ freezing of the core to assure complete removal.

Trying to relate surface fines or embeddedness to subsurface fines is tenuous at best. Platts et al. (1989) on the South Fork Salmon River found a significant but weak relationship between surface and subsurface fines. Nelson et al. (1997) found that relationships between Wolman pebble count estimates and estimates from core samples (i.e., depth fines) were poor.

The Riffle Stability Index (RSI) indicates the relative percentage of the streambed that is mobile during channel forming flows. Bed mobility affects habitat stability for invertebrates, scouring of redd sites, and formation or filling of pools. It is more related to pool quality and abundance than it is to fine sediments. In a survey of B-channel streams of the St. Joe River drainage in northern Idaho, reaches with lower RSI values had greater residual pool volume (Cross and Everest 1992). Pool habitat provides critical refuge for juvenile and adult salmonids.

3.1 Embeddedness

3.1.1 Biological background

Embedded substrates lack the interstitial spaces that allow intergravel flow and provide habitat and cover for benthic invertebrates and juvenile fish. The value of measuring embeddedness varies according to area. Embeddedness targets are applicable primarily to riffles in cobble-bedded streams, though interstitial spaces in pool and marginal substrates can also provide valuable habitat for juvenile salmonids. In a study of habitat restoration in a highly sedimented Idaho stream, Hillman et al. (1987) found that interstitial spaces among cobbles may be essential winter habitat for juvenile chinook salmon. When large cobble was added to an otherwise embedded stream, juvenile populations increased. When that same cobble became embedded, the population decreased.

Information relating embeddedness levels to effects on aquatic fauna is limited. Embeddedness in the range of 67% caused changes in the macroinvertebrate fauna (Bjornn et al. 1977). Nelson et al. (1997) found an average embeddedness of 35% in natural streams in granitic watersheds (i.e., South Fork Salmon River, Idaho). Based on their review of existing data, Chapman and McLeod (1987) were unwilling to generalize on the effects of embeddedness level of surface fines and salmonid rearing densities. They did conclude that abundance of insects declines at an embeddedness level of about 2/3 to 3/4. They go on to say, however, that embeddedness levels this high would probably violate spatial needs of overwintering fish for sediment-free interstices.

The Payette and Boise Forest Plan (cited by Nelson et al. 1997) specifies that embeddedness conditions should be demonstrably improving. It also sets thresholds for streams in the South Fork Salmon River watershed that are contingent on 1988 sediment conditions. For locations with 1988 embeddedness measured at greater than 32%, five year average embeddedness is not to exceed 32%, with no single year exceeding 37%. For locations with 1988 embeddedness measured at greater than 27%and less than 32%, five-year average embeddedness is not to exceed 27%, with no single year exceeding 29%. Nelson et al. (1997) found these thresholds to be too restrictive in light of natural embeddedness conditions, which were 35% embedded on average in the South Fork Salmon River. They suggested embeddedness targets and free matrix percentage appropriate for their findings (Table 6).

Table 6. Cobble embeddedness and free matrix criteria proposed by Nelson et al. (1997) for streams in granitic Idaho watersheds. Trend data must be based on a minimum of 3 years of data. Criteria 1 – 3 are always applicable. Only one of criteria 4 – 7 are applied, depending on starting conditions and the parameter being measured.

1	Demonstrated improvement in cobble embeddedness or establishment of a significant downward trend using either measured or predicted cobble embeddedness (but not both);		
2	Measured or predicted embeddedness levels consistently at or near 50% should be considered unacceptable;		
3	Demonstrated improvement in percent free particles from 30-hoop free matrix measurements or establishment of a significant upward trend;		
	Starting conditions	3 - 5 year average	No more than 2 of any 5 years
4	< 30% embedded	<30%	>35%
5	30 – 40% embedded	<40%	>45%
6	>20% free matrix particles	>20%	<15%
7	10 - 20% free matrix particles	>15%	<10%

Levels of embeddedness linked with high, moderate, or low habitat conditions for endangered species were determined for Clearwater and Nez Perce National Forests and Cottonwood (Idaho) area BLM (USDA-FS et al. 1998). High levels of habitat conditions were associated with embeddedness < 20%. At > 30%, habitat conditions were considered low. Intermediate embeddedness was considered a moderate habitat condition.

3.1.2 Collection Methods

A high degree of variability can result from embeddedness measures that are collected with different methods, calculations, or observers. Sylte (2002) and Kramer (1989) suggest that embeddedness values within a single method are sensitive to substrate size. Sylte also found that the embeddedness method used by Nelson et al. (2002a) and described below was more consistent and closer to visual estimates than other methods of calculating embeddedness. Both Nelson et al. (2002a) and Sylte (2002) found correlations between embeddedness values and free matrix particle counts. Nelson et al. went on to explain that the free matrix counts were more reliable, more representative of the entire stream reach, and could be used to predict embeddedness.

Cobble embeddedness: Embeddedness was measured within a 60 cm hoop randomly located in an area of potential spawning gravel with a water velocity between 24 and 67 cm/s and depth between 15 and 45 cm. Within the hoop, 100 particles were measured (extra hoops were used if 100 particles were not available in the first hoop). Two measurements per particle were recorded: the total height of the particle and the depth of the particle below the plane of embeddedness. Percent embeddedness for each particle is calculated as the embedded depth over the total particle height. Percent embeddedness for the sample is the average percent embeddedness.

Free matrix: The free matrix (those particles entirely unembedded) were counted within 30 randomly distributed 60 cm hoops. Embedded particles were then counted and tabulated separately. Only particles between 45 and 300 mm were counted, and only hoops in less than 60 cm of water were counted. The number of free particles divided by total particles is the percent free matrix.

3.1.3 Other states

Several approved TMDLs in California have a target for riffle embeddedness that is <= 25% or a decreasing trend toward 25% (see Appendix C). While the 25% figure is universal in the TMDLs that consider embeddedness, there is little supporting evidence for this threshold. The fact that an improving trend is also acceptable shows that the threshold was loosely interpreted.

New Mexico has established embeddedness thresholds for aquatic life use support. Streambeds that are less than 33% embedded represent fully supporting sediment conditions and are not compared to reference conditions. For streams with greater than 33% embeddedness, support is defined in comparison to reference conditions. Embeddedness values less than 27% greater than reference values are supporting and embeddedness values more than 40% greater than reference conditions are non-supporting (NMED 2002).

3.1.4 Recommendation

We cannot recommend a specific target for embeddedness of streambed cobble by fine (< 6.35 mm) material. IDEQ (1991) has previously recommended targets in the South Fork Salmon River TMDL: that is, for those streams with cobble embeddedness less than 32%, maintain the existing embeddedness level; for those streams that exceed the 32% threshold, reduce cobble embeddedness to a 5-year mean not to exceed 32% with no individual year to exceed 37%. Tim Burton (Boise National Forest, personal communication) also questioned trying to establish any universal embeddedness criteria, although he did feel that targets could be established for interstitial space using the Interstitial Space Index (ISI) method (Burton and Harvey 1990). Burton suggested that reference streams be used for establishing embeddedness, as measured by the procedure suggested by Burton and Harvey (1990), criteria within strata. For southern Idaho, streams would best be stratified according to geology (e.g., batholithic vs. metamorphic), size, and stream gradient.

3.2 Surface Sediment

3.2.1 Biological background

Salmonids prefer mid-sized substrates with interstitial cover to either fine sediment or boulders and bedrock. Ephemeroptera, Plecoptera, and Trichoptera (important fish-food organisms) also respond positively to gravel and cobble substrates (Waters 1995). However, the percent coverage of fine sediments by area and the effects on salmonids and invertebrates have not been extensively investigated. Several examples can be found that use a median or geometric mean particle size as an indicator of suitable habitat conditions (see Appendix C). The percent fines are integral to the particle size distribution, but Nelson et al. (1997) found no relationship between percent fines and median particle size. Some authors have argued against percent fines suggesting instead that geometric mean (Platts et al. 1979) or fredle index (Lotspeich and Everest 1981, Beschta 1982) be used. Richards and Bacon (1994) in their longitudinal study of Bear Valley Creek, Idaho, found stream size influenced macroinvertebrate colonization of the streambed surface more than fine sediment accumulation. Surface fines may be most useful in trend analysis.

Hill et al. (2000) found that percent fines (< 2 mm) negatively correlated with periphyton biomass in mid-Atlantic streams. In a study of 562 streams in four northwestern states, Raylea et al. (2000) found that changes in invertebrate communities (especially % Ephemeroptera, Plecoptera, Trichoptera [EPT]) occur as fine sediments (<= 2 mm) increase above 20% coverage by area. In an analysis of data from 279 stream sites in Idaho, Mebane (2001) found that higher levels of surface sediment less than 6.0 mm negatively affected EPT taxa and salmonid and sculpin fish species. Significant ($p < 0.05$) inverse relationships between number of EPT taxa and percentage of fine sediment measured across both bankfull and instream channel widths were found. More age classes of salmonids and sculpins were significantly ($p < 0.05$) associated with less instream fine sediments. Multiple age classes of both salmonids and sculpins were uncommon where average instream surface fines were greater than 30%, and nearly absent above 40%. Zweig et al. (2001) in their work on four Missouri streams determined that taxa richness significantly linearly decreased with increasing deposited sediment in 3 of 4 streams (over a range of 0 to 100% deposited sediments). Density, Ephemeroptera, Plecoptera, Trichoptera (EPT) richness, and EPT density were significantly negatively correlated with deposited sediment across all four streams. Taxa richness and EPT/Chironomidae richness were significantly negatively correlated in three streams.

A relationship exists between channel morphology and the expected sediment composition in a well adjusted or dynamically equilibrated channel. Overton et al. (1995) summarized sediment monitoring in the Salmon River basin, Idaho, and found that natural conditions for surface sediment averaged 25% in A-channels (SD = 23), 23% in B-channels (SD = 21), and 34% in C-channels SD = 25). Overall mean for all reaches equaled 26%with a standard deviation of 22. Mebane (2001) agreed with Overton et al. regarding natural surface sediment coverage. Percent surface fines (particles < 6 mm) were interpreted as indicating high, moderate, or low habitat conditions with respect to endangered species determinations in the Clearwater and Nez Perce National Forests and Cottonwood (Idaho) area BLM lands (USDA-FS et al. 1998). High levels of habitat conditions were associated with surface fines <= 10% in A- and B-channels and <= 20% in C- and E-channels. At >= 21% in A- and B-channels or >= 31% in C- and E-channels, habitat conditions were considered low. Intermediate sediment coverages were considered moderate habitat conditions. Surface fine sediment levels have been recommended by the Forest Service and Bureau of Land Management in their draft Environmental Impact Statement for the Upper Columbia River Basin (Interior Columbia Basin Ecosystem Management Project 1997). Their recommendations are stratified by channel type and watershed geology (Table 7).

Table 7. Surface fine sediment (< 6.0 mm) levels developed by the Forest Service and Bureau of Land Management for the Upper Columbia River Basin. In metamorphic C channels, fine sediment levels were to be established by local field units.

	Geologic Type		
Channel Type	**Plutonic**	**Volcanic**	**Metamorphic**
A	26	25	14
B	23	27	16
C	37	17	no data

In chinook salmon and steelhead trout spawning areas of the South Fork Salmon River (Idaho), surface and subsurface fine sediment (< 4.75 mm) accumulations were monitored for a 20-year period (Platts et al. 1989). The period began with a logging moratorium imposed because of detrimental logging activity, followed by streambed recovery, and resumption of limited logging activity. In the worst condition (1966), surface sediments covered as much as 46% of the stream area. By 1985, surface sediments averaged 19.7% of the spawning area and further recovery seemed possible.

3.2.2 Other states

Many states have general narrative standards that do not allow any activity which would result in the degradation of beneficial uses. The draft South Steens TMDL in Oregon references objectives in a water quality management plan developed by the Bureau of Land Management, one of which calls for a “downward trend” in “percent of silt and sand on substrate” with an eventual goal of 20% or less (ODEQ 1998). The Upper Grande Ronde River (Northeast Oregon) Sub-basin TMDL specified a target of 20% or less of the streambed area covered in fine sediments (ODEQ 2000 citing the PACFISH target). The Deep Creek TMDL in Montana, although not setting a surface fines target, does suggest surface fines monitoring through Wolman pebble counts (Endicott and McMahon 1996).

New Mexico has established surface sediment thresholds for aquatic life use support. Streambeds that have less than 20% fines (< 2 mm, by pebble count) are fully supporting. For streams with greater than 20% fines, support is defined in comparison to reference conditions. Percent fines values less than 27% greater than reference values are supporting and percent fines values more than 40% greater than reference conditions are non-supporting (NMED 2002).

3.2.3 Recommendation

Despite the congruence of the work of Overton et al. (1995) and Mebane (2001), we cannot recommend a specific target for surface sediment (i.e., surface fines). Chapman and McLeod (1987) found no functional predictors that would serve in evaluating quantitative effects of surface sediment on the natural incubation, rearing, or wintering phases of salmonids in the northern Rocky Mountains. Tim Burton (Boise National Forest, personal communication) agreed that establishing a target for surface sediment would be difficult. He did maintain that surface sediment information (e.g., Wolman pebble count) can be used to monitor trends. Burton pointed out that the Wolman pebble count, in addition to producing the percent surface fines, also allows for an estimate of median particle size. Potyondy and Hardy (1994) found pebble counts useful in assessing the effect of forest fires on fine sediment in streams of the Boise River drainage. Furthermore, the Payette and Boise National Forests have had success using the 30 hoop free matrix procedure (Nelson et al. 1997) for surface sediment in the granitic watersheds of the South Fork Salmon River, Idaho.

3.3 Subsurface Sediment

3.3.1 Biological background

Information on the biological effects of subsurface sediment varies according to the size of sediment and geographic area of concern. Some of the variability is reduced by standardizing the habitat and stream types (e.g., Rosgen [1994] level II) sampled. Subsurface sediment targets are most applicable in riffles and spawning areas in streams with gravel/cobble/boulder streambeds.

Excessive subsurface fines have detrimental effects on salmonid and invertebrate habitat suitability and redd conditions. The target for subsurface sediments is supported by studies of salmonid embryo survival rates in redds with varying fine sediment composition. The laboratory and *in situ* redd studies must be carefully applied such that expected redd conditions can be deduced from ambient streambed conditions. A comparison of ambient streambed subsurface fines to substrate composition in adjacent redds was made by Kondolf (2000), who found that redds typically had one-third less fine sediment than the adjacent streambed throughout the incubation period. Applying results of laboratory studies of redd sediment composition for predicting egg survival and fry emergence in natural conditions should take the gravel cleaning actions of spawning into account or be used only to detect trends or ranks of condition (not numerically absolute conditions).

Other studies on sediment and salmonid survival abound. Hall (1986) found survival (eyed egg to emergence) of coho, chinook, and chum salmon to be only 7-10% in gravel mixtures made up of 10% fines < 0.85 mm as compared to 50-75% survival in gravel mixtures with no fines < 0.85 mm. Reiser and White (1988) observed little survival of steelhead and chinook salmon eggs beyond 10-20% fines < 0.84 mm. In a laboratory study, fry survival declined significantly when fines < 0.25 mm in diameter approached 5% of the substrate in the egg pocket of artificial trout redds (Bjornn et al. 1998). In the Kootenai National Forest (MT), numbers of bull trout redds were compared to percent subsurface fines (Wegner 1998, 2003a). The numbers of redds were apparently negatively related to percent subsurface fines in spawning areas, though the comparisons were not statistically rigorous and another report showed ambiguous response to slight changes (Wegner 2003b). Based on Burton et al. (1990), a 27% target for subsurface sediment (< 6.5mm) would be applicable to central and southern Idaho.

In a study of Yellowstone cutthroat trout, Thurow and King (1994) described redd siting and substrate characteristics, and tested the effect of habitat conditions on the completed redds in Pine Creek, Idaho. They found that the spawned sites contained particles up to 100 mm, though

most were less than 32 mm, 20% were less than 6.35 mm, and 5% were less than 0.85 mm. Results from Nelson et al. (2002b) showed that in important spawning areas of the Payette and Boise National Forests, smaller fines (< 0.85 mm) consistently represented less than 10% of the core samples. With the exception of one site that had been severely degraded by historic mining activities, the percentage of smaller fines averaged approximately 5% over a 25-year monitoring period. However, in these regions of restricted logging, the percentages of larger fines (< 6.3 mm) from the same sample locations were routinely found to be near 30%. While these are not pristine watersheds, they have been managed for sediment reduction since the 1960s (with a 20-year logging moratorium followed by limited logging).
Upon testing a fisheries sediment response model in the Clearwater River drainage, Nelson and Platts (1988) recommended that three tiers of subsurface sediment conditions be delineated. At < 20% subsurface fines (< 6.3 mm), the conditions are considered good for embryo incubation and survival. From 20 to 27%, conditions are marginal and influences of other environmental factors cause variable survivability. Above 27% subsurface fines, survivability was considered improbable.

Federal land management agencies (Forest Service and BLM) have developed guidelines specific to their local conditions. Evaluation of the effects of subsurface sediment on habitat conditions on Clearwater and Nez Perce National Forests and Cottonwood (Idaho) area BLM lands showed high levels of habitat conditions associated with < 20% fines (<= 6 mm) at depth, while at > 25% fines, habitat conditions were considered low (USDA-FS et al. 1998).

On the Salmon-Challis National Forest, the Forest Plan for the Challis Zone sets a threshold of 30% fines < 6.3 mm such that activities which would result in the exceedance of the threshold are not allowed (Challis National Forest 1987). The Forest Plan for the Salmon Zone has standards of 20% fines by depth for streams supporting anadromous fish and 28.7% fines by depth for streams supporting only resident salmonid populations (Salmon National Forest 1987). Recent thinking on the Salmon and Challis National Forest bases subsurface sediment standards on watershed geology (Betsy Rieffenberger, Salmon and Challis National Forest, personal communication). In quartzite drainages, the Forest classifies streams in good condition as having subsurface sediment < 20%, streams in fair condition have 20-25% fines, and streams in poor condition will have over 25% fines. In granitic, volcanic, and sedimentary drainages, streams in good, fair, and poor condition will have < 25%, 25-30%, and > 30% fines, respectively.

Studies documenting effects of fine sediment on macroinvertebrates are limited. A field study of benthic invertebrate colonization of trays with varying percentages of fine sediments showed significant (though weak) responses to increases in sediment from 0 to 30% (Angradi 1999).

3.3.2 Collection Methods

Core sampling methods described by Nelson et al. (2002b) for the Salmon River watershed could be applied throughout the state. These or similar methods would produce data that are comparable to the recommended targets. Generally, 40 samples were collected using a 30.4 cm diameter core, worked into the gravel to a depth of 25 cm in randomly selected locations within potential spawning areas of specified reaches. Randomization was by way of a rectangular grid superimposed on the reach. Approximately 8–10 L of streambed material were excavated from the core sampler. Sediment samples were then strained through sieves of decreasing mesh size and drained to remove excess water. The volume of sediment retained by each sieve was determined on-site using water displacement measures. Sieve sizes should include, at a minimum, 0.85 mm and 6.3 mm.

3.3.3 Other states

Several states and one province have established targets for subsurface sediments. In British Columbia, targets for aquatic life use are that fine sediment in streambed substrates should not exceed 10% having a diameter of less than 2.00 mm, 19% having a diameter of less than 3.00 mm, and 25% having a diameter of less than 6.35 mm at potential salmonid spawning sites. Montana recognized a subsurface sediment target in the Deep Creek TMDL (Endicott and McMahon 1996). They set a subsurface sediment target of 30% fines < 6.35 mm, to be monitored by triplicate samples in at least three riffles.

Alaska's applicable water quality criterion for sediment for propagation of aquatic wildlife states that: the percent accumulation of fine sediment in the range of 0.1 mm to 4.0 mm in the gravel bed of waters used by anadromous or resident fish for spawning may not be increased more than 5 percent by weight above natural conditions. In no case may the 0.1 mm to 4.0 mm fine sediment range in those gravel beds exceed a maximum of 30 percent by weight.

Several approved TMDLs in California set targets for subsurface sediments that are based on multiple studies. The approved TMDLs (e.g., U.S. EPA 2000, U.S. EPA 2002) set targets that were within the ranges of fine sediments found to be suitable for spawning by Chapman (1988) and Kondolf (2000), who summarized conditions in redds and spawning reaches. Most of the targets were for <= 14% intrusive fines (< 0.85mm) and <=30% trapping fines (< 6.4 mm) in sediments of potential spawning areas (see Appendix C). These thresholds take into account the cleaning effect that spawning has on fine sediments, i.e., the measured sediments are from unspawned gravels, though the embryo and fry survival curves were developed from redd gravel composition. They are also selected such that 50% survival will be expected. Though this does not sound overly protective, natural survival rates are comparable (NCASI 1984, Maret et al. 2003).

3.3.4 Recommendation

We propose two criteria for subsurface sediment (i.e., depth fines) in riffles. Our first recommendation follows the South Fork Salmon River TMDL (IDEQ 1991). For those streams with subsurface sediment (< 6.35 mm) less than 27%, maintain the existing sediment volume level. For streams that exceed the 27% threshold, reduce subsurface sediment to a 5-year mean not to exceed 27% with no individual year to exceed 29%. Our second recommendation is that concentrations of subsurface fines < 0.85 mm not exceed 10%. These targets are appropriate only for those portions of a stream channel, such as riffles and pool tail outs, where spawning typically occurs.

3.4 Riffle Stability

3.4.1 Biological background

The Riffle Stability Index (RSI) has been used as an indicator of beneficial use, especially as related to cold water biota. The RSI is measured as the percentage of the substrate particles (from a Wolman pebble count) that are smaller than the largest particles that are moved in channel forming flows. Particles on point bars are measured to determine the largest mobile particles.

The substrate mobility expressed by RSI may be related to the density and species composition of stream insects (Kappesser 1993). Cobb, Galloway, and Flannagan (1992) reported a decrease in insect density up to 94% in an unstable riffle compared to no reduction in a stable riffle. In Colorado, von Guerard (1991) concluded that as the grain size of streambed material approaches that of bedload, benthic invertebrate populations might be adversely affected. Kappesser (1993) looked at RSIs from B-channel streams in northern Idaho. He reported an RSI range from 29 riffles in un-entered (e.g., relatively undisturbed) watersheds of 33 to 74 (mean 50.8) while RSIs from 286 riffles in entered watersheds ranged from 38 to 100 (mean 79.5). In a survey of B-channel streams of the St. Joe River drainage (Idaho), bull trout redds were consistently found in reaches with RSI values less than 65 and were missing from reaches with higher RSI values (Cross and Everest 1992).

Pools are critical habitat for salmonids (Spangler 1997, Saffel 1994, Stichert et al. 2001, Harwood et al. 2002, Kruzic et al. 2001, Jakober et al. 2000, Solazzi et al. 2000). As riffle stability degrades, pool habitat decreases, reducing daytime and winter refugia. Destabilized stream reaches may contain lengthened riffles and shallow pools (Lisle 1982). In the St. Joe River drainage (Idaho), reaches with lower RSI values had greater residual pool volume (Cross and Everest 1992).

Riffle stability may be a factor effecting redd scour if bankfull flows occur during the incubation period. The likelihood of mortality from scour increases for stocks of fish incubating during seasons when peak flows commonly occur (Seegrist and Gard 1972). To avoid scouring flows that would disturb deposited eggs, salmonids either bury their eggs below the annual scour depth or avoid egg burial during times of likely bed mobility. Such protective patterns were noted in west-slope pacific Northwest watersheds (Montgomery et al. 1999), and are likely to be prevalent throughout Idaho.

3.4.2 Other states

No state or province has a standard for riffle stability. However, the Heavenly Valley Creek (CA) TMDL specified a target for the related Pfankuch Stability Rating that showed improving trends towards a “good” rating and several approved TMDLs in California include a target for residual pool volume (V*) (see Appendix C). Residual pool volume (V*) is the percentage of pool volume that is filled with fine sediment, is a measure of the in-channel supply of mobile bedload sediment (Lisle and Hilton 1991), and may be comparable to the Riffle Stability Index.

A common target for V* is <= 0.21, based on north slope California streams (e.g., U.S. EPA 2001b, U.S. EPA 2002).

3.4.3 Recommendation

We recommend a Riffle Stability Index (RSI) not to exceed 70. Index numbers less than 70 indicate systems that are in dynamic equilibrium (Kappesser 1993). The RSI is most appropriately applied in belt series geology as found in northern Idaho (Kappesser 1993). The procedure also appears to be applicable to granitics, basalts, and mica schists, though applicability of the recommended target should be verified in those geologies.

4. Intergravel Dissolved Oxygen

4.1 Biological background

One effect of the accumulation of fine sediment in the aquatic environment is reduced permeability of the substrate resulting in less oxygen exchange to support fish embryos and macroinvertebrates. Salmonids excavate streambed substrate to deposit eggs then backfill the "egg pocket" to protect the eggs during the incubation period. The eggs are dependent on the flow of oxygen-rich water through the substrate to survive. The accumulation of fines in the redd restricts water flow and reduces oxygen to the eggs which results in decreasing survival (Shapovalov and Berrian 1939; Wickett 1954; Shelton and Pollock 1966). Intergravel dissolved oxygen is more of a concern in areas outside the Idaho batholith. Fines in the batholith are mostly in the sand to fine gravel range and permeability associated with these textures are not restrictive to the transport of dissolved oxygen (Burton et al. 1990).

Dissolved oxygen (DO) in intergravel flow is a more direct measure of streambed suitability for salmonid egg development than subsurface sediments. Intergravel flow may be more or less dependent on ambient streambed sediment conditions, depending on local hyporheic conditions. If water flows into the redd from the overlying water column then there is the chance of the flow being choked by the intrusion of fine sediments in the bedload. If, however, redds are located in areas of hyporheic discharge, then the surface sediment conditions and delivery during incubation may be less important because the oxygenated water source is from below the redd. Fall chinook salmon and bull trout select spawning sites based at least in part on influences of hyporheic flow (Spangler 1997, Geist 1998). Bull trout embryo survival was found to be significantly higher and less variable in areas with groundwater discharge and higher water temperatures over the incubation period (Baxter and McPhail 1999).

Several studies have related intergravel dissolved oxygen to egg/fry survival. Survival of embryos has been positively correlated with intergravel dissolved oxygen in the redds for steelhead (Coble 1961) and brown trout (Maret et al. 2003). Silver et al. (1963) found that embryos incubated at low and intermediate DO concentrations produced smaller and weaker alevins than embryos incubated at higher concentrations. Weak sac fry cannot be expected to survive rigorous natural conditions. In a review of embryo development studies, Chapman (1988) noted several examples of developmental impairment at lower DO concentrations, but did not recommend a single threshold. Bjornn and Reiser (1991) recommended that intergravel DO concentrations should be at or near saturation, and that temporary reductions should drop to no lower that 5.0 mg/L.

Observations of the effects of intergravel flow on macroinvertebrates are much less extensive than those for fish. Excessive sediment affects macroinvertebrates by accumulating on the body surfaces and reducing the effective area of the respiratory structures (Lemly 1982) or by covering pupae cases and reducing the flow of oxygenated water to the metamorphosing insect (Rutherford and Mackay 1986).

4.2 Other states

Several states, including Idaho, and British Columbia have standards for intergravel dissolved oxygen (Table 2). The minimum in Montana and Wyoming is 5 mg/L. In Oregon and British Columbia, the minimum is 6 mg/L. In British Columbia, the 30-day average guideline for intergravel dissolved oxygen in spawning areas is 8.0 mg/L. The Trinity River (CA) TMDL specified a target for a related measure, gravel permeability, which should show improving trends (see Appendix C).

4.3 Recommendation

We affirm the intergravel dissolved oxygen standard (Water Quality Standards and Wastewater Treatment Requirements 58.01.02.250.02.f.i.1) for Idaho’s streams to protect salmonid spawning of not less than 6.0 mg/L for a 7-day mean and not less than 5.0 mg/L for a 1-day minimum (Idaho Department of Environmental Quality n.d.a.).

5. Conclusions and Recommendations

Setting targets for surrogate measures of sediment load is a process that attempts to account for yields, delivery, transport, and deposition in both natural and potentially disturbed conditions. A surrogate is often selected for relative efficiency of measurement and because the effects on biological endpoints are better understood than general effects of higher sediment loads. The targets recommended in this document are guidelines that may be directly applicable for a specific TMDL, or may serve as points of departure for development of modified targets based on local reference conditions.

If viable fish and macroinvertebrate assemblages are the primary beneficial uses of a waterway then maintenance of that viability becomes the goal of Idaho’s water quality standard and it follows that measures of the assemblages should be the ultimate determinants of TMDL success. The fish and macroinvertebrate assemblages are the living resources that should be protected through TMDL planning and measurements of their condition should be integral to TMDL evaluation. If they do not show signs of impairment, then it may be assumed that environmental conditions are suitable and excessive sediments are not a problem. If, however, they do show impairment, then the sediment targets will help determine a probable cause of impairment and gauge progress towards elimination of sediment stressors.

In Idaho, macroinvertebrate and fish community integrity is measured using the Stream Macroinvertebrate Index (SMI, Jessup and Gerritsen 2000) and the Stream Fish Index (SFI, Mebane 2002), respectively. Reference conditions have been described for macroinvertebrates and fish after recognizing variability in natural stream types in Idaho. Departure from reference conditions (lower index score) indicates that the community is exposed to a stressor. Neither the SMI nor the SFI are specifically calibrated to sediments as a stressor, rather they are sensitive to a range of stressors in Idaho, including sediments. Procedures for integrating Idaho's bioassessment data with other data are detailed in "Waterbody Assessment Guidance II" (Grafe et al. 2002).

Eight instream parameters have been evaluated as appropriate measures of sediment pollution (Table 8), we have recommended target values for five. These parameters were selected for three reasons: 1) because data collection is relatively simple and repeatable, 2) because methods and baseline data have been established in Idaho for the parameters, and 3) because effects to periphyton, aquatic invertebrates, and sensitive fish species are understandable, documented, and generally quantifiable. Three of the parameters are measured in the water column, four are measurements of streambed substrates, and one is a measure of hyporheic oxygen supply.

Table 8. Recommended instream sediment parameters and associated target levels.

Instream Sediment Parameter	Recommended Target Levels
Turbidity	Not greater than 50 NTU instantaneous or 25 NTU for more than 10 consecutive days above baseline background, per existing Idaho water quality standard. Chronic levels not to exceed 10 NTU at summer base flow
Light Penetration	Not to reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life
Total Suspended Solids and Suspended Sediment	No specific recommendation, establish site specific reference
Embeddedness	No specific recommendation, establish site specific reference
Surface Sediment	No specific recommendation, establish site specific reference
Subsurface Sediment in Riffles	For those streams with subsurface sediment less than 27% - do not exceed the existing fine sediment volume level. For streams that exceed the 27% threshold - reduce subsurface sediment to a 5-year mean not to exceed 27% with no individual year to exceed 29%. Percentage of subsurface sediment < 0.85 mm should not exceed 10%
Riffle Stability	Not to exceed a Riffle Stability Index of 70
Intergravel Dissolved Oxygen	Not less than 5.0 mg/L for a 1-day minimum or not less than 6.0 mg/L for a 7-day average mean, per existing Idaho water quality standard

5.1 Other options

In addition to the parameters addressed in detail above, other parameters may be appropriate for a specific TMDL. These include measurements of channel and watershed characteristics. The effects of channel and watershed conditions on aquatic life are less direct than instream measurements, and are therefore less reliable as predictors of impacts to individuals, populations, or habitats. However, a TMDL developer may determine that channel or watershed measurements provide better characterization of critical processes or compliment the recommended instream measures.

Channel characteristics appropriate as TMDL targets include the following with variations: width/depth ratio, sediment rating curves, pool frequency and quality, bank stability, and changes in peak flow (see Appendix A). Watershed characteristics that have been used in approved TMDLs in western states include the following and several variations: land area disturbed (especially in unstable areas) and road crossings, length, hydrologic connectivity, or condition (see Appendix C). Targets are difficult to establish for channel and watershed characteristics and are commonly narrative or specify improving trends.

The relationships between sediment sources and biological endpoints or critical habitat are documented, but with little general applicability for establishing numeric targets. It is not surprising that juvenile chinook salmon had higher survival rates in natural watersheds compared to those in watersheds with young, managed timberlands (Paulsen and Fisher 2001), but the results can not specify a degree of naturalness that is required to maintain acceptable survival rates. Likewise, correlation between bull trout redd numbers and the density of logging roads over time and across basins (Baxter et al. 1999) shows that the general link between source and endpoint exists without quantifying the linkage.

Numeric models have been developed to link sediment sources to habitat conditions and salmonid populations. Models are usually described with caveats regarding assumptions and limitations imposed by calibration data, so that results must be interpreted with a substantial degree of uncertainty. However, such models may be useful for investigating trends with simulations of load allocation, watershed management, or stream restoration alternatives. Sediment-habitat response curves were developed for the Nez Perce National Forest that related the percentage of sediment delivery above natural levels to embeddedness and subsurface fines (Stowell et al. 1983). These models were intended for use with a second model of sediment supply (Cline et al. 1981). The models were tested and improved by Nelson and Platts (1988) to address some of the inherent uncertainties. Espinosa (1992) outlined a model of habitat suitability for salmonid species in Idaho in which several of the habitat variables were related to sediment parameters. This model may be useful in identifying habitat conditions that may be limiting to the population, or at least in prioritizing habitat elements that are less than optimal.

The targets recommended in this paper were derived from literature values for studies primarily in the northwest U.S. While we sought out the best available sources of current information on sediment effects on stream biota, a comprehensive effort at assembling a database of sediment conditions in streams that are supporting their aquatic life uses would allow targets to be refined using local reference conditions. The State of Colorado assesses sediment impacts by establishing a scale of conditions calibrated to reference conditions, thus test conditions can be evaluated as a percentage of reference (CDPHE 2002). Attainment of certain percentages of the reference conditions (both sediment and biological conditions) is associated with acceptable or unacceptable sediment conditions. This model may be appropriate in Idaho when sufficient data are obtained.

Reference conditions for a specific stream should be defined using unimpaired streams that are in the same ecoregion, of approximately equal size (e.g., same stream order), and have similar geomorphology, geology, slope, topography, soils, etc. Because of uncertainty in categorizing existing stream geomorphology, appropriate geomorphology for the landscape, and stage of channel evolution, predictive modeling of expected sediment conditions should consider multiple factors in addition to (or instead of) stream type. Expected channel and sediment characteristics might be predicted for different morphological settings using continuous variables because systems are continuous, not fixed or categorical. Such models could set expectations for physical conditions. They could also be used to set acceptable ranges of conditions under different land uses.

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APPENDIX A

USE OF CHANNEL CHARACTERISTICS AS SEDIMENT TARGETS

Appendix A. Use of Channel Characteristics as Sediment Targets

Biological effects of channel characteristics are inherently more difficult to quantify than the effect of streambed and water column measures discussed earlier. Little published work is available to guide the regulator in establishing channel characteristic targets. Thus, targets based on channel characteristics will not be recommended, but must be site specific and established relative to reference conditions. For example, the percentage of stable banks could be determined from a similar watershed that is meeting its beneficial uses. The measure of achievement could be the percentage bank instability reduced from pre-TMDL conditions.

Width/Depth Ratio and Channel Cross-Section

The shape and dimension of a stream channel in a given location are sensitive to the balance between sediment load and stream flow or energy (Leopold et al. 1964). When sediment loads become excessive a channel will aggrade, becoming shallower with a loss of pools and an increased width to depth ratio (e.g., Clifton 1989). This ratio is also sensitive to the direct effects of bank trampling or breakdown leading to increased channel erosion and loss of near bank fish habitat (Bauer and Burton 1993). Others have found a direct relation of width/depth ratio to salmonid biomass (Kozel and Hubert 1989).

Expected width to depth ratios are dependent upon the geomorphic setting of a stream or channel type (Rosgen 1996). Recent research in the Salmon River subbasin of Idaho provides further data on expected width/depth ratios based upon channel type and major rock types - granitic, sedimentary, or volcanic (Overton et. al. 1995). Examples of bankfull width depth ratios that indicate high habitat quality in the Nez Perce and Clearwater National Forests and Cottonwood BLM lands are as follows, by channel type: A - <10, B - <20, C - <40, E - <7, F - <35, and G - <9 (USDA-FS et al. 1998).

To avoid the effect of differences in stream flow on measurement, width and depth must be based upon a fixed stage. The bankfull width and depth of a stream are most characteristic of channel cross-section. Such measurements are quite quickly and easily obtained. Calculation of a stream’s average width/depth ratio should be based upon several (3-6) permanent transects representing a given reach. The Van Duzen River and Yager Creek (CA) TMDL for sediments (U.S. EPA 1999) specified a target for mean bed elevation (decreasing trends), which could be monitored over time using fixed transects.

A related, but more detailed and sensitive, measure of changes in channel cross-section is provided by the Gini-coefficient (Olson-Rutz and Marlow 1992). Calculation of this coefficient requires repeated measurements of channel depth at fixed distances across a permanent transect. Again, several transect should be established in order to provide an average condition characteristic of a particular reach of stream. A positive change in the Gini-coefficient indicates a narrowing and deepening of a stream channel.

Use of changes in channel cross-section is not appropriate in bedrock channels: channel cross-section is most sensitive to human influence in alluvial channels with banks consisting of fine grained material. As with other channel characteristics, width/depth is best used only as a relative measure of change or trend in channel condition. The Gini coefficient is strictly an indicator of change.

Although general guidelines for width/depth can be suggested based upon published literature, no absolute values can be offered. For example, one might look for a fifty percent reduction in width/depth ratio over several years for a Rosgen C-type channel with a current ratio of 40. It is essential that such relative targets be combined with a direct measure of beneficial use support, such as provided by the Idaho Division of Environmental Quality BURP results and Waterbody Assessment (IDEQ 1996a, b). Use of reference conditions is strongly recommended.

Channel shape can also be measured longitudinally and targets can be set for the thalweg profile. If aggradation has caused a loss of pools, the target for the thalweg profile might be to find increasing trends in channel complexity and pool depth, or increasing variation from the mean channel thalweg profile. This approach has been applied in several TMDLs in California (e.g., U.S. EPA 2000, U.S. EPA 2001b, U.S. EPA 2002).

Sediment Rating Curves

A stream’s discharge of sediment is highly variable due both to variation in stream flow and because suspended sediment concentrations and bedload are strongly correlated with flow, although they typically exhibit hysteresis (i.e., the relation is different between increasing and decreasing flow) (Leopold 1994; Mount 1995; Leopold and Emmett 1997). As a result, sediment discharge ranges wildly from time to time due primarily to timing of weather events and the supply of hillslope and streambed sediment (Ketcheson 1986). This renders individual measurements all but useless, makes longer term load estimation suspect, and effects of human influence hard to detect through direct measurement of either concentration or load.

The relation of suspended sediment concentration and bedload to stream discharge, the sediment rating curve, is much more characteristic of erosional processes and long-term sediment discharge rate than any one concentration or load. This is because the sediment rating curve provides a characterization of sediment discharge over a range of flows thus overcoming day to day, or even year to year, differences in flow.

A sediment rating curve can be established with as few as ten to fifteen measurements if spread out across the full range of flows in an annual hydrograph (Ketcheson 1986). Using a sediment rating curve, reasonably accurate estimates of periodic sediment discharge can be made based upon more or less continuous records of discharge and relatively few sediment measurements (Campbell and Bauder 1940; Lewis 1996). Thus annual or partial-year loads can be estimated based upon an annual hydrograph or other record of flows. With greater flow variability, flow measurements should be recorded more frequently (Dolan et. al. 1981).

It is also possible to use a sediment rating curve to relate a given flow to an estimated concentration of total suspended solids (TSS), thus a record of flows could be used to determine the likely frequency of exceedance of a suspended solids target. Reductions in erosion and/or sediment delivery to a stream will be reflected in a decrease in the slope and/or intercept of the sediment rating curve (Rosgen 1996). This can be used to monitor post-implementation effectiveness of control measures.

Sediment rating curves also have direct application in the setting of TMDL targets and determination of needed load reductions. For example, using an average or typical hydrograph, a desired reduction in the frequency of exceedance of a TSS target and/or bedload can be related to a reduction in the slope of the sediment rating curve and a corresponding reduction in average annual or typical sediment load. While any particular series of post-implementation sediment discharge measurements might show an increase or decrease in sediment load, due primarily or even solely to differences in flow, a reduction in the slope of the sediment rating curve is evidence of improved conditions independent of wet or dry years.

Use of sediment rating curves as an indicator of changes in sediment discharge is usually only applicable where there exists a continuous flow gaging station and a companion record of suspended sediment and/or bedload measurements adequate to produce a reliable rating curve. However, for a given site with a limited flow record (i.e., 1 or 2 years of continuous record) which is near sites with long-term continuous records, the hydrograph can be extended using techniques summarized by Hirsch (1982) and Alley and Burns (1983). For rating curves to be truly useful, there must be a commitment to continue monitoring flow and sediment after TMDL development and implementation.

An alternative sediment rating curve method, proposed by Rosgen (1996), uses existing stream discharge-sediment load data in a more general way. Leopold et al. (1964) suggest rating curves for different stream systems are very similar and can be converted to dimensionless curves by expressing flow (Q) and TSS as ratios of their bankfull values:

$$(Qi/QBF) \text{ and } (TSSi/TSSBF).$$

Where Qi and TSSi are values for a range of flows, and QBF and TSSBF are the discharge and sediment concentration at bankfull flow. These dimensionless curves are stratified by channel type, watershed characteristics, and land use for comparison to other watersheds of interest. In effect, these curves are landform specific sediment-discharge relationships and provide expected values for the relationships.

At least one pair of measurements for a watershed needs to be at bankfull to construct the dimensionless ratio. Thus, for a watershed with no data, the TSS, bedload, and stream discharge are measured at bankfull flow. These measurements are used to calculate a ratio that should fall near the dimensionless sediment rating curve for watersheds with similar physical characteristics. A TSS or bedload target could then be set by taking into account the departure of this ratio from the dimensionless sediment rating curve.

Kunhle and Simon (2000) criticize the dimensionless ratio technique because it obscures differences in bankfull transport rates. Instead, they advocate standardization by carefully identifying comparable reference conditions, with particular attention to stage of channel evolution as well as channel form. When reference conditions are selected such that sediment transport processes are recognized, direct comparisons can be made between test and reference sediment delivery statistics (slope of sediment-transport rating, total sediment load at bankfull, and sediment magnitude-duration relations).

Pool Parameters

Numerous studies have demonstrated a link between management activities, sediment production, and reduction in pool frequency, depth, and volume (Overton et al. 1993, Meehan 1991, Sedell and Everest 1990, MacDonald et al. 1991). De-stabilized stream reaches (higher Riffle Stability Index values) may contain lengthened riffles and shallow pools (Lisle 1982, Cross and Everest 1992). As a result, pool measures like pool frequency and residual pool volume (V*) are practical and effective sediment targets. Much like pool frequency, the ideal pool volume is related to stream characteristics, so that the status of the stream in question should be defined in comparison to a reference stream. The two measures may be related; as V* is reduced, the pool frequency increases. Together, V* and pool frequency can be used as combined sediment targets with the conditions in a reference stream providing a reasonable target of desired conditions.

Pool Frequency:

Pool frequency as a sediment target is a measure of fish habitat availability in a given stream reach where the number of existing pools in a reach is related to the desired number of pools. The ideal number of pools for a stream reach is a function of geology, valley-channel morphology, stream flow, and sometimes large woody debris. Leopold et al. (1964) and Rosgen (1996) show that there are relationships between channel characteristics and pool frequency. The best way to determine the proper or desired pool frequency in a given stream reach is to use reference conditions (Overton et al. 1995).

Habitat conditions in the Clearwater and Nez Perce National Forests and the Cottonwood BLM lands were considered “high” when pool frequency and quality targets were met (Matrix 1998). For frequency, the targets were specified in a table relating number of pools per mile to channel width (e.g., channels 15 – 20 feet wide should have more than 56 pools per mile). Also considered were elements for sustaining pools such as a supply of large woody debris, which has been established as beneficial for salmonid habitat and sensitive to logging activities (Haur et al. 1999). Pool quality was rated using a locally developed methodology.

Predominance of pool habitat is a measure of the percentage of pool habitat in a given reach. As such, the number of pools is not as critical as the linear extent of the few or many pools. In several TMDLs approved in California, a target was specified for primary pool habitat to cover more than 40% of the reach (e.g., U.S. EPA 2000, U.S. EPA 2001b, U.S. EPA 2002). Primary pools were described as being at least 3 feet deep in third order or larger streams.

Residual pool volume (V*) and depth:

Residual pool volume (V*) is a measure of the fraction of pool volume filled with fine sediment (Lisle and Hilton 1991). Residual pool depth is a measure of pool depth which is not dependent upon discharge at the time of measurement (Lisle 1989). These measures are effective sediment targets because they primarily reflect chronic sediment sources (Lisle and Hilton 1991). Common targets for V* for north slope California streams are <= 0.15 (e.g., U.S. EPA 2000, U.S. EPA 2001a) or <= 0.21 (e.g., U.S. EPA 2001b, U.S. EPA 2002).

Bank Stability

Bank instability is often a chronic source of sediment in disturbed stream systems (Reid and Dunne 1996). Bank stability measures are a cost effective sediment target which are complemented by a wealth of historic data. Federal land management and state agencies, including DEQ, commonly collect this information using the method developed by Pfankuch (1975) as part of stream inventories and habitat assessments.

The desired condition of streambanks is typically near 100 percent stable. Overton et al. (1995) showed undisturbed streams typically have between 90 to 100 percent bank stability for source, transport, and response reaches. In the Nez Perce and Clearwater National Forests and Cottonwood BLM lands, streambank stability indicating high quality habitats is expected to be >90% in C channels, > 95% in A & B channels, and 100% in E channels (USDA-FS et al. 1998). In the Umatilla River Basin (OR), less than 25% eroding banks were expected to fulfill the streambank component of the sediment load allocation. The target was established through regression analysis of TSS and eroded banks, setting the eroded bank target as the value corresponding to the TSS target of 80 mg/L (ODEQ 2001).

Changes in Peak Flow

Management activities (i.e., activities which remove vegetation and increase soil compaction) are known to increase the magnitude and frequency of peak flow events (Jones and Grant 1996; Harr et al. 1975; MacDonald et al. 1991). Increased peak flows disrupt the balance between channel form and sediment flux. A stream out of equilibrium with sediment input is typically limiting to beneficial uses. If changes in peak flow magnitude and/or frequency can be statistically demonstrated, then a possible sediment target might be a measurable decrease in peak flow events. A possible statistical method is ANOVA using two periods of time (pre and post-TMDL) (Jones and Grant 1996; Riggs 1968) or a BACI design (before-after control-impact). The target might be a statistically significant decrease in the magnitude and frequency of peak flow events following implementation of the TMDL.

APPENDIX B

TOTAL SUSPENDED SOLIDS SAMPLING AND ANALYSIS

Appendix B. Total Suspended Solids Sampling and Analysis

Total Suspended Solids Sampling Protocols

Site selection:

Typically, total suspended solids (TSS) water samples are collected at or near a fixed gaging station or bridge to ease difficulties associated with high flow measurements. However, if TSS data are to be related to watershed and channel geomorphic characteristics, sample sites should be located in an area representative of the catchment (Edwards and Glysson 1998). In either case, sample sites are to be located where the channel is quasi-stable.

Sample collection:

TSS samples are collected using one of several depth-integrated samplers in resistant glass or plastic bottles. Edwards and Glysson (1998) discuss several different types of samplers commonly used. In general, the type of sampler depends on the characteristics, primarily size, of the stream. These samplers, such as the DH-48, have an intake port which restricts the size of particles sampled to 2.0 mm or less. Generally this causes little if any bias as particles greater than this size are not typically in suspension. However, the difference in particle size between TSS and the typical biological definition of fines as being less than 6.35 mm must be borne in mind when interpreting TSS measurements.

> When collecting TSS samples, stream stage or instantaneous stream discharge is also measured. Because TSS concentrations are ultimately used to calculate sediment flux or load, TSS samples should be collected frequently during high flow periods and infrequently during low flow periods. Flood events should be intensively sampled during the rising and falling limb of the hydrograph, if possible. Several authors offer strategies to optimize sampling of the hydrograph for load estimation purposes (Lewis 1996; Thomas and Lewis 1995; Preston et al. 1989; Dolan et al. 1981).

Depth-integrated TSS samples best represent the total amount of suspended sediment passing a point at a given time. However, a relationship can be developed between total TSS concentration and values obtained sampling a single point in the stream cross-section (Guy and Norman 1970). U. S. Environmental Protection Agency (1982) provides additional TSS sampling guidance.

Total Suspended Solids Sample Analysis

There are two common suspended sediment analytical methods. APHA et al. (1995) described total suspended solids analysis protocols, the method recommended by U. S. Environmental Protection Agency (1983b). The U. S. Geological Survey (USGS) analyzes samples for total suspended sediment (Guy 1969). The primary difference in these two methods is that the USGS protocol requires the entire field sample be filtered for analysis, while the U. S. Environmental Protection Agency (EPA) procedure allows sub-sampling of as little as 100 ml in the laboratory. By comparing the two analytical methods, the USGS has shown significant differences in the results (Greg Clark, personal communication). In general, the difference between the two methods is greater in sand dominated systems, whereas, in fine grain silt-clay systems the difference is less. An unpublished USGS document reports as much as a 2:1 difference of total suspended sediment to total suspended solids.

Total Suspended Solids Data Analysis

The TSS target needs to be related to natural sediment yield, watershed and channel characteristics, and existing land uses. Natural background TSS is determined using either conservative assumptions (e.g., natural background TSS is zero), the sediment budget method, or reference streams with similar geomorphic characteristics and limited land use. The TSS target value also needs to be related to stream discharge and/or season. The sediment rating curve is an effective method to achieve the latter.

Three different approaches have been used in recent TMDLs. The Deep Creek TMDL (Endicott and McMahon 1996) approved in Montana, used the sediment rating curve to set TSS reductions. The Yakima River TMDL (Joy and Patterson 1997) in Washington, uses the 90th percentile TSS concentration during a selected season. The Paradise Creek TMDL in Idaho (IDEQ 1998b) relates TSS back to the State of Idaho’s turbidity standard, such that TSS cannot exceed 100 mg/L instantaneously or 50 mg/L for ten consecutive days above natural background. For Paradise Creek, natural background TSS was estimated using the sediment budget method.

APPENDIX C

LIST OF REVIEWED SEDIMENT TMDLs

Table C-1. List of reviewed sediment TMDLs.

Title	Submitting agency	Location	Date
Albion River TMDL for Sediments	U.S. EPA	CA	2001
Big River TMDL for Sediments	U.S. EPA	CA	2001
Careless Creek Sediment TMDL	MT DEQ	MT	2001
Cedar Creek TMDL	IL EPA	IL	2002
Deep Creek, Montana, Development of a TMDL to reduce non-point source sediment pollution to	MT DEQ	MT	1996
East Fork Kaskaskia River TMDL and Implementation Plan	IL EPA	IL	2002
Garcia River Sediment TMDL	U.S. EPA	CA	1898
Gualala River TMDL for Sediment	U.S. EPA	CA	2000 - 01
Heavenly Valley Creek TMDL		CA	2002
Lower Arkansas River Basin TMDL		AK	2002
Mattole River TMDL for Sediments and Temperature	U.S. EPA	CA	2003
Navarro River TMDL for Temperature and Sediments	U.S. EPA	CA	2000
North Fork Eel River TMDL	U.S. EPA	CA	2002
Noyo River TMDL for Sediments	U.S. EPA	CA	1999
Nutrioso Creek TMDL		AZ	2000
Redwood Creek TMDL for Sediments	U.S. EPA	CA	1998
San Miguel River TMDL for Sediment	CO Water Quality Control Division	CO	2000
South Fork Eel River TMDL for Sediment and Temperature	U.S. EPA	CA	1999
Styles Brook TMDL for Sediment (Draft)	VT DEC	VT	2001
Tammany Creek Sediment TMDL	ID DEQ	ID	2001
Ten Mile River TMDL for Sediments	U.S. EPA	CA	2000
Trinity River TMDL for Sediments	U.S. EPA	CA	2001
Umatilla River Basin TMDL and Water Quality Management Plan	OR DEQ	OR	2001
Upper Grande Ronde River sub-Basin TMDL	OR DEQ	OR	2000
Van Duzen River and Yager Creek TMDL for Sediments	U.S. EPA	CA	1999

Table C-2. Examples of indicators and targets for sediment TMDLs.

Indicator	Target	References in TMDL text	Title
Instream Indicators			
Benthic Macroinvertebrates	improving trends, EPT, Richness & % Dominant Taxa	Bybee 2000, Plafkin et al. 1989	Albion River TMDL for Sediments
Benthic Macroinvertebrates	improving trends, EPT, Richness & % Dominant Taxa	Bybee 2000, Plafkin et al. 1989	Big River TMDL for Sediments
Benthic Macroinvertebrates	improving trends		Gualala River TMDL for Sediment
Benthic Macroinvertebrates	improving trends, EPT, Richness & % Dominant Taxa	Bybee 2000, Plafkin et al. 1989	Mattole River TMDL for Sediments and Temperature
Benthic Macroinvertebrates	improving trends, EPT, Richness & % Dominant Taxa		Navarro River TMDL for Temperature and Sediments
Benthic Macroinvertebrates	improving trends, EPT, Richness & % Dominant Taxa		North Fork Eel River TMDL
Benthic Macroinvertebrates	Thresholds for 7 index metrics		Styles Brook TMDL for Sediment (Draft)
Benthic Macroinvertebrates	improving trends, EPT, Richness & % Dominant Taxa	Bybee 2000, letter to EPA	Ten Mile River TMDL for Sediments
Benthic Macroinvertebrates	improving trends, EPT, Richness & % Dominant Taxa		Trinity River TMDL for Sediments
Benthic Macroinvertebrates	Improving trends in indices for EPT, taxa richness, and % dominant taxa	Plafkin et al. 1989; DFG-WPCL 1996	Van Duzen River and Yager Creek TMDL for Sediments
Benthic Macroinvertebrates	improving trends in benthic invertebrate community metrics over time, compared to reference site		Heavenly Valley Creek TMDL
Benthic Macroinvertebrates	>=40% EPT in assemblage		Lower Arkansas River Basin TMDL

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Instream Indicators (cont'd)			
d50	>=69mm (mean), >37mm (min), in 3rd order streams with slopes 1-4%		Garcia River Sediment TMDL
d50	>=69mm (mean), >37mm (min)	Knopp 1993	Redwood Creek TMDL for Sediments
d50	improving trend		Trinity River TMDL for Sediments
d50	Increasing trend toward >69mm	Klein 1998, Knopp 1993	Van Duzen River and Yager Creek TMDL for Sediments
Fine sediment volume of active bed matrix	decreasing trend in volume stored in subsurface of gravel bars	Lisle and Hilton 1999	Gualala River TMDL for Sediment
Fine sediment volume of active bed matrix	decreasing trend in volume stored in subsurface of gravel bars	Lisle and Hilton 1999	Navarro River TMDL for Temperature and Sediments
Frequently mobilized channelbed surface	see text - channel specific - perhaps a regulated river	US FWS 1999	Trinity River TMDL for Sediments
Large Woody Debris	increasing distribution, volume and number of key pieces or distribution of LWD-formed habitats	Flosi et al. 1998	Albion River TMDL for Sediments
Large Woody Debris	increasing distribution, volume and number of key pieces or distribution of LWD-formed habitats	Flosi et al. 1998	Big River TMDL for Sediments
Large Woody Debris	increasing distribution, volume and number of key pieces or distribution of LWD-formed habitats	Flosi et al. 1998	Mattole River TMDL for Sediments and Temperature
Large Woody Debris	increasing trend	Bilby and Ward 1989, Lisle 1986	Navarro River TMDL for Temperature and Sediments

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Instream Indicators (cont'd)			
Large Woody Debris	increasing distribution, volume and number of key pieces	Bilby and Ward 1989, Beechie and Sibley 1997, USDA 1994	Noyo River TMDL for Sediments
Large Woody Debris	improving trends toward increased large woody debris		Redwood Creek TMDL for Sediments
Large Woody Debris	increasing distribution, volume and number of key pieces		Trinity River TMDL for Sediments
Large Woody Debris	increasing distribution, volume and number of key pieces	Bilby et al. 1989, Beechie et al. 1997, USDA 1994	Van Duzen River and Yager Creek TMDL for Sediments
Permeability of spawning gravel	improving trend, permeability standpipe driven 35cm into substrate (Matthews 2001a)		Trinity River TMDL for Sediments
Pfankuch Channel Stability Rating	increasing trend over time from "fair-poor" to "good"		Heavenly Valley Creek TMDL
Riffle Embeddedness	<=25% or improving (decreasing) trend toward 25%	Flosi et al. 1998, Mangelsdorf & Clyde 2000	Albion River TMDL for Sediments
Riffle Embeddedness	<=25% or improving (decreasing) trend toward 25%	Flosi et al. 1998, Mangelsdorf & Clyde 2000	Big River TMDL for Sediments
Riffle Embeddedness	<=25% or improving (decreasing) trend toward 25%		Gualala River TMDL for Sediment
Riffle Embeddedness	<=25% or improving (decreasing) trend toward 25%	Flosi et al. 1998, NCRWQCB 2001	Mattole River TMDL for Sediments and Temperature
Riffle Embeddedness	<=25% or improving (decreasing) trend toward 25%		North Fork Eel River TMDL
Riffle Embeddedness	Increasing percentage of riffle habitat units that are <25% embeddeded	Flosi and Reynolds 1994, DFG 1995	Noyo River TMDL for Sediments
Riffle Embeddedness	<25%		Styles Brook TMDL for Sediment (Draft)

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Instream Indicators (cont'd)			
Riffle Embeddedness	<=25%		Ten Mile River TMDL for Sediments
Riffle Embeddedness	<=25% or improving (decreasing) trend toward 25%	Flosi et al. 1998	Trinity River TMDL for Sediments
Riffle Embeddedness	<25%	Flosi et al. 1998	Van Duzen River and Yager Creek TMDL for Sediments
Sediment Substrate Composition	<=14% <0.85mm and <=30% <6.4mm	Burns 1970, CDF 1994, McHenry et al. 1994, Mangelsdorf & Lundborg 1998, Valentine 1997	Albion River TMDL for Sediments
Sediment Substrate Composition	<=14% <0.85mm and <=30% <6.4mm	Burns 1970, CDF 1994, McHenry et al. 1994, Mangelsdorf & Lundborg 1998, Valentine 1997	Big River TMDL for Sediments
Sediment Substrate Composition	<=30% <6.35mm		Deep Creek, Montana, Development of a TMDL to reduce non-point source sediment pollution to
Sediment Substrate Composition	<=14% <0.85mm and <=30% <6.5mm		Garcia River Sediment TMDL
Sediment Substrate Composition	<=14% <0.85mm and <=30% <6.4mm	Burns 1970, Peterson et al. 1992, Kondolf 2000	Gualala River TMDL for Sediment
Sediment Substrate Composition	<=14% <0.85mm and <=30% <6.4mm	Burns 1970, CDF 1994, McHenry et al. 1994, Mangelsdorf & Lundborg 1998, Valentine 1997, NCRWQCB 2000	Mattole River TMDL for Sediments and Temperature

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Instream Indicators (cont'd)			
Sediment Substrate Composition	<=14% <0.85mm and <=30% <6.4mm	Peterson 1992, Burns 1970, Kondolf 2000	Navarro River TMDL for Temperature and Sediments
Sediment Substrate Composition	<=10% <0.85mm, <=30% <6.4mm, and <=15% <2mm	Matthews 2001, Kondolf 2000, Chapman 1988	North Fork Eel River TMDL
Sediment Substrate Composition	<=14% (mean, as wet volume)	Burns 1970, CDF 1994	Noyo River TMDL for Sediments
Sediment Substrate Composition	<=14% <0.85mm, <=30% <6.5mm and <10-20% <2mm	Chapman 1988, Tappel & Bjorn 1983, Madej 1998, Peterson 1992, Burns 1970, Tappel & Bjorn 1983, Chapman & McLeod 1987, Young et al. 1991	Redwood Creek TMDL for Sediments
Sediment Substrate Composition	< 14% <0.85 mm	Peterson 1992, Burns 1970	South Fork Eel River TMDL for Sediment and Temperature
Sediment Substrate Composition	<8% fines (size not specified)		Styles Brook TMDL for Sediment (Draft)
Sediment Substrate Composition	<20% <8mm		Styles Brook TMDL for Sediment (Draft)
Sediment Substrate Composition	<=14% (mean, as wet volume) <0.85mm in pool tailouts or potential spawning areas	Burns 1970, CDF 1994, Mangelsdorf & Lundborg 1998	Ten Mile River TMDL for Sediments
Sediment Substrate Composition	<=10% <0.85mm, <=30% <6.4mm, and <=15% <2mm	Matthews 2001, Kondolf 2000, Chapman 1988	Trinity River TMDL for Sediments
Sediment Substrate Composition	<=20% streambed area fines (correlated to streambank vegetation)		Upper Grande Ronde River sub-Basin TMDL

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Instream Indicators (cont'd)			
Sediment Substrate Composition	<=14% (mean, as wet volume)	CDF 1994, McHenry et al. 1994	Van Duzen River and Yager Creek TMDL for Sediments
Silt	<=34% of stream area dominated by silt		Cedar Creek TMDL
Silt	<=34% of stream area dominated by silt		East Fork Kaskaskia River TMDL and Implementation Plan
Instream Water Quality Indicators			
Suspended Sediment Concentration Curve Rating	decreasing temporal trend (flow v. TSS)		Gualala River TMDL for Sediment
Suspended Sediments	<=155 mg/l sediment concentration (suspended and bedload combined) during stable flow of 150 cfs		Careless Creek Sediment TMDL
Suspended Sediments	<=116 mg/l in all but one sample collected over 3 years		Cedar Creek TMDL
Suspended Sediments	<=116 mg/l in all but one sample collected over 3 years		East Fork Kaskaskia River TMDL and Implementation Plan
Suspended Sediments	Decreasing trend in days of turbidity exceedance, develop turbidity rating curve and relate to biological effects	Newcombe and Jensen 1996	Trinity River TMDL for Sediments
Suspended Solids	Narrative: excess suspended solids not to interfere with wildlife or its habitat		Lower Arkansas River Basin TMDL

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Instream Water Quality Indicators (cont'd)			
Temperature	<=16.8, 7 day running mean		Ten Mile River TMDL for Sediments
TSS	0.26 slope of TSS v. Q plot		Deep Creek, Montana, Development of a TMDL to reduce non-point source sediment pollution to
TSS	<=80 mg/l or value locally correlated to 30 ntu turbidity		Umatilla River Basin TMDL and Water Quality Management Plan
TSS/Turbidity	183 lbs/day, spring flows; 19.8 lbs/day average base flow conditions		Nutrioso Creek TMDL
Turbidity	<= 20% above naturally occuring backgrounds	Basin Plan (NCRWQCB 1996)	Albion River TMDL for Sediments
Turbidity	<= 20% above naturally occuring backgrounds	Basin Plan (NCRWQCB 1996)	Big River TMDL for Sediments
Turbidity	<= 20% above naturally occuring backgrounds, decreasing days above threshold	Newcombe and Jensen 1996, Sigler et al. 1984	Gualala River TMDL for Sediment
Turbidity	<= 20% above naturally occuring backgrounds	Basin Plan (NCRWQCB 1996)	Mattole River TMDL for Sediments and Temperature
Turbidity	<= 20% above naturally occuring backgrounds		North Fork Eel River TMDL
Turbidity	<= 20% above background	Basin Plan 1994, Reid 1999	Noyo River TMDL for Sediments
Turbidity	<= 20% above naturally occuring backgrounds		South Fork Eel River TMDL for Sediment and Temperature

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Instream Water Quality Indicators (cont'd)			
Turbidity	<=50 ntu instantaneous and <=25 ntu for 10 days		Tammany Creek Sediment TMDL
Turbidity	<= 20% above naturally occuring backgrounds	Basin Plan (NCRWQCB 1996)	Trinity River TMDL for Sediments
Turbidity	<=30 ntu over 48 hours		Umatilla River Basin TMDL and Water Quality Management Plan
Turbidity	<= 20% above background	Basin Plan 1994	Van Duzen River and Yager Creek TMDL for Sediments
Channel Indicators			
Cross Sections (bed elevations)	Decreasing trend in mean bed elevations towards pre-1964 levels	Kelsey 1997, Klein 1998	Van Duzen River and Yager Creek TMDL for Sediments
Periodic channel migration	channel specific	US FWS 1999	Trinity River TMDL for Sediments
Periodic channelbed scour and fill	channel specific	US FWS 1999	Trinity River TMDL for Sediments
Pool depth	mean depth of pools at low flow exceeds 2 m	Flosi & Reynolds 1994	Redwood Creek TMDL for Sediments
Pool depth 3rd & 4th Order Tribs	mean depth of pools at low flow exceeds 1-1.5 m		Redwood Creek TMDL for Sediments
Pool Distribution	Increasing trends towards reference values		Ten Mile River TMDL for Sediments
Pool Residual Depth	>2' in low order, >3' in 3rd & higher order, at low flow	Flosi et al. 1999	Gualala River TMDL for Sediment
Pool/Riffle Distribution & depth of pools	increasing trend toward >40% length of pools > 2-3'	Flosi et al. 1998	Albion River TMDL for Sediments

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Channel Indicators (cont'd)			
Pool/Riffle Distribution & depth of pools	increasing trend toward >40% length of pools > 2-3'	Flosi et al. 1998	Big River TMDL for Sediments
Pool/Riffle Distribution & depth of pools	Pools > 2' deep (>3' in 3rd order) over 40% of length		Garcia River Sediment TMDL
Pool/Riffle Distribution & depth of pools	increasing trend toward >40% length of pools > 2-3'	Flosi et al. 1998	Mattole River TMDL for Sediments and Temperature
Pool/Riffle Distribution & depth of pools	increasing trend toward >40% length of pools > 2-3'	Flosi et al. 1998	Navarro River TMDL for Temperature and Sediments
Pool/Riffle Distribution & depth of pools	increasing trend toward >40% length of pools > 2-3'		North Fork Eel River TMDL
Pool/Riffle Distribution & depth of pools	Pools > 2' deep (>3' in 3rd order) over 40% of length	Flosi and Reynolds 1994	Noyo River TMDL for Sediments
Pool/Riffle Distribution & depth of pools	increasing trend toward >40% length of pools > 2-3'		Trinity River TMDL for Sediments
Pool/Riffle Distribution & depth of pools	Pools > 2' deep (>3' in 3rd order) over 40% of length	Flosi et al. 1998	Van Duzen River and Yager Creek TMDL for Sediments
Pools: Backwater	Increasing trend		Navarro River TMDL for Temperature and Sediments
Pools: Backwater	Increasing number per habitat length	Dietrich 1998	Noyo River TMDL for Sediments
Riffle Distribution	< 25-30% riffles (when gradient <2%)	Madej 1998	Redwood Creek TMDL for Sediments
Spatially complex channel morphology	channel specific	US FWS 1999	Trinity River TMDL for Sediments
Thalweg profile	increasing variation from the mean	Trush 1999, Madej 1999	Albion River TMDL for Sediments

Table C-2. (cont'd)..

Indicator	Target	References in TMDL text	Title
Channel Indicators (cont'd)			
Thalweg profile	increasing variation from the mean	Trush 1999, Madej 2000	Big River TMDL for Sediments
Thalweg profile	increasing variation from the mean		Gualala River TMDL for Sediment
Thalweg profile	increasing variation from the mean	Trush 1999, Madej 1999	Mattole River TMDL for Sediments and Temperature
Thalweg profile	increasing variation from the mean		Navarro River TMDL for Temperature and Sediments
Thalweg profile	increasing variation from the mean		North Fork Eel River TMDL
Thalweg profile	increasing trend in channel complexity and pool depth	Trush 1999, Madej 1999	Noyo River TMDL for Sediments
Thalweg profile	increasing variation in the thalweg elevation around the mean thalweg profile slope	Klein 1998	South Fork Eel River TMDL for Sediment and Temperature
Thalweg profile	increasing variation from the mean	Thrush 1999, Madej 1999	Ten Mile River TMDL for Sediments
Thalweg profile	increasing variation from the mean		Trinity River TMDL for Sediments
Thalweg profile	increasing trend in channel complexity and pool depth	Thrush 1999, Madej 1999	Van Duzen River and Yager Creek TMDL for Sediments
USFS Region 5 SCI "Stream Condition Inventory"	improving trends in channel morphology over time		Heavenly Valley Creek TMDL
V*, Residual pool volume	<0.21 or <0.10	Lisle & Hilton 1992, Knopp 1993, Lisle 1989, Lisle & Hilton 1999	Big River TMDL for Sediments
V*, Residual pool volume	<=0.21 (mean), <= 0.45 (max), in 3rd order streams with slopes 1-4%		Garcia River Sediment TMDL

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Channel Indicators (cont'd)			
V*, Residual pool volume	<=0.15	Lisle & Hilton 1992, 1999, Knopp 1993	Gualala River TMDL for Sediment
V*, Residual pool volume	<0.21 (fransiscan) or <0.10 (other)	Lisle & Hilton 1992, Knopp 1993, Lisle 1989, Lisle & Hilton 1998	Mattole River TMDL for Sediments and Temperature
V*, Residual pool volume	<=0.15	Lisle & Hilton 1999, Knopp 1993	Navarro River TMDL for Temperature and Sediments
V*, Residual pool volume	<0.21 (fransiscan) or <0.10 (other)	Lisle & Hilton 1992	North Fork Eel River TMDL
V*, Residual pool volume	0.27	Knopp 1993	Noyo River TMDL for Sediments
V*, Residual pool volume	<0.10	Lisle & Hilton 1992	South Fork Eel River TMDL for Sediment and Temperature
V*, Residual pool volume	<=0.21 (mean) in pools	Knopp 1993	Ten Mile River TMDL for Sediments
V*, Residual pool volume	<0.21 (fransiscan) or <0.10 (other)	Lisle & Hilton 1992	Trinity River TMDL for Sediments
V*, Residual pool volume	<0.21 or <0.10	Lisle & Hilton 1992, Knopp 1993, Lisle 1989, Lisle & Hilton 1998	Albion River TMDL for Sediments
Watershed Indicators			
Activities in unstable areas	avoid and/or eliminate	Dietrich et al. 1998, Weaver and Hagans 1994, PWA 1998	Albion River TMDL for Sediments
Activities in unstable areas	avoid and/or eliminate	Dietrich et al. 1998, Weaver and Hagans 1994, PWA 1998	Big River TMDL for Sediments

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Watershed Indicators (cont'd)			
Activities in unstable areas	avoid and/or eliminate	Dietrich et al. 1998, Weaver and Hagans 1994, PWA 1998	Mattole River TMDL for Sediments and Temperature
Activities in unstable areas	avoid and/or eliminate		Navarro River TMDL for Temperature and Sediments
Activities in unstable areas	avoid and/or eliminate		North Fork Eel River TMDL
Activities in unstable areas	avoid and/or eliminate	Dietrich et al. 1998, Weaver and Hagans 1994, Pitliick 1982, PWA 1998	Noyo River TMDL for Sediments
Activities in unstable areas	avoid and/or eliminate	Dietrich et al. 1998, Weaver and Hagans 1994, PWA 1998	Ten Mile River TMDL for Sediments
Activities in unstable areas	avoid and/or eliminate		Trinity River TMDL for Sediments
Activities in unstable areas	Reduce the number of roads and intensity of timber management located on inner gorge and potentially unstable headwall areas	PWA 1999	Van Duzen River and Yager Creek TMDL for Sediments
Annual road inspection and correction	Increasing % of road to 100%	EPA 1998	Albion River TMDL for Sediments
Annual road inspection and correction	Increasing % of road to 100%	EPA 1998	Big River TMDL for Sediments
Annual road inspection and correction	Increasing % of road to 100%		Gualala River TMDL for Sediment
Annual road inspection and correction	Increasing % of road to 100%	EPA 1998	Mattole River TMDL for Sediments and Temperature

Table C-2. (cont'd).

Indicator	Target	References in TMDL text	Title
Watershed Indicators (cont'd)			
Annual road inspection and correction	Prevent sediment delivery		Navarro River TMDL for Temperature and Sediments
Annual road inspection and correction	Increasing % of road		North Fork Eel River TMDL
Annual road inspection and correction	Increasing % of road to 100%	EPA 1998	Ten Mile River TMDL for Sediments
Annual road inspection and correction	Increasing % of road		Trinity River TMDL for Sediments
Balanced fine and course sediment budgets	channel specific	US FWS 1999	Trinity River TMDL for Sediments
Disturbed areas	decrease in area covered by roads, landings, trails, agricultural, etc.	Lewis 1998	Albion River TMDL for Sediments
Disturbed areas	decrease in area covered by roads, landings, trails, agricultural, etc.	Lewis 1999	Big River TMDL for Sediments
Disturbed areas	decrease in area covered by roads, landings, trails, agricultural, etc.	Lewis 1998	Mattole River TMDL for Sediments and Temperature
Disturbed areas	decrease in area covered by roads, landings, trails, agricultural, etc.	Lewis 1998	Noyo River TMDL for Sediments
Disturbed areas	decrease in area covered by roads, landings, trails, agricultural, etc.	Lewis 1999	Trinity River TMDL for Sediments
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm	Weaver and Hagans 1994, Flanagan et al. 1998	Albion River TMDL for Sediments
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm	Weaver and Hagans 1994, Flanagan et al. 1998	Big River TMDL for Sediments
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm		Gualala River TMDL for Sediment

Table C-2 (cont'd).

Indicator	Target	References in TMDL text	Title
Watershed Indicators (cont'd)			
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm	Weaver and Hagans 1994, Flanagan et al. 1998	Mattole River TMDL for Sediments and Temperature
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm	NMFS 2000, Flanagan et al. 1998	Navarro River TMDL for Temperature and Sediments
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm	Weaver and Hagans 1994	North Fork Eel River TMDL
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm	Weaver and Hagans 1994, Flanagan et al. 1998	Noyo River TMDL for Sediments
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm	Weaver and Hagans 1994, Flanagan et al. 1998	Ten Mile River TMDL for Sediments
Diversion and stream crossing failure potential	<=1% of crossings divert or fail in 100 year storm	Weaver and Hagans 1994	Trinity River TMDL for Sediments
Diversion potential and stream crossing failure potential	Eliminate diversion potential (I.e., functional dips are in place at stream crossings); no unculverted fill or log crossings (designed for 50 yr. Flow)	Weaver and Hagans 1994 and 1999; Furniss et al. 1998	Van Duzen River and Yager Creek TMDL for Sediments
Fill failures	Prevent unstable fill failures that could deliver sediment to streams	Weaver and Hagans 1994 and 1999	Van Duzen River and Yager Creek TMDL for Sediments
Hydrologic connectivity of roads	decreasing length of connected roads to <=1%	Ziemer 1998, Flanagan et al. 1998, Furniss 1999	Albion River TMDL for Sediments
Hydrologic connectivity of roads	decreasing length of connected roads to <=1%	Ziemer 1998, Flanagan et al. 1998, Furniss 2000	Big River TMDL for Sediments
Hydrologic connectivity of roads	<=5% length of road draining to stream	Weaver and Hagans 1994	Gualala River TMDL for Sediment
Hydrologic connectivity of roads	decreasing length of connected roads to <=1%	Ziemer 1998, Flanagan et al. 1998, Furniss 1999	Mattole River TMDL for Sediments and Temperature

Table C-2 (cont'd).

Indicator	Target	References in TMDL text	Title
Watershed Indicators (cont'd)			
Hydrologic connectivity of roads	<=10% length of road draining to stream	RWB 2000a	Navarro River TMDL for Temperature and Sediments
Hydrologic connectivity of roads	decreasing length of roads	Weaver and Hagans 1995	North Fork Eel River TMDL
Hydrologic connectivity of roads	decreasing length of connected roads (and railroads)	Ziemer 1998, Furniss 1999	Noyo River TMDL for Sediments
Hydrologic connectivity of roads	decreasing length of connected roads to <=1%	Ziemer 1998, Furniss 1999	Ten Mile River TMDL for Sediments
Hydrologic connectivity of roads	decreasing length of connected roads to <=1%	Weaver and Hagans 1995	Trinity River TMDL for Sediments
Hydrologic connectivity of roads	Road surfaces and streams are disconnected from streams (<5% of stream crossings may be infeasible)	Weaver and Hagans 1994 and 1999	Van Duzen River and Yager Creek TMDL for Sediments
Road location, surfacing, sidecast	decreasing length next to stream, increasing % outsloped and hard surfaced roads	EPA 1998	Albion River TMDL for Sediments
Road location, surfacing, sidecast	decreasing length next to stream, increasing % outsloped and hard surfaced roads	EPA 1998	Big River TMDL for Sediments
Road location, surfacing, sidecast	decreasing length next to stream, increasing % outsloped and hard surfaced roads	EPA 1998	Mattole River TMDL for Sediments and Temperature
Road location, surfacing, sidecast	appropriate design construction and maintenance to reduce landslides		Navarro River TMDL for Temperature and Sediments
Road location, surfacing, sidecast	decreasing length next to stream, increasing % outsloped and hard surfaced roads		North Fork Eel River TMDL
Road location, surfacing, sidecast	decreasing length next to stream, increasing % outsloped and hard surfaced roads	EPA 1998	Ten Mile River TMDL for Sediments

Table C-2 (cont'd).

Indicator	Target	References in TMDL text	Title
Watershed Indicators (cont'd)			
Road location, surfacing, sidecast	decreasing length next to stream, increasing % outsloped and hard surfaced roads		Trinity River TMDL for Sediments
Sediment delivery	30% reduction of sediment from early spring runoff		San Miguel River TMDL for Sediment