COLORADO
Water Quality
Control Commission
Department of Public Health & Environment

Guidance for Implementation of

Colorado's Narrative Sediment Standard

Regulation #31, Section 31.11(1)(a)(i)

Policy 98-1

Adopted: November 10, 2014
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List of Acronyms and Abbreviations

303(d) List	List of Impaired Waters (pursuant to section 303(d) of the federal Clean Water Act)
AAH	Administrative Action Hearing
BMPs	Best Management Practices
Basic Standards	Basic Standards and Methodologies for Surface Water (5 CCR 1002-31); also known as Regulation #31
CAFO	Confined Animal Feeding Operation
CCR	Colorado Consolidated Regulations
CDPS	Colorado Discharge Permit System
CFR	Code of Federal Regulations
CPW	Colorado Parks and Wildlife
CRS	Colorado Revised Statures
CWQCA	Colorado Water Quality Control Act
CWA	Clean Water Act
Commission	Colorado Water Quality Control Commission
Division	Colorado Water Quality Control Division
EPA	U.S. Environmental Protection Agency
FAQ	Frequently Asked Questions
M&E List	Monitoring and Evaluation List
MMI	Multi-Metric Index
NA	Not Applicable
Q & A	Questions and Answers
RBP	Rapid Bioassessment Protocol
RMH	Rulemaking Hearing
Regulation #31	Basic Standards and Methodologies for Surface Water
SED	Sediment
SBP	Statement of Basis and Purpose
SOP	Standard Operating Procedures
TAC	Technical Advisory Committee
TIV	Tolerance Indicator Value
TMDL	Total Maximum Daily Load

UAA	Use Attainability Analysis
USFS	U.S. Forest Service
WQCC	Colorado Water Quality Control Commission
WQCD	Colorado Water Quality Control Division
WQS	Water Quality Standards

Definitions

"Bedload": Bedload is sediment that moves by rolling or sliding along the bed and is essentially in contact with the stream bed in the bed layer.

"List of Impaired Waters" (303(d) List): Colorado's List of Impaired Waters identifies those waters for which technology-based effluent limitations and other required controls are not stringent enough to implement water-quality standards, pursuant to section 303(d) of the federal Clean Water Act (adopted by the Commission as part of Regulation #93).

"Monitoring and Evaluation List" (M&E List): Colorado's Monitoring and Evaluation List identifies water bodies where there is reason to suspect water quality problems, but there is also uncertainty regarding one or more factors, such as the representative nature of the data (adopted by the Commission as part of Regulation #93).

"Multi-Metric Index" (MMI): Colorado's Multi-Metric Index (MMI) bioassessment tool is designed to detect environmental stress that results in alteration of the biological community. It provides biological thresholds for the Aquatic Life Use in streams with a watershed area less that 2700 mi^2. (see Policy 10-1)

"redd": a hollow in sand or gravel on a river bed, scooped out as a spawning place by salmon, trout, or other fish.

"Total Maximum Daily Load" (TMDL): A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. Pollutant sources are characterized as either point sources that receive a wasteload allocation, or nonpoint sources that receive a load allocation.

"Use Attainability Analysis" (UAA): A UAA is an assessment of the factors affecting the attainment of aquatic life uses or other beneficial uses, which may include physical, chemical, biological, and economic factors.

"TIV_{SED}": The weighted average Tolerance Indictor Value that results in a final unitless score for a benthic macroinvertebrate sample from a given site. Values range from zero to ten. Higher values indicate the macroinvertebrate community is more tolerant of fine-sediment deposits.

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Guidance for Implementation of Colorado's Narrative Sediment Standard Regulation # 31, Section 31.11(1)(a)(i)

WQCC Policy 98-1

I. INTRODUCTION

This policy document is intended to provide guidance to the Water Quality Control Division ("Division") staff and to the public regarding the implementation of the Colorado Water Quality Control Commission's ("Commission") "narrative standards" as they apply to sediments which may form deposits detrimental to the beneficial uses. The Basic Standards and Methodologies for Surface Water, Regulation 31 (5 CCR 1002-31) ("the Basic Standards"), are the basis for establishing this guidance. In particular, section 31.11 of this regulation provides the following language:

> All surface waters of the State are subject to the following basic standards; however, discharge of substances regulated by permits which are within those permit limitations shall not be a basis for enforcement proceedings under these basic standards:
>
> (1) Except where authorized by permits, BMP's, 401 Certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which:
>
> (a) For all surface waters except wetlands;
>
> (i) can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud;

Policy 98-1 provides guidance in implementing the narrative standard for bottom deposits in all state surface waters (except wetlands). However, different methods and thresholds are appropriate for different geographic settings and different beneficial uses.

The contents of this document have no regulatory effect, serving instead to summarize the Commission's thinking and actions in a single public document. In other words, as opposed to a rule or regulation, this policy statement has no binding effect on the Commission, the Division, or the regulated community. Moreover, this policy is not intended, and should not be interpreted, to limit any options that may be considered or adopted by the Commission in future rulemaking proceedings. Therefore, this policy statement can, and will, be modified over time as warranted by future rulemaking decisions.

Section II of this document records the history of the Commission's actions and sets out the core concepts that are the foundation of the Sediment Guidance. Section III includes a discussion of the applicability of the narrative standard to beneficial uses, the concept of expected condition, and the general framework for attainment decisions. Section IV provides guidance on assessing sediment impacts to the Aquatic Life Use and describes the numerical thresholds for sediment impacts on the Aquatic Life Use (including macroinvertebrates and salmonid spawning), where the thresholds are applicable, and how they were derived. Section V discusses the general method for assessment of sediment impacts where the methods in section IV do not apply. Section VI describes the relationship between the sediment guidance and other related policies. Frequently Asked Questions are included in Appendix A. Protocols for pebble count and benthic macroinvertebrate sampling are included as Appendices B and C, respectively. Additional information on the development of the methodology and numerical thresholds is provided in Appendices D, E, and F. A literature review pertaining to the relationship between salmonid spawning and percent fines is presented in Appendix G.

II. HISTORY

Colorado's narrative sediment standard (see (31.11(a)(1)(i))) was included in the Basic Standards adopted by the Commission in 1979. Unfortunately, in the Statement of Basis for that hearing and subsequent hearings there is no direct discussion of why the narrative standards were included or how they were to be interpreted.

All states have adopted similar narrative standards, and EPA considers that the narrative criteria apply to all designated uses, at all flows, and are necessary to meet the statutory requirements of section 303(c)(2)(A) of the CWA [1]

In the mid 1990s, national interest arose in developing quantitative methods for determining the impact caused by sedimentation in the nation's water ways.

A. Initial Policy Development

In 1996, the Colorado Sediment Task Force was convened with the goal of developing a guidance document for implementing the narrative sediment standard. The product of the Task Force was the *Implementation Guidance for Determining Sediment Deposition Impacts to Aquatic Life in Rivers and Streams* ("Sediment Guidance"). The Sediment Guidance was adopted as "provisional" by the Water Quality Control Commission in 1998 with a review required in 2 years to allow agencies and other stakeholders to gain experience applying the guidance. The expiration date was extended in 2000 and again in 2002.

The initial version of the guidance was specifically intended to apply to the assessment of aquatic life uses in higher gradient, cobble-bed, coarse-grained mountain stream and wadeable river environments. It was not intended to address sediment impacts in sandy-bottom, lower-gradient streams, large unwadeable rivers, or lakes and reservoirs. The Sediment Task Force's intention was to continue to work on approaches for these other environments, but other priorities arose. Much of the momentum from this effort was diverted to the Aquatic Life Use Work Group effort (that culminated in Policy 10-1) and the nutrient criteria development effort.

B. First Major Revision: May 2005

The Sediment Task Force was reconvened in January 2003 to address shortcomings that the Task Force members had experienced when using the Provisional Guidance. As a result of the Task Force's work, changes were proposed to:

- Augment the discussion of particle size and the importance of and steps in substrate evaluation;
- Modify the use support categories/percentages for substrate to reflect other sampling/measurement protocols and recent experience;
- Modify the use support percentages for biological assessment to reflect recent experience;

[1] U.S. EPA. 2012. *Water Quality Standards Handbook: Second Edition*. EPA-823-B-12-002

- Add more information regarding biological metrics that indicate sediment impairment, including tables that identify macroinvertebrate and fish metrics that are sensitive to sedimentation effects; and
- Add example assessments of fictional stream reaches in an appendix.

The Division proposed the document as revised by the Task Force for consideration by the Commission. At the May 2005 AAH, the Commission adopted the revised Sediment Guidance as final (as opposed to "provisional"), with an expiration date of May 2007.

Post-Sediment Task Force Input: After the Sediment Task Force process ended in 2005, the US Forest Service[2] identified serious concerns with the guidance. They noted that in their experience, the guidance was too nebulous, the decision matrix excluded sites that should be considered "impaired," and the "two part test" should not always be required.

After the adoption of the May 2005 version guidance, the Division and other agencies used the guidance to evaluate streams suspected of sediment impairment. Many streams that had previously been included on the M&E list were re-assessed and over 70 were removed from the list. A few of these were added to the 303(d) list. The Division, along with USFS and EPA, also used the guidance to evaluate streams for post-TMDL project effectiveness.

2007 Review: At this time, the focus of biological assessment work had entirely shifted to development of the Aquatic Life Use Policy 10-1. At the March 2007 review, the Division recommended that the Sediment Guidance be continued as final guidance with an extended expiration date of May 2010.

2010 Review: At the March 2010 review, the Division recommended that the Sediment Guidance be continued as final guidance with an extended expiration date of May 2013. Further, the Division identified two issues that could be addressed in the guidance in the future, when resources were available:

- Because the guidance was specifically written to address high-gradient, cobble-bedded streams, it has limited usefulness in sandy-bottomed xeric or plains streams. Assessment methodologies should be explored to expand the utility in the other portions of the state.
- Once the Division and stakeholders have more experience with the aquatic life assessment methodologies and the macroinvertebrate multi-metric index (MMI) tool, Policy 98-1 should be updated to incorporate use of the MMI tool in assessment of attainment of the narrative sediment standard.

2012 Section 303(d) List (Regulation #93) hearing, December 2011: Sediment Guidance became an issue (see WQCD Rebuttal, 303(d) List RMH, November 30, 2011 pp 46-52). Following the methodology in Policy 98-1 resulted in a determination that the waterbody was impaired. However, following the methodology in Policy 10-1, the waterbody was not impaired. In other cases, it was found that streams met the Aquatic Life Use attainment thresholds in Policy 10-1, but were considered impaired under the methodology in Policy 98-1.

2012 Memo to Commission: In November 2012, the Division discussed the timing of the review of Policy 98-1 (which was set to expire May 31, 2013) with the Commission. It

[2] USFS letter, April 27, 2005

was the Division's recommendation that the Commission extend the expiration date to December 31, 2014, and schedule an AAH to consider a revised draft at the October 2014 Commission meeting. The Commission followed the Division's recommendation.

C. Second Major Revision: November 2014

In the fall of 2013, the Division and stakeholders undertook a review of Policy 98-1 with the intent of addressing the shortcomings that have been identified above.

A Technical Advisory Committee ("TAC") was empanelled and given the charge to:

> Develop a scientifically sound tool (s) (or methodology(ies)), that is/are generally based on existing Colorado data, to the extent existing Colorado data are adequate to address the question. The tool(s) should be able to be used to identify or predict the degree of impact to the aquatic community caused by deposits of sediment at a given test site. The procedure must be an improvement (e.g., in terms of accuracy or reduction in ambiguity) over the procedure that is currently included in Policy 98-1.

The remainder of the stakeholder group focused discussion on whether and how the Policy 98-1 document should be revised to address the larger universe of situations where anthropogenic sediment causes problems, such as policy and implementation issues.

Besides format and updating, the major changes that came about from this effort are:

- Removal of redundant material;
- Articulation of the general framework for implementing the narrative sediment standard;
- Development of specific methodologies to evaluate attainment of the narrative sediment standard in terms of effects on the macroinvertebrate and salmonid fish spawning aspects of the Aquatic Life Use; and
- Metrics and thresholds based on Colorado-specific data that are to be used in certain defined Sediment Regions.

The Commission adopted the revised proposal on November 10, 2014 with an expiration date of December 31, 2017.

D. [*Reserved for periodic updates regarding future Commission policy decisions*.]

III. CENTRAL CONCEPTS

The assessment methodology is a means to determine whether or not a specific waterbody is "free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which can settle to form bottom deposits detrimental to the beneficial uses" (Regulation 31.11(1)(a)(i)). This section includes a discussion of the central concepts for identifying sediment impairment, including a description of "beneficial uses" and the concept of the expected condition of a water body.

A. Beneficial Uses versus Classified Uses

The Colorado Water Quality Control Act and the Basic Standards use both the terms "beneficial use" and "classified use." Although some beneficial uses of the water have been identified in the classification system for added protection, beneficial use is a broader concept that is also used in the water rights context (see, e.g., 25-8- 105(1)). In the water rights setting, the uses of water are considered beneficial if they are lawfully appropriated and "employ reasonably efficient practices to put the water to use." The Commission must recognize the beneficial uses of state waters to be protected, and it must do so in a public rulemaking hearing.

The narrative sediment standard in Regulation 31.11 applies to all state surface waters except wetlands, and provides protection to all beneficial uses, even if they have not been classified.

B. Expected Condition as a Concept

The assessment approach described in this guidance is based on the concept of comparing the actual conditions of a specific study stream reach or segment with the expected conditions for the same stream to determine attainment of the narrative standard. This Guidance uses the term "expected condition" rather than the EPA terminology of "reference condition". Expected condition is used in this guidance in an attempt to avoid the concern that sometimes arises when reference condition is narrowly interpreted to mean pristine streams.

Key to the concept of expected condition is the premise that streams minimally affected by human activity will exhibit biological, chemical and physical conditions that are representative of what is most natural and attainable for streams in the region. Sites that are undisturbed by human activities may be ideal sites; however, land and water use practices and atmospheric pollution have so altered water resources that truly undisturbed sites are rarely available. In practice, most sites will reflect some of these impacts.

Defining the expected condition of a specific stream is a critical step. One approach is to identify an individual expected condition site to use as a direct comparison to the study site. Sometimes that site can be upstream or in a neighboring watershed from the study site. Another approach relies on describing the characteristics of the expected condition from a combination of the attributes of minimally disturbed sites. In this approach, the region of application must be defined and key metrics identified and measured. A third approach relies on a policy statement - for instance, that as a matter of policy, it is the Commission's expectation that where habitat is suitable for salmonid spawning, deposits of sediment shall not be present in amounts that can harm the survival of salmonid eggs or young.

C. General Framework for Attainment Decisions

In order to protect and maintain Colorado's beneficial uses of water, wherever possible, defined methods and a consistent approach should be used to determine whether sedimentation has impaired the beneficial or classified uses of a water body. The methods and approaches are based on the following general framework for determining whether the narrative standard is attained.

1. <u>Comparison of Actual Condition with Expected Condition:</u> The Commission supports the use of "expected condition" as the basis for characterizing use support. It is important to note that this concept of use support embraces considerable variation in stream morphology, the biological community, and

geographical setting.

2. Impairment is a Significant Departure from Expected Condition: The Commission affirms the position taken in prior decisions made in the context of the Section 303(d) Listing Methodology — that clear and convincing evidence is needed to show impairment, and the status of non-attainment represents a significant departure from reference or expected condition. Consistent with the CWQCA at section 25-8-204(5), the Commission requires that statistical methodologies be based on assumptions that are compatible with the water quality data. Application of those methodologies should be transparent with respect to uncertainty and risk of mistaken conclusions.

3. Watershed Review: Consistent with the narrative standard, the standard only applies to sediment that is attributable to human causes. A watershed review must be undertaken to inform an impairment decision.

IV. AQUATIC LIFE USE IMPACTS - ASSESSMENT METHODOLOGIES

Excessive deposition of sediment on the bottom of streams and rivers is an important cause of impacts to aquatic life. These impacts usually result from the loss of critical habitat for fish, aquatic invertebrates, and algae. Sediment impacts have been addressed in a detailed review by Waters (1995) and other literature reviews. Impacts to fish can include the smothering of fish spawning gravels and cobble surfaces with fine sediment, resulting in decreased intergravel oxygen and a reduction in survival and growth rates; loss of fish food sources; and loss of pool and other habitat types through changes in stream channel morphology. Impacts to aquatic invertebrates can include the smothering and infilling of the interstitial spaces normally found in clean gravel and cobble. This loss of habitat space can result in changes to the aquatic invertebrate community, including changes in community structure, such as relative abundance, and the loss of sensitive species.

Only human-caused discharges of sediment in amounts, concentrations, or combinations which can settle to form bottom deposits detrimental to beneficial uses are considered in this guidance. Therefore, naturally occurring erosive processes across a variety of geologic conditions must be considered before implementing this guidance.

The following assessment methodology applies to sediment causing stress to aquatic life through the deposition of materials. This method is not intended to provide a complete analysis of Aquatic Life Use attainment. Other analyses (e.g., chemical and toxicity analysis) would be necessary to determine attainment of other standards and to understand the full range of possible stressors which may be impacting aquatic life. It is also not intended to apply to evaluating stress caused by organic or contaminated sediments.

Consistent with policy statements in Policy 10-1, it is the Commission's intent that there should be predictable, transparent, and understandable techniques for evaluating Aquatic Life Use impairment by sediment. It is the Commission's policy to apply, wherever possible, a defined method and a uniform approach to determine whether the Aquatic Life Use is impaired due to sediment for a specific water body.

A. Protection of Benthic Macroinvertebrates

Aquatic benthic macroinvertebrate communities respond to and therefore may be indicators of a variety of physical and chemical environmental conditions that occur within stream systems and associated watersheds. The addition of excessive fine sediments, whether in a suspended or deposited state, is expected to have negative impacts on some aquatic life in streams (Waters 1995; Wood and Armitage 1997; Henley et al. 2000). An increase in fine sediment bedload in a stream typically results in a reduction in habitat complexity by filling spaces that exist between cobbles and gravel, and consequently a reduction in macroinvertebrate density and diversity (Wohl 2000). Sediment in transit reduces light transmission and can have abrasive properties, while the deposition of fine sediment reduces benthic habitat and can smother benthic organisms (Culp et al. 1986; Wood and Armitage 1997). It is likely that the percentage of fine sediment in the substrate, the concentration of suspended sediments, and duration of exposure are all important factors when considering the response of benthic macroinvertebrates to sedimentation (Culp et al. 1986; Doeg and Milledge 1991; Newcombe and MacDonald 1991).

Because sedimentation is one of the most common and widespread forms of pollution in the western United States recent research has focused on the development of macroinvertebrate indicator values and community response metrics for the development of biologically-based sediment criteria (Relyea et al. 2000; Carlisle et al. 2007; Bryce et al. 2010; Relyea et al. 2012; Extence et al. 2013). In general, the negative impacts associated with sedimentation on aquatic life are not the result of toxicity, but the result of habitat alteration, displacement, or interference with feeding strategies and/or habits. For these reasons, Waters (1995) suggested that macroinvertebrate density may be one of the most sensitive indicators of sedimentation in streams, and metrics that rely on measures of diversity may only respond to high levels of sedimentation or prolonged exposure. In order to identify and monitor low, medium, and high levels of impact specifically related to sedimentation, recent studies have recommended that individual common taxa be categorized according to sediment tolerance or assigned tolerance values based on the sensitivity of each taxon (Carlisle et al. 2007; Relyea et al. 2012; Extence et al. 2013). This is the approach used to assess protection of macroinvertebrates.

1. Summary of the Method

This method applies to sites within one of the defined Sediment Regions and uses three components: a measure of the percent fines, a TIV_{SED} score, and a review of available watershed information. All three components should be used to inform a listing decision. Figure 1 presents a decision tree that displays the relationship of the steps in the method.

a. Comparison of Actual Condition with Expected Condition: This method uses the approach that combines attributes from reference sites in a Sediment Region.

i. The expected conditions for sediment deposition and the macroinvertebrate community are established from analysis and combination of the attributes of minimally disturbed reference sites in each Sediment Region.

ii. The actual conditions of the study site are determined by measuring sediment deposition and the macroinvertebrate community. The percent of the area within the wetted width covered by particles that are less than 2 mm is the sediment deposition metric. The Sediment Tolerance Indicator Value (TIV_{SED})

is the biological metric.

b. Impairment is a Significant Departure from Expected Condition: Study-site metrics for sediment deposition and biological condition are compared to those of the expected condition for the Sediment Region. If the study site's metrics for both indicators exceed the respective thresholds for each indicator the site is significantly different than the expected condition for that Sediment Region.

c. Watershed Review: If both indicators exceed the respective threshold, then the third component in the method is to review available watershed information. This step is intended to identify whether or not the excess sediment is likely due to "human caused point source or nonpoint source discharge(s)." In addition the watershed review should evaluate whether the watershed characteristics for the site are within the range of conditions used to establish the expected condition for the Sediment Region (see Table 1 and Appendix D).

The development and components of this method are further discussed in the following sections.

Figure 1. Assessment of Macroinvertebrate Protection - Decision Tree

1 – Using Figures 2-4 or Appendix D, determine the Sediment Region for your site.

A. Region 1 – go to 2
B. Region 2 – go to 3;
C. Region 3 – go to 4;
D. Other – go to 5

2 – **Sediment Region 1:** Compare site information with the thresholds. Does the site exceed both thresholds?

Sediment Region 1	Threshold Values
WA TIV_{SED}	6.1
% fines <2 mm	27.5

A. Yes – site may be impaired for sediment, go to 6
B. No – site is not impaired for sediment

3 – **Sediment Region 2**: Compare site information with the thresholds. Does the site exceed both thresholds?

Sediment Region 2	Threshold Values
WA TIV_{SED}	7.0
% fines <2 mm	29.3

A. Yes – site may be impaired for sediment, go to 6
B. No – site is not impaired for sediment

4 –**Sediment Region 3**: Compare site information with the thresholds. Does the site exceed both thresholds?

Sediment Region 3	Threshold Values
WA TIV_{SED}	6.3
% fines <2 mm	41.0

A. Yes – site may be impaired for sediment, go to 6
B. No – site is not impaired for sediment

5 – **Other Regions:** Conduct individual site assessment to determine macroinvertebrate expected condition and sediment deposition expected condition (see section V)

6 – **Watershed Review:** What does the review of available watershed information tell you?

A. Are the watershed characteristics for the site within the range of conditions used to establish the expected condition for the Sediment Region?
   - Yes – go to part B
   - No – if the expected condition for the Sediment Region is different from the expected condition for the site, then assess the site using the method at Section V.

B. Does evaluation of available site-specific information identify that the excess sediment is likely a human-caused condition?
   - Yes – site is impaired, the macroinvertebrate use is not protected
   - No – site is not impaired

2. Sediment Regions

In order to increase the value of the sediment assessment tool, the state was divided or stratified into regions with similar erosion/deposition rates. Approximately half of the state has been included in Sediment Regions 1, 2, and 3. This represents the limits of the existing data and reference sites which formed the basis for assessment tool development. As more data are collected in the rest of the state, it is anticipated that this approach can be extended and more Sediment Regions will be established. Table 1 describes the Sediment Regions, which are also displayed in Figures 2, 3, and 4. Appendix D further describes the development of the Sediment Regions.

Table 1. Description of Sediment Regions 1, 2, and 3

		Sediment Region 1	**Sediment Region 2**	**Sediment Region 3**
Description		High mountains with steep slopes. Glaciated. Alpine and subalpine forest.	Mid-elevation mountains. Partially glaciated. Mid-Elevation Forests	Low mountains, mid-elevation hills, ridges and foot slopes. Unglaciated. Woodland and shrubland.
Reference Site Conditions	Ecoregion IDs (See Appendix D)	21a, 21b, 21e, and 21g	21c, 21f, and 21h	18d, 20c, 20e, and 21d
	Number of Reference Sites	32	18	16
	Reference Site Range of % Fines <2 mm; median value	1 – 28%; 5%	4 – 52%; 9%	9 – 41%; 18%
	Reference Site Range of Stream Course Slopes (ft/ft); median value	0.008 – 0.235; 0.06	0.01 – 0.1; 0.05	0.004 – 0.1; 0.03
	Reference Site Elevation Range (ft); median value	7400 - 12000, 9600	6600 – 10200, 7800	4900 – 7800, 6200

Figure 2. Map of Sediment Region 1 (Western Colorado).

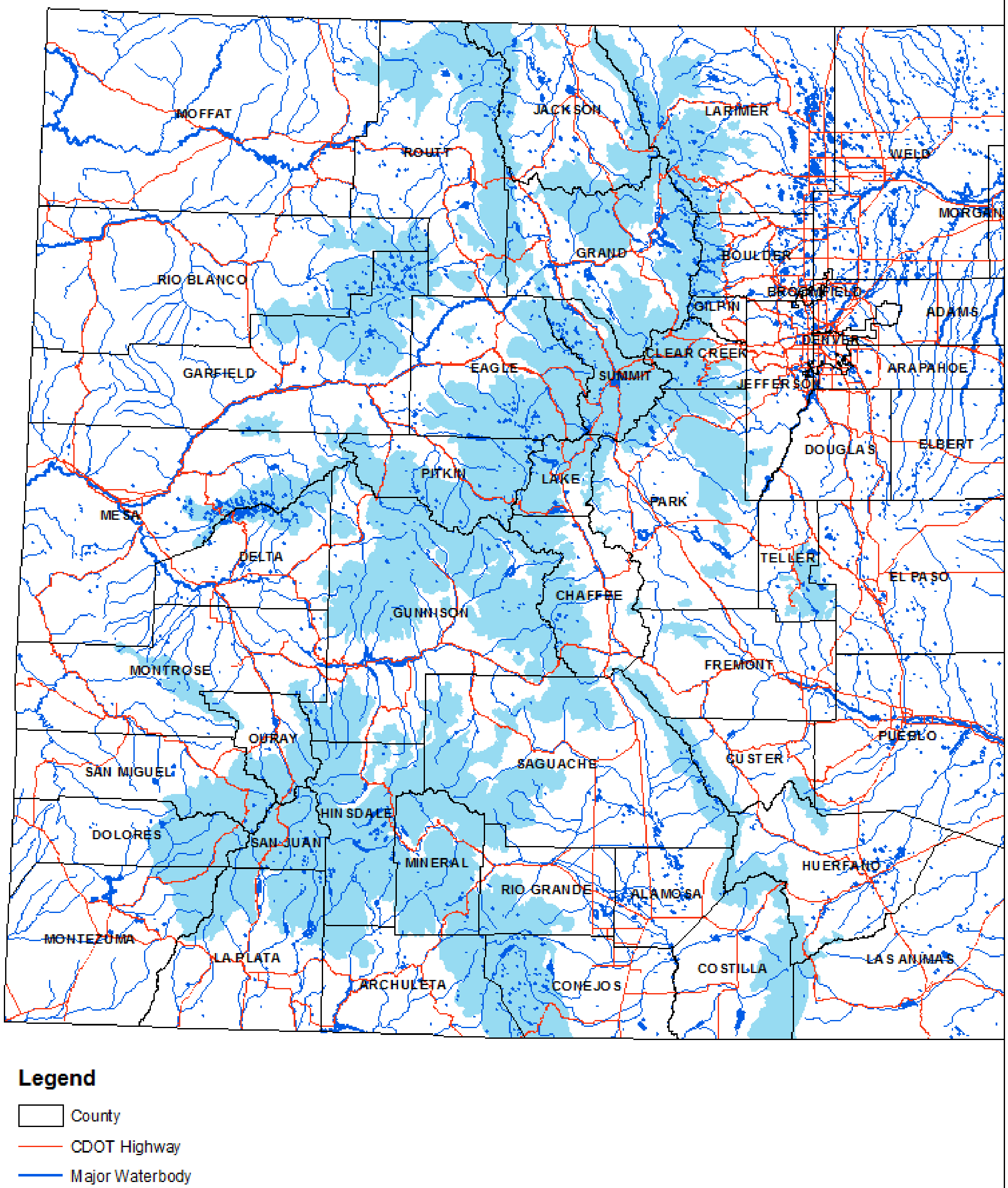


Figure 3. Map of Sediment Region 2 (Western Colorado).

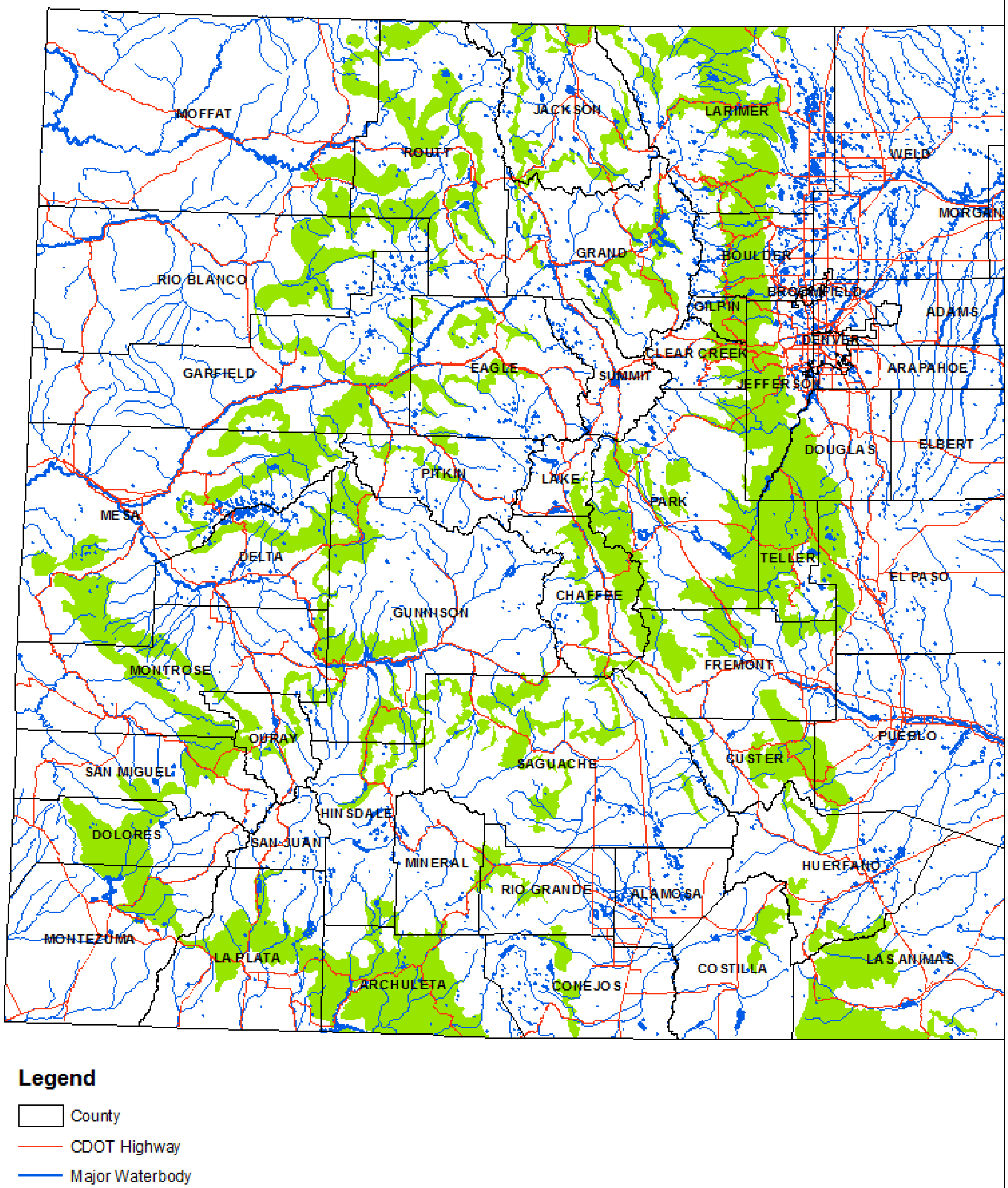
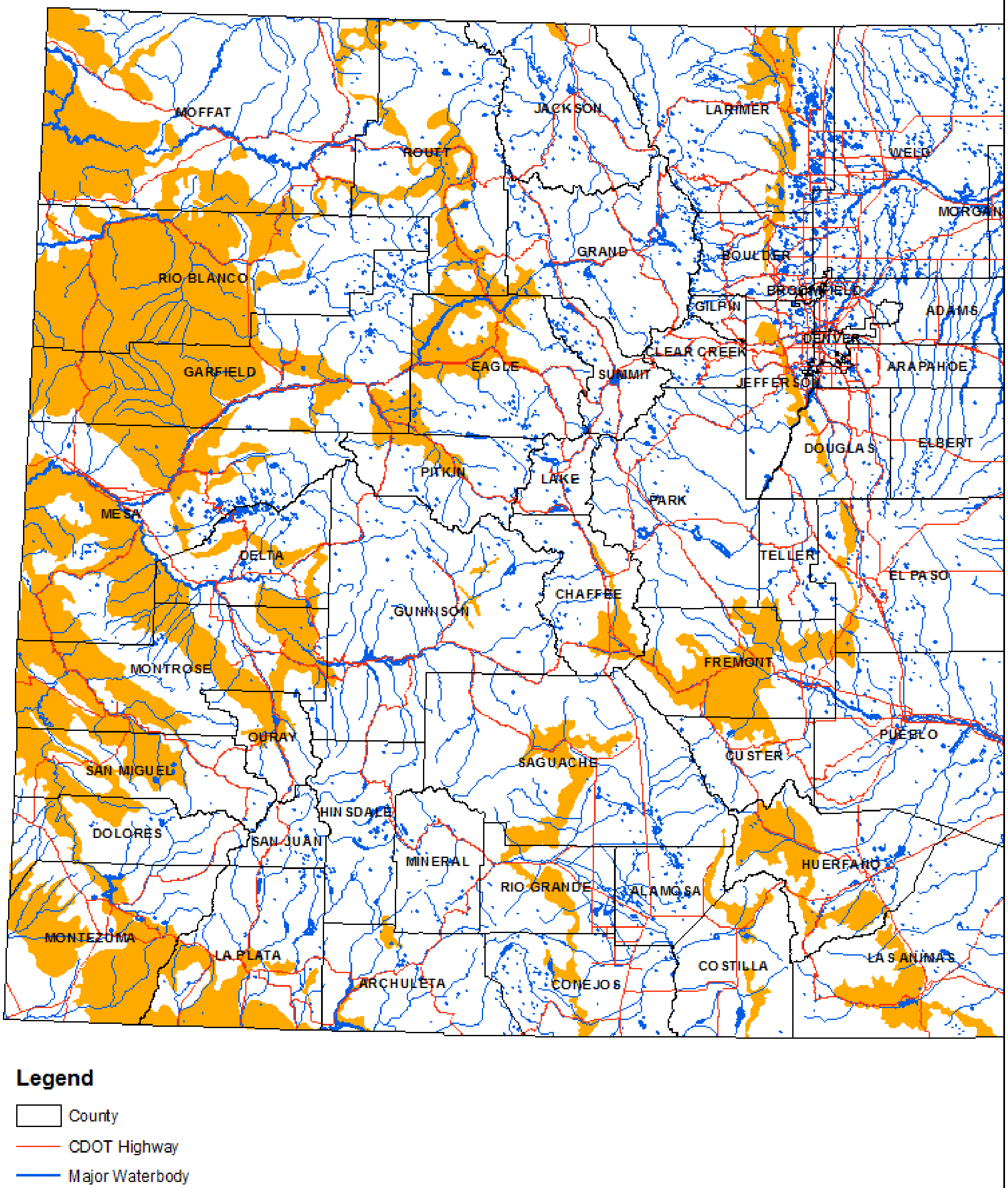


Figure 4. Map of Sediment Region 3 (Western Colorado).



3. Measure of Sediment Deposition (Percent Fines)

The exposure indicator for bedded sediments is the percent of particles with a grain size <2 mm, or "percent fines." The grain size of <2 mm was selected because the body of literature on sediment impacts to macroinvertebrates indicates that the small fines (<2 mm) have the most significant impact (Bryce et al. 2010). The method that the WQCD uses to measure percent fines is the Modified Wolman Pebble Count Method, while USEPA and the USFS used other methods developed for their own specific projects. For measuring percent fines, the WQCD will employ its Pebble Count Standard Operating Procedure (see Appendix B) or use sediment data collected using a comparable method to determine the percent fines that are <2 mm that are within the wetted width of the stream.

Measured percent fines from the site should be compared to the Threshold for Percentage of Bedded Fines (<2 mm) for the Sediment Region. If the measured percent fines are below the threshold, the site is attaining the narrative standard. If the measured percent fines are above the threshold, then the next step is to evaluate macroinvertebrate data (i.e., biological sediment indicator) from the site.

Threshold for Percent Fines (<2 mm)	
Sediment Region 1	27.5%
Sediment Region 2	29.3%
Sediment Region 3	41.0%

4. Measurement of the Biological Indicator (TIV_{SED})

Sediment Tolerance Indicator Values (TIV_{SED}) for macroinvertebrates were developed as the biological indicator of impacts by excess fine sediments. The TIV_{SED} reflects both the reduction in relative abundance of sediment-sensitive taxa and the increase in relative abundance of sediment-tolerant taxa. The method for calculating TIV_{SED} was developed using recommended methods from the National Water Quality Assessment Program (Carlisle et al. 2007). A complete description of the method for developing the TIV_{SED} and the steps for calculating a TIV_{SED} is included in Appendix E.

The calculated TIV_{SED} score from the site should be compared to the threshold for the Sediment Region. If the TIV_{SED} score from the site is below the threshold, the site is attaining the narrative standard (even if the sediment threshold is exceeded). If both the measured percent fines and the TIV_{SED} score for a site are above the thresholds, then the next step is to complete a watershed review.

Threshold for TIV_{SED}	
Sediment Region 1	6.1
Sediment Region 2	7.0
Sediment Region 3	6.3

5. Watershed Review

The purpose of the watershed review is to answer these questions:

1) Are the watershed characteristics for the site within the range of conditions used to establish the expected condition for the Sediment Region? (This step is only appropriate for the macroinvertebrate method at section IV.A.)

2) Is the excess sediment attributable to human-caused point source or nonpoint source discharge(s)?

3) If a site is determined to be impaired, which portion of the stream segment is not in attainment (i.e., should the entire segment or only a portion of the segment be listed)?

Because different types of data may be useful on a site-specific basis, this method should remain flexible about the types of data and information that can be used to inform the watershed review. The watershed assessment could include qualitative or quantitative information. The following options are suggestions, and should not be interpreted as requirements or limitations.

A) Information which may be useful for determining whether the watershed characteristics for the site are within the range of conditions used to establish the expected condition for the Sediment Region:

- Relative location of the site within the watershed
- Comparison of local site characteristics (e.g., slope, elevation, geology, etc) to the range of conditions within the Sediment Region (See Appendix D)

B) Information which may be useful for determining whether excess sediment is attributable to a natural cause or human sources:

- Types and density of vegetation in the riparian zone and any observed damage to vegetation or areas of bare soil
- Bank stability (e.g., observations of slumping banks or streambank erosion)
- Evidence of channelization
- Flow sequences (depth/velocity regimes)
- Ratio of Pool/Riffle/Run habitats within the stream reach
- River geomorphology
- Information regarding the timing and potential effect of recent precipitation events
- Description of surrounding land uses
- Observations of erosion in the surrounding watershed
- Photographs of the site and surrounding watershed
- Review of aerial photographs

For the assessment method at Section IV.A, if the characteristics of a particular site support a conclusion that the deposition of fines is expected to be higher than the range of percent fines observed at reference sites in the region, then it can be determined that the thresholds developed for the Sediment Region are not representative or applicable. In such a case, an alternative expected condition for percent fines and/or the macroinvertebrate community should be developed and used as site-specific threshold(s) to assess attainment following the general method in Section V.

For assessment using any of the methods, available information that points to a natural cause (e.g., beaver dams) as the best explanation for excess sediment can be used to inform the listing decision. In this example, a decision could be made that the excess sediment is not the result of human-caused point source or nonpoint source discharges.

If available information indicates that there are point or nonpoint sources of sediment (e.g., evidence of anthropogenic erosion), then it can be determined that the site is impaired. The watershed review may be qualitative and should identify potential source(s) of excess sediment. It is not necessary to quantify all potential sources of sediment loading before listing the water body (this would be analogous to developing a TMDL before making a listing decision).

Finally, for assessment using any of the methods, if it is determined that a site is impaired for sediment, the information regarding potential sources of sediment should also be used to identify the extent of impairment, if possible. Aerial photographs, land use coverage maps, information regarding potential sources and observations made at the site could also be useful for identifying the extent of impairment. If only a portion of the segment is not in attainment with the narrative standard, then it is only necessary to list the impaired portion.

B. Protection of Fish Spawning Habitat – Site Specific

In some circumstances, this guidance can be used to evaluate attainment of the narrative sediment standard in terms of protection of fish spawning habitat. Excessive amounts of fine sediments can affect salmonid spawning in various ways, such as smothering eggs and restricting intragravel flow during incubation and blocking fry emergence from gravel.

For streams with aquatic life that includes salmonids (i.e., trout), measurements of particles smaller than 6.35 mm are commonly used to describe spawning gravel quality (Chapman 1988). Chapman (1988) presented results from several studies showing effects on embryo survival when the percentage of fine sediment ranging from <0.83 mm to <6-12 mm exceeds 10-20%. Weaver and Fraley (1991) observed a significant inverse relationship between the percentage of fine sediments smaller than 6.35 mm and the emergence success of trout species (Figure 5). Reviews by Kondolf (2000) and Jensen et al. (2009) presented data from several salmonid spawning studies that also reported impacts of fine sediments (e.g., particles smaller than 6.35 mm) on embryo survival and fry emergence. Kondolf (2000) reported 50% fry emergence (which the authors considered a productive amount of emergence success) for several salmonid species when there is a maximum of 10-30% fines ranging from <2 to <9.5 mm. Jensen et al. (2009) reported decreases in salmonid eyed egg survival when percent fines <6.4 mm exceeded 20-25%. U.S. Fish and Wildlife Service Habitat Suitability Index models (Hickman and Raleigh 1982; Raleigh 1982; Raleigh et al. 1984; Raleigh et al. 1986) for brook, brown, cutthroat, and rainbow trout recommend <5% fines <3 mm for optimal spawning, with 30% fines <3 mm expected to cause low embryo survival and fry emergence. Similar results were reported in several earlier studies (Koski 1966; Bjornn 1969; Phillips et al. 1975; Hausle and Coble 1976; Tappel and Bjornn 1983; Witzel and MacCrimmon 1983; Burton et al. 1990; Bennett et al. 1993; McHenry et al. 1994). Appendix G provides additional information regarding the basis of the salmonid spawning guideline, including summaries of the literature reviewed and a summary table of literature-reported thresholds.

Considering the studies presented above and in Appendix G, the provisional guideline for protection of salmonid spawning is that less than 20% of the spawning area may be covered by particles that are less than 8 mm for a site to be considered attaining the narrative standard.

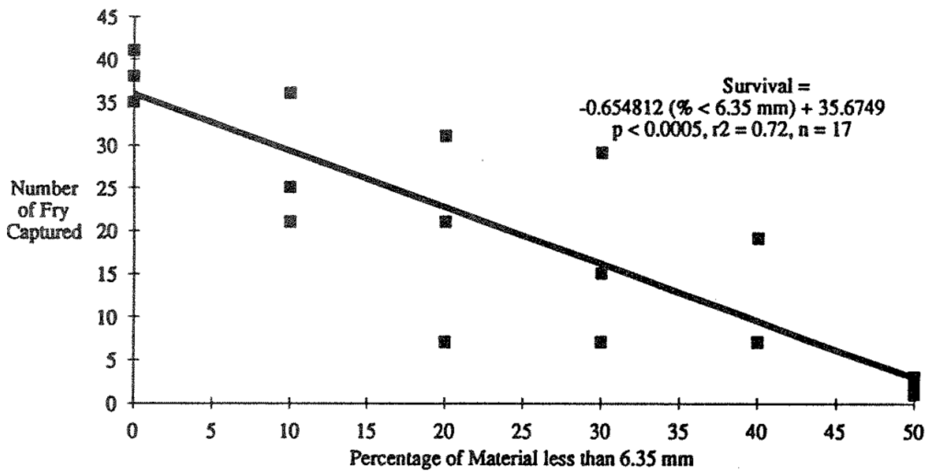


Figure 5. Relationship between numbers of westslope cutthroat trout fry successfully emerging from replicates of six gravel mixtures and the percentage of material smaller than 6.35 mm in each mixture (from Weaver and Fraley 1991).

1. Summary of the Method

This method applies to sites where salmonid fish are expected to spawn. Section 3 below addresses identification of those sites. Figure 6 presents a decision tree that displays the relationship of the steps in the method.

a. <u>Comparison of Actual Condition with Expected Condition</u>: This method uses the approach that establishes an expected condition through a policy statement.

i. It is the Commission's expectation that where habitat is suitable for salmonid spawning, deposits of sediment shall not be present in amounts that can harm the survival of salmonid eggs.

ii. The actual condition of the study site is determined by measuring sediment deposition. The percent of the area within the location suitable for spawning that is covered by particles less than 8 mm is the sediment deposition metric.

b. <u>Impairment is a Significant Departure from Expected Condition:</u> The study site metric for sediment deposition of <8 mm particles is compared to the provisional guideline of 20%. If a site's metric exceeds the provisional guideline, the site is significantly different than the expected condition.

c. Watershed Review: The watershed review step is intended to identify whether or not the excess sediment is likely due to "human caused point source or nonpoint source discharge(s)."

Figure 6. Assessment of Salmonid Spawning Habitat Protection - Decision Tree

1 – Is the site expected to support salmonid spawning?

- Yes – go to 2
- No – Salmonid Spawning Provisional Guideline does not apply

2 – **Salmonid Spawning Provisional Guideline**: What is the percentage of the wetted area that is covered by particles smaller than 8 mm? (Using transects through the spawning area only)

- Less than 20% – the site is not impaired for sediment
- 20 % or more? – go to 3

3 – **Watershed Review:** What does the review of available watershed information tell you? Does evaluation of available site-specific information identify that the excess sediment is likely a human-caused condition?

- Yes – site is impaired, the salmonid spawning use is not protected
- No – salmonid spawning habitat is protected

2. Applicability – Identification of Appropriate Locations

This methodology is applicable at sites where salmonid fish spawning is expected. Therefore, the first step is to determine whether salmonid fish spawning is expected to occur at the site. A determination that salmonid fish spawning is expected to occur at the site may be based on a determination by knowledgeable persons who have the training and/or experience in performing such evaluations and using the salmonid spawning habitat information provided below. Assessment reports should include a statement of the qualifications of the person determining that salmonid fish spawning is expected to occur at the site, and should also include the basis for such determination. Such persons may include knowledgeable local fishing experts, biologists, technicians, or Colorado Parks and Wildlife biologists. Figure 6 presents the decision tree.

The four most important factors that determine where salmonids spawn, in order of importance, are substrate size, water depth, water velocity, and stream width (Knapp and Preisler 1999). Salmonids generally construct redds in gravel areas near the downstream end of a pool or at the head of a riffle (Hickman and Raleigh 1982; Raleigh 1982; Raleigh et al. 1984). Salmonids often prefer areas with groundwater inflow (Raleigh 1982). Colorado Parks and Wildlife (CPW) recommends using a set of habitat characteristics as guidelines for identifying ideal spawning habitat for brook, brown, cutthroat, and rainbow trout (Table 2).

Table 2. Guidelines for identifying stream conditions suitable for salmonid redds (Hickman and Raleigh 1982; Raleigh 1982; Raleigh et al. 1984; Raleigh et al. 1986;

Knapp and Preisler 1999).

Water Column Velocity	Substrate Size	Water Depth	Stream Width
1 — 92 cm/sec	0.3 cm — 10 cm diameter	6.4 cm — 91.4 cm	200 cm — 800 cm

Because salmonids may use less than ideal spawning habitat if more suitable habitat is unavailable, the values in Table 2 should be used only as general guidelines. For instance, salmonids may spawn in areas with higher amounts of fine sediment, but as described in the literature (see discussion above and Appendix G), expected survival would be low.

The most reliable way to identify spawning habitat is to directly observe spawning activity, but this may be infeasible and can cause disturbance to the spawning fish. Redds and egg pockets constructed during spawning are sometimes visible and can be identified as a series of depressions followed by a downstream mound of sediment, called the tailspill. Because female salmonids create redds by clearing the upper layer of sediment from an area, there are often distinct patches of disturbed substrate that are a different color than undisturbed sites which remain coated in sediment and algae (Figure 7).

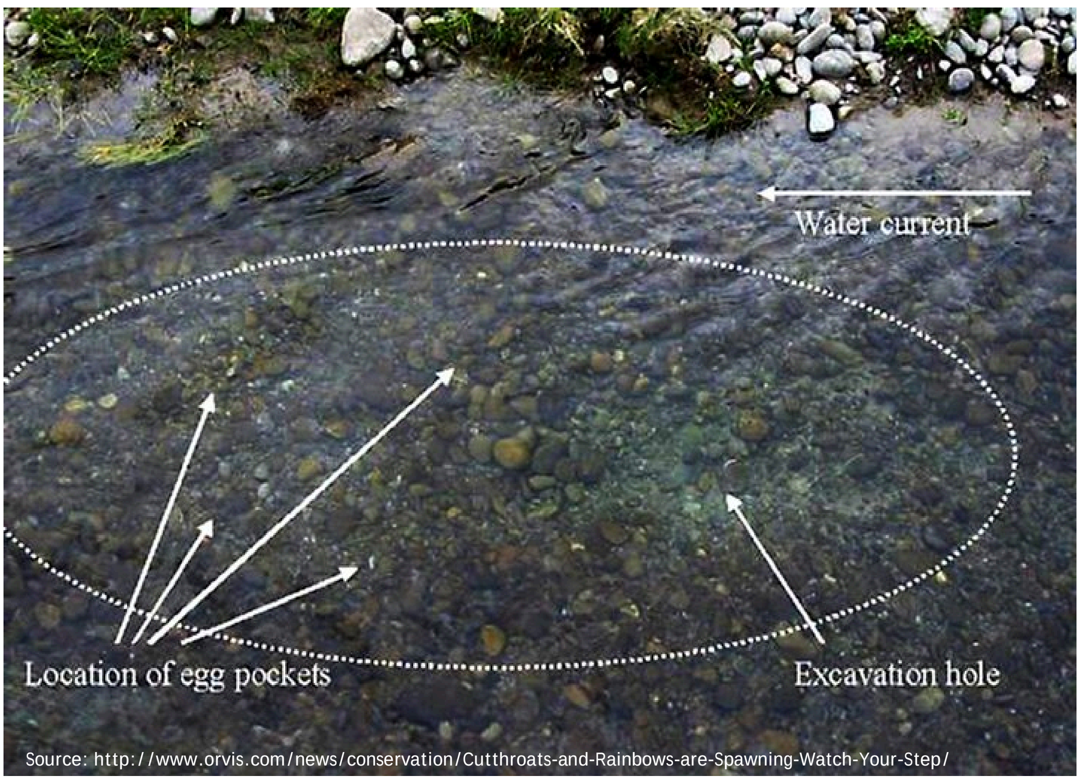


Figure 7. Example of a salmonid redd.

The time from spawning to emergence can be several months, resulting in the likelihood that salmonid embryos, alevins, or fry are present in the gravel year-round (Table 3). Cutthroat trout and rainbow trout spawn in the spring, while brook trout, brown trout, and mountain whitefish spawn in the fall. Spring spawners' eggs incubate throughout the summer and emerge from the gravel just before the fall spawners lay their eggs. The fall spawners’ eggs incubate in the winter and emerge just before the spring spawners lay their eggs (Table 3).

While conducting sediment assessments during salmonid spawning periods would help ensure that sediments were being measured when relevant to the fish, such an approach has complications. As mentioned above, different salmonid species spawn at different times of the year, including spring, summer, and fall, making it difficult to identify when a given site may be in use by salmonids. In addition, narrowing the sampling period to a known time when salmonids are actively spawning could result in disturbance and flushing of spawning adults, crushing of redds, or disturbance of sediment resulting in burial of redds. Finally, natural variability in the timing of spawning could make it difficult to determine exactly when sampling should occur in a given year. For these reasons, salmonid spawning habitat assessments cannot be restricted to a specific time of year.

Table 3. Timing of spawning, incubation, and emergence for salmonids in Colorado. Information from Colorado Temperature Criteria Methodology Policy Statement 06-1.

Colorado Fishes, Early Life Stage Expectation and Temperature Criteria Tiers Shaded cells indicate ELS default assumption.													
Species	**Temp. Tier**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Cutthroat Trout	CS-I				S	S	S	S,I	I,E				
Brook Trout	CS-I	I	I	E	E	E				S	S	I	I
Mountain Whitefish	CS-II	I	I	I						S	S	S	I
Brown Trout	CS-II	S,I	I	I	I,E					S	S	S	S
Golden Trout	CS-II						S	S	I,E				
Rainbow Trout	CS-II			S	S	S	S	I	E				
Lake Trout	CL	I	I	I	I						S	S	S,I
Kokanee	CL	I	I	I						S	S	S	I
A. Grayling	CL				S	S	S	S,I					

Notes: S = Spawning period, I = Incubation period for eggs, E = Emergence/Time period when sac-fry are in gravels Source: https://www.colorado.gov/pacific/sites/default/files/T1_WQCC_Policy06-1.pdf

3. Measure of Sediment Deposition

This method is based on assessment of the percent of sediment that is less that 8 mm and its potential impacts on fish spawning habitat. This method was developed based on an assessment of the literature documenting scientific studies of sediment impacts on salmonid fish spawning. The grain size of <8 mm was selected because the body of literature on sediment impacts to salmonid spawning success indicates that particles <10 mm have the most significant impact on salmonid embryo survival and fry emergence (Koski 1966; Phillips et al. 1975; Hausle and Coble 1976; Tappel and Bjornn 1983; Chapman 1988; Weaver and Fraley 1991 and 1993; McHenry et al. 1994; Kondolf 2000; Jensen et al. 2009). While the particle size of 6.35 mm is often used to describe spawning gravel quality (e.g., Chapman et al. 1988), the gravelometer used by WQCD and other parties does not include a 6.35 mm size class. The tool provides data regarding the <5.6 mm and <8 mm size classes. Therefore, the salmonid spawning guideline is based on sediment particles <8 mm. A guideline of 20% was chosen because it is the percent of small sediment particles (<8 mm) frequently associated with negative effects to salmonid spawning, as reported in the literature (see discussion above and Appendix G).

Using a modified approach to the WQCD's Pebble Count Standard Operating Procedure (see Appendix B), determine the percent of sediment particles that are < 8 mm within the wetted width of the stream. Because fish can be selective of microhabitat, it is important to measure sediment deposition at the location where spawning is expected. Therefore, it is necessary to modify the WQCD's Pebble Count Standard Operating Procedure (Appendix B) so that sediment is sampled from locations along each transect only within the portion of the stream where spawning habitat may be present. Alternatively, other methods for assessing sediment deposition in salmonid spawning habitat can be used. For instance, Montana Department of Environmental Quality (2013) assesses fines in spawning habitat using the grid toss method or "percent fines by grid."

4. Provisional Guideline

The Provisional Guideline of 20% <8 mm was selected to protect salmonid spawning habitat. This value is supported by the literature (see Appendix G). Using the information in Figure 5, 20% fines would result in a reduction of approximately 30%, which is a significant reduction. However, based on evidence presented in a rulemaking hearing, the Commission can and should make a case-by-case determination, using the information contained in this Policy document as perspective, not rule.

If the measured percent of sediment materials <8 mm is above 20% at a site, then the next step is to complete a watershed review (see Figure 6).

V. GENERAL METHOD FOR DETERMINATION OF IMPAIRMENT BY SEDIMENT

This method can be used to assess sites for impacts to any beneficial use by excess sediment, where the methods at Section IV are not applicable. It is the Commission's intent that the beneficial uses of water shall be protected from impairment by sedimentation. Because of the wide range of uses and the variety of settings, at this time the Commission is relying on the following narrative statements:

- Clear and convincing evidence is needed to show impairment; and
- Impairment represents a significant departure from the expected condition.

The Commission expects that the proponents of an impairment decision will provide the Commission and hearing participants with clear and convincing evidence that:

- Establishes what the representative expected condition is (in terms of sediment deposition) for the specific water body in question;
- Demonstrates that the actual observed sedimentation condition for that specific water body is significantly different than the expected condition;
- Demonstrates that the sediment is attributable to an anthropogenic source; and
- Documents that there is a beneficial use and that the excess sediment could be a detriment to a beneficial use.

VI. IMPLEMENTATION AND ASSOCIATION WITH OTHER

POLICIES

This policy document is intended to provide guidance regarding the implementation of the narrative sediment standard as it applies to sediments which may form deposits that can be detrimental to beneficial uses. As such, it has no regulatory effect, serving instead to summarize the Commission's thinking and actions in a single public document and has no binding effect on the Commission, the Division, or the regulated community. It is not intended to limit any options that may be considered or adopted by the Commission in future rulemaking proceedings.

Only the Commission can make decisions about uses and impairment through noticed public rulemaking hearings. Determinations of whether water bodies are impaired by sediment are made by the Commission in the context of Regulation #93, Colorado's List of Impaired Waters (also known as the 303(d) List). The process for developing the Listing Methodology is described more below in section B.

The Commission has other policies and policy-like documents that have some overlap with this Sediment Guidance, namely Policy 10-1 (Aquatic Life Use Attainment: Methodology to Determine Use Attainment for Rivers and Streams) and the Section 303(d) Listing Methodology, which is prepared for each Impaired Waters Listing cycle. Each is described below.

A. Aquatic Life Use Attainment Policy

Policy 10-1 (Aquatic Life Use Attainment: Methodology to Determine Use Attainment for Rivers and Streams) provides the Commission's methodology for determining whether the Aquatic Life Use is attained in rivers and streams. The procedures detailed in the guidance rely upon direct measurement of the Aquatic Life Use rather than on comparing existing water quality to numeric standards for individual pollutants. Policy 10-1 provides Colorado's Multi-Metric Index (MMI) bioassessment tool which is designed to detect environmental stressors that result in alteration of the biological community. No specific stressors are identified because the intent of the MMI is to have a generalized tool that responds to a wide range of potential stressors. The MMI tool cannot determine if the stressor is a specific pollutant, pollution or habitat limitation (including flow). The other important part of Policy 10-1 is that it provides biological thresholds for the Aquatic Life Use in streams with a watershed area less than 2700 mi^2. These thresholds establish the minimum expectations for MMI scores for waters to be deemed to be in attainment of the Aquatic Life Use.

Both policies 98-1 and 10-1 use the approach of assessing impairment by comparing an actual condition of a test site with the expected condition for that site. Both policies provide at least one tool (which uses biological metrics) for determining attainment of the respective policy's topic in portions of the state. However, each policy has a specific, distinct focus. Policy 10-1 addresses attainment of the aquatic life use, regardless of the stressor. Policy 98-1 addresses attainment of the narrative sediment standard. There will be cases where the MMI tool in Policy 10-1 results in a decision that a site is attaining its aquatic life use, yet the TIV_{sed} /% fines tool results in a decision that the same site is not attaining the narrative sediment standard. That is not unlike what occurs when a numeric chemical standard is exceeded yet the bulk of the aquatic community is not affected. In both cases, the site is included on the 303(d) List as impaired by those constituents.

B. Section 303(d) Listing Methodology

The Listing Methodology provides a framework for the determination of attainment of non-attainment of assigned water quality standards and uses. The Listing Methodology is reviewed and revised by the Commission (in a noticed public hearing) in preparation for the biennial development of the List of Impaired Waters as required by Section 303(d) of the Clean Water Act.

The Listing Methodology generally relies on previous policy decisions made by the Commission, and acts as a useful repository for all the guidance about attainment/non-attainment decisions. Where guidance resides in other documents, the Listing Methodology references those documents rather than repeating the guidance. For instance, for assessment of the Aquatic Life Use, the Listing Methodology refers to the protocols establish in Policy 10-1[3,4]. For assessment of numeric standards, the methods are detailed in the Listing Methodology itself[4]. The methods in Policy 98-1 are referred to at Section III.D.7.d. as the assessment methods to be used for listing decisions.

[3] In the 2012 Listing Methodology at section III.D.7.a
[4] In the 2012 Listing Methodology at section III D.4

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Sediment Policy 98-1 Frequently Asked Questions			
Question		**Answer**	**Citation**
1 General			
1a	What is the narrative sediment standard?	"Except where authorized by permits, BMPs, 401 certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which: (a) for all surface waters except wetlands; (i) can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud;"	31.11 (a)(i)
1b	The narrative standard contains the phrase "Except where authorized by permits…." What is the meaning of this phrase?	The phrase "[e]xcept where authorized by permits" should be read in conjunction with the Introductory Paragraph for this regulatory section, which states: All surface waters of the state are subject to the following basic standards; however, discharge of substances regulated by permits which are within those permit limitations shall not be a basis for enforcement proceedings under these basic standards. With respect to Regulation 31, this statement means that where discharges of sediment are authorized by permits, enforcement could result from exceeding the permit limits, but not from the receiving water exceeding the narrative standard.	31.11
1c	If all the discharges of anthropogenic sediment are covered by a stormwater permit, and the permittees are in compliance with permit conditions, could a receiving water still be identified as impaired?	Yes. If the Commission determines that the narrative standard for sediment has been exceeded, the water body would be identified as "impaired" on the State's Section 303(d) List (Regulation #93). At that point, the Division would rely on data and policy to inform the permitting process.	
1d	The narrative standard phrase goes on to enumerate controls other than permits: "Except where authorized by permits, BMPs, 401 Certifications or plans of operation approved by the Division or other applicable agencies, ..." What are the other applicable agencies?	At this time there are no other "applicable agencies" in Colorado. The Colorado Water Quality Control Act specifies that "No person shall discharge any pollutant into any state water from a point source without first having obtained a permit from the division for such discharge..." § 25-8-501, C.R.S. Some states have delegated the some functions regarding erosion control to local agencies, but that has not happened in Colorado. EPA is the only other "applicable agency." EPA is the permitting authority for federal facilities and EPA is also able to waive some Clean Water Act requirements under some situations for Superfund clean-up sites.	
1e	What kinds of state surface waters does	Policy 98-1 provides assistance in implementing the narrative standard in all	

	this Policy address?	state surface waters (except wetlands). However, different methods and thresholds are available for different geographic settings and different beneficial uses.	
1f	Does the Policy apply to intermittent or ephemeral water bodies?	Yes. The narrative standard applies to all state surface waters (except wetlands). However, the expected condition of an intermittent or ephemeral waterbody will be representative of the best attainable condition for that type of waterbody, not for a perennial stream.	
1g	How does the Policy accommodate natural variability?	Natural variability is accounted for by using an approach that compares the observed condition to the expected condition of a reference site.	
1h	How does the Policy ensure that the interpretation of the narrative sediment standard is based on representative data?	There are several aspects of methodologies identified in this policy that describe expectations for representative information. • The Pebble Count Standard Operating Procedure (SOP) (see Appendix B) • The Benthic Macroinvertebrate Sampling Protocols (Appendix C) • Watershed Review (Section IV.5)	
1i	How is this Policy different from Policy 10-1?	Policy 10-1 is used to determine aquatic life use attainment, but not to identify a stressor. Policy 98-1 applies specifically to identifying impairment of water bodies by excess deposition of sediment. Policy 98-1 defines a process and quantification method for evaluation of the narrative standard with respect to protection of the macroinvertebrate use and salmonid spawning habitat. It also provides a general method for assessing protection of other beneficial uses.	
2	**Expected Condition**		
2a	What is the expected condition?	Expected condition corresponds to what is most natural and attainable for streams in the region. They reflect the potential condition of the candidate stream after controllable stressors have been controlled but recognizing that some stressors may be irreversible.	
2b	How do we characterize the expected condition for aquatic life use?	The expected condition of the aquatic macroinvertebrate community is represented by a Sediment Tolerance Indicator Values (“TIV_{SED}”) of reference sites within each of the three Sediment Regions. TIV_{SED} were developed as the biological indicator of impacts by excess fine sediment. The TIV_{SED} scores reflect both the relative decline of sensitive taxa and the relative increase of sediment-tolerant taxa. The methods for calculating TIV_{SED} were developed from the National Water Quality Assessment Program (Carlisle et al, 2007). For areas outside these three Sediment Regions the expected condition must be characterized on a case by case basis.	See Appendices C and E
2c	How do we characterize the expected condition for sedimentation?	The expected condition of sediment deposition is based on pebble count data for reference sites within each of the three Sediment Regions. For areas outside these Sediment Regions the expected condition must be	See Appendix B

		characterized on a case by case basis.	
2d	How is deposition measured?	The Policy specifies standardized 400 count Pebble Count method. For assessment of impacts to the macroinvertebrate community, the metric is the percent of substrate with a grain size that is less than or equal to 2 mm. For an assessment of impacts to salmonid spawning habitat, the metric is the percent substrate with a grain size less than or equal to 8 mm. For other uses or assessments, other measurements may be appropriate (e.g. bathymetry, volume of deposition, aerial extent, etc.)	See Appendix B
2e	How does the Policy address landscape-scale processes that increase sediment deposition in the watershed such as wildfires or floods?	The narrative standard specifically applies to human-caused discharges of material that are deposited in amounts that can cause harm to beneficial uses. Wildfire and floods do not constitute human-caused discharges.	31.11 (a)(i)
2f	How do you determine whether the sediment deposition is attributable to human-caused point or non-point source discharges?	Identification of human-caused sources of sediment requires a review of available information about the watershed (e.g., aerial photos, mapping) and evaluation of site-specific information to separate natural sources (e.g., beaver dams or landslides) from anthropogenic sources (e.g., agriculture, silviculture, roads, urbanization).	
2g	Is the deposition threshold the same regardless of the beneficial use that is being evaluated?	The *conceptual* threshold is the same. Clear and convincing evidence must show that there is a "significant difference" between the actual deposition and the expected deposition. The thresholds for impacts to aquatic life in terms of macroinvertebrate habitat and salmonid fish spawning are discussed at Section IV of the Policy document.	
3	**Beneficial Uses**		
3a	What are the "beneficial uses" in the Colorado Water Quality Control Act framework?	"…domestic, agriculture, municipal and industrial uses, the protection and propagation of fish and wildlife, recreation, drinking water or such beneficial uses as the commission deems consistent with the policies of 25-8-102 and the need to minimize negative impacts on water rights."	25-8-203(2)(e)
3b	What are the "beneficial uses" in Regulation #31?	"This regulation is based on the best available knowledge to insure the suitability of Colorado's waters for beneficial uses including public water supplies, domestic, agriculture, industrial and recreational uses, and the protection and propagation of terrestrial and aquatic life."	31.2(2), 2nd paragraph
3c	How are beneficial uses described in Colorado water law framework?	"Beneficial use is the basis, measure and limit of a water right. Colorado law broadly defines beneficial use as a lawful appropriation that employs reasonably efficient practices to place water to use. What is reasonable depends on the type of use and how the water is withdrawn and applied. The goal is to avoid water waste so that the water resource is available to as many decreed water rights as possible."	Colorado Foundation for Water Education – Citizen Guide to Colorado Water Rights. (pg 9)

3d	How can you show that the narrative sediment standard is exceeded?	In order for the Commission to determine impairment, there must be anthropogenic sediment in an amount that is both a significant departure from expected condition and can be harmful to a beneficial use.	31.11 (a)(i) and the 303(d) Listing Methodology
3e	How do you determine if there is harm to beneficial uses other than the aquatic life use?	That would depend on the beneficial use that you are investigating. "Harm" equates to a determination that the use is not as robust as it should be, or that the water is not as *useful* as is expected. For a reservoir where the beneficial use is water storage, bottom deposits in the reservoir could be detrimental to that beneficial use. For a head gate structure where the use is irrigation diversions, if sand bars form and replacement or repair of the structure is required more frequently than expected, bottom deposits in this situation might be determined to be detrimental to that beneficial use.	
3f	Is showing that the beneficial use is harmed enough to reach a conclusion that a waterbody is impaired?	No. Proponents of an impairment decision need to provide clear and convincing evidence that: • Establishes what the representative expected condition is (in terms of sediment deposition) for the specific water body in question • Demonstrates that the observed sedimentation condition for that specific water body is significantly different than the expected condition. • Documents that the excess sediment could be a detriment to a beneficial use. • Documents that the excess sediment is human-caused.	
4	**Aquatic Life**		
4a	How does the Policy address the effects of chronic excessive sediment on aquatic life?	The assessment methodologies (described in Section IV of the Policy document) are intended to assess chronic or persistent deposition, since it relies on the integration of the effects of sediment into an aquatic community metric. For assessment of impacts to macroinvertebrate habitat in Sediment Regions 1, 2, and 3, the assessment methodology in Section IV A is the preferred approach. For assessment of impacts to salmonid spawning habitat, the assessment methodology in Section IV B is the preferred approach. For other regions, the general assessment framework should be followed.	
4b	How does the Policy address the effects of acute excessive sediment on aquatic life?	Since the Assessment Methodology (described in section IV of the Policy document) addresses the effects of chronic or persistent deposition, it is not an appropriate tool for assessing acute effects. Acute effects would be addressed through the general assessment framework as follows: • Establish the representative expected condition (in terms of sediment deposition) for the specific water body in question • Demonstrate that the observed sedimentation condition for that specific water body is significantly worse than the expected condition. • Document that the excess sediment could be a detriment to a beneficial use. • Document that the excess sediment is human caused.	

4c	How do you determine the amount of sediment that can cause harm to the macroinvertebrate community?	Colorado data relating to macroinvertebrate communities and sediment deposition in both non-impacted sites and other sites were used to evaluate the relationship between sediment deposition and community structure. Thresholds are set at the Upper Prediction Limit which identifies whether a new observation is likely to be from the same distribution asst the reference data set.	See Appendix F.
4d	Why does the aquatic life sediment assessment tool focus on macroinvertebrates?	The combination of relatively long life spans, limited mobility, presence in most Colorado habitats, and ease of collection make macroinvertebrates the best single assemblage for bioassessment.	Policy 2010-1 Section IV. A (page 4, v2010)
4e	How does the Policy address sediment impacts on fisheries?	Salmonid fish spawning habitat is addressed through the second assessment method that is described at Section IV, B. This method assesses the percent of the substrate that is covered by sediment with grain size less than 8 mm.	
5	**Implementation**		
5a	How does the Policy address the effects of instream conditions from short-term construction activities such as those that require 404 permits?	If the short-term construction activities have been authorized by a US Army Corps of Engineers 404 permit, this guidance would not apply since the narrative standard specifically excludes cases "where authorized by permits, BMPs, 401 certifications of plans of operation approved…"	31.11 (a)(i)
5b	How does the Policy affect operation under a CAFO or Stormwater permit?	The Policy would have no effect on operations under a duly authorized permit.	See also # 1b, 1c and 1d above
5c	What happens if a waterbody is not attaining the narrative sediment?	The Water Quality Control Division or and external party would propose the waterbody for the Commission's consideration for the Section 303(d) List, (Regulation #93) rulemaking hearing. If the Commission, after reviewing the evidence presented, agrees, the waterbody would be included on the Section 303(d) List, (Regulation #93), the List of Impaired Waterbodies.	
5d	If the methodology in Policy 10-1 shows that a waterbody's aquatic life use is supported, but the methods in this policy shows that the macroinvertebrate use is not protected, what is the result?	The Division would propose waterbody for listing as impaired by sediment for the Commission's consideration for the Section 303(d) List, (Regulation #93), the List of Impaired Waterbodies rulemaking hearing. The two Policies are independent and use different metrics to assess different endpoints. For Policy 10-1, the metrics indicate the overall health of the aquatic community. For Policy 98-1, the metric indicates whether the aquatic community is dominated by organisms that are tolerant to sediment.	
5e	What happens once a waterbody is included on the Section 303(d) List for non-attainment of the narrative sediment standard?	The Division must develop a Total Maximum Daily Load ("TMDL") for each impaired waterbody. A TMDL is a study that results in determination of which sources are responsible for the impairment and the amount of reduction that is necessary to return the waterbody to fully supporting the use. A sediment TMDL would be developed to assign responsibility for sediment reductions. For permitted point sources, the TMDL would be implemented in a revised permit which might include more restrictive conditions or additional best management practices.	

Appendix B

Pebble Count Standard Operating Procedure

Sampling Frames

Improved sampling techniques are needed to increase the accuracy of pebble-count particle-size distributions used for stream studies in gravel-bed streams. However, pebble counts are prone to operator errors introduced through subjective particle selection, serial correlation, and inaccurate particle-size measurements. Errors in particle-size measurements can be minimized by using a gravel template. Operator influence on particle selection can be minimized by using a sampling frame, 60 by 60 cm, in which sampling points are identified by the cross points of thin elastic bands. Serial correlation can be minimized by adjusting the spacing between the cross points and setting it equal to the dominant large particle size (=D95).

The sampling frame consists of 4 aluminum bars that are connected to form a square with an inside diameter of 60 by 60 cm. The frame is sturdy and can be stepped upon to hold it down on the stream bottom in fast flow. Small slots cut in 5 cm increments along the outside edges of the frame hold thin white elastic bands in place that are stretched horizontally across the frame. Together with elastic bands stretched in a vertical direction, a grid with four or more cross-points is defined. The spacing of the grid points is adjusted to a size equal to or larger than the D_{max} particle size.

Using the sampling frame:

Set the sampling location:

1. Locate the bankfull position of the stream.

<u>Bankfull</u>: is the place on the bank where the stream rises during a large water event, a 1-2 year flood event. Look for evidence of bankfull location on streambanks: changes in slope, vegetation, no soil vs. soil, evidence of scouring activity (bare tree roots), etc… See Figure 2.

> Indicators of bankfull stage:
>
> Tops of Point-bars. Point-bars consist of channel material deposited on the inside of meander beds. The top elevation of point-bars is the lowest bankfull stage, because this is the location where the floodplain is being constructed by deposition.
>
> Changes in Vegetation. Look for the low limit of perennial vegetation on the bank, or a sharp break in the density or type of vegetation.
>
> Change in Slope. Changes in slope occur often along the cross-section (e.g., from vertical to sloping, from sloping to vertical, or from vertical or sloping to flat at the floodplain level).
>
> Change in bank materials. Any clear change in particle size may indicate the operation of different processes (e.g., coarse, scoured gravel moving as bedload in the active channel giving way to fine sand or silt deposited by overflow).

Bank undercuts. Look for bank sections where the perennial vegetation forms a dense root mat.

Stain Lines. Look for frequent-inundation water lines on rocks. These may be marked by sediment or lichen.

2. Measure the distance from the bankfull to bankfull across the stream. This is the bankfull width. Take the average of 3 bankfull measurements at different locations along the stream.

3. The sampling reach length should be 20 times the bankfull width. Walk the stream to determine the best site for the sampling location. The stream reach needs to include at least 2 meander wavelengths, or 2 cycles of riffle, run, pools in sequence.

4. Mark the top and bottom of the sampling reach with surveyors tape.

5. Begin at the bottom of the sampling reach. Pebble counts will be conducted moving upstream, so that sampling procedures will not disturb the particles that might be picked up in the next transect.

To use the sampling frame in the stream:

1. A tape measure is stretched across from bankfull to bankfull along a transect. Beginning at the bottom of the sampling reach, transects are spaced $1/10^{th}$ of the total sampling reach length.

   For example:

   The average bankfull width is 40'.

   The sampling reach would therefore be 800'.

   800 / 10 = 80' and is the distance between transects. There are 10 transects per sampling reach.

2. The sampling frame is placed onto the stream bottom so that one of the corners aligns with even-spaced marks on the tape, beginning at the bankfull position of one end of the transect. Divide the transect length by 10. This is the interval used to move the frame along the measuring tape.

   For example:

   The width from bankfull to bankfull for transect 1 is 50'.

   50 / 10 = 5' and is the distance to move the frame along the tape.

Beginning at the bankfull position, the frame is placed at the start of the measuring tape stretched across the stream. After the pebbles are recorded, explained below, the frame will be moved down 5' along the tape.

3. Grid points derived by the intersections of the 4 elastic bands are used to visually define the particle to be selected. The pebbles directly under the grid intersections are the particles that will be measured with a Gravelometer.

4. Once a particle is selected, it is extracted from under one of the grid points and measured with a Gravelometer. See instructions for use of the Gravelometer below.

5. If the flow is too deep or too fast to see the particle under the grid intersection, the particle to be included in the sample has to be identified by touch. A pointed index finger is placed in a corner of the grid intersection, and vertically lowered onto the sediment surface.

6. Particles are collected from under all four grid points and recorded on the appropriate field form. Also marked on the form is habitat, such as riffle, run, pool and left and right bank. Left and right bank will be determined working upstream.

7. Place the particles measured approximately into the same position from which they are taken, or throw them downstream. Never throw any pebbles upstream while sampling.

8. The frame is then moved to the next position along the tape, or 1/10 of the sampling reach length. The sampling frame can be used on both sides of the measuring tape, if necessary.

9. At least 400 pebble counts are to be collected.

Using the Gravelometer:

A Gravelometer is an aluminum or plastic template with several sieve-sized square-holes. The hole sizes correspond to the Wentworth particle size classes. After the particle is selected for measurement, the operator pushes the particle through the various holes in the template. The aim is to determine a particle's sieve diameter either in terms of "greater than" or "smaller than" the hole of a given size. The "greater than" approach records the largest hole size that is smaller than the particle diameter. The "smaller than" approach records the smallest hole size through which the particle could be passed. For example, a rock with a 60 cm b-axis would be tallied in the larger than 45 mm class using the greater than approach, or as smaller than 64 mm in the smaller than approach. One approach needs to be followed consistently. The Division will use the greater than approach.

References

Bunte, K., and Abt, S.R., 2001, Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and stream-bed monitoring: U.S. Department of Agriculture Forest Service Rocky Mountain Research Station General Technical Report RMRS-GTR-74, 428 p

Appendix C

Benthic Macroinvertebrate Sampling Standard Operating Procedure

Water Quality Control Division
Standard Operation Procedure
WQCDSOP-001
May 2010

1. Overview

The use of benthic macroinvertebrates for assessing and monitoring the condition of lotic systems has become increasingly widespread and acceptable in the domain of Colorado's water quality standards setting. Macroinvertebrates are particularly suitable indicators of the condition of lotic systems as they are found in almost all freshwater environments, are easy to sample and identify, and different taxa show varying degrees of sensitivity to pollution and other impacts (Boothroyd & Stark 2000). The recent advent of statewide multimetric indices or the "bioassessment indicator tool" necessitates supplementary macroinvertebrate data from which to support the use of this indicator tool within the Water Quality Control Division's assessment methodology.

2. Scope and Applicability

This standard operation procedure describes semi-quantitative methods for collecting a single aquatic benthic macroinvertebrate sample from perennial, wadeable streams.

Perennial is defined as a well-defined channel that contains water year round during a year of normal rainfall with the aquatic bed located below the water table for most of the year. A perennial stream exhibits the typical biological, hydrological, and physical characteristics commonly associated with the continuous conveyance of water.

Wadeable is defined as a waterbody that can be safely traversed when collecting samples. Separate protocols are provided for hard-bottomed and soft-bottomed streams. Benthic macroinvertebrate data collected on unwadeable large rivers or intermittent type streams are beyond the scope of this procedure.

2.1 Index Period

The index period is the period of time that samples should be collected to minimize seasonal variation. The standard index period utilized by the Water Quality Control Division is summer to early fall, namely July 1 to October 1. This period is congruent with the central tendency of sample dates of macroinvertebrate replicates used to regionally calibrate the multimetric indices.

Eastern plains, as defined by the boundaries of EPA Level III Ecoregions Western High Plains and Southwestern Tablelands within Colorado, and Western xeric streams, as defined by those streams with elevations less than 1500 meters within EPA Level III Ecoregions Colorado Plateaus and Arizona/New Mexico Plateau within Colorado, may be sampled from May 1 to October 1.

Unforeseen severe runoff or summer drought conditions may predispose WQCD planners to employ alternative sampling schedules that deviate from the standard index period listed above (see Section 2.2).

2.2 Sampling Frequency

This protocol recommends that benthic macroinvertebrate samples be collected once per year and within the standardized index period provided in Section 2.1.

If a second sample is taken, it should be collected before runoff (May) in the mountains streams and late summer (August-September) for plains/xeric streams. The spring sample in the mountains will provide a clearer representation of the stonefly fauna and the late summer sample in the plains/xeric streams will supplement the annual picture especially for some mayflies and midges. The fauna of plains/xeric streams may appear depauperate by late fall.

2.3 Site Selection

The study reach length should be one of the following: 1) 20 times the bankfull width of the wadeable waterbody or 2) long enough to encompass multiple riffles/runs (for hard- bottomed sites) or glides/pools/microhabitats (for soft-bottomed sites) from which to produce a single, representative sample from the predominant habitat type. The study reach should be representative of the typical habitat conditions that occur at or immediately above and below the greater stream segment.

Riffle habitat refers to the portions of the stream where moderate velocities and substrate roughness produce turbulent conditions which break the surface tension of the water and may produce whitewater (Bain and Stevenson, eds. 1999). Run habitat refers to the portions of the stream where there are moderate velocities, but lack the turbulent conditions that break the surface tension of the water (Bain and Stevenson, eds. 1999). A glide generally refers to a calm stretch of shallow water flowing smoothly.

Although riffle/run areas with hard-bottomed substrates are generally the most diverse and productive habitat type in mountain streams, these may not be entirely representative of the overall types of habitat present within the study reach. Alternately, although glide/pool areas with soft-bottomed substrates are generally the most diverse and productive habitat type in plains and plateau streams, these may not be entirely representative of the overall types of habitat present within the study reach.

There are some advantages to taking samples in or near the thalweg. Especially in small streams, the thalweg portion of the riffle usually has larger and cleaner substrate, better food supply and more reliable flow. When the thalweg is not or cannot be sampled, attention must be paid to the recent history of flow. Many Colorado streams are subject to flow variation on a short time scale due to flow regulation. Substrate that has been inundated only recently or that is inundated only occasionally should not be sampled because it is unlikely to support many specimens.

2.3.1 Hard-Bottomed Streams

A hard-bottomed stream is one where the stream substrate is dominated by particles gravel size or larger. Riffle/run habitats are common in these high to moderate gradient streams. Gravel, cobble and boulder sized substrate are frequent in these streams. These types of streams are conducive to the single habitat approach described in Section 2.4.

2.3.2 Soft-Bottomed Streams

Soft-bottomed streams are usually low gradient, often found in the Eastern Plains and in the far western xeric plateaus of Colorado, and are dominated by glide/pool habitats. The dominant substrate is sand, silt, clay or mud. Gravel, cobble and boulder sized substrate are naturally rare or entirely absent in these low gradient streams. These types of streams are conducive to the multihabitat approach described in Section 2.4.

2.4 Sample Collection Information

There are two macroinvertebrate sampling procedures used by the WQCD to collect the required single representative sample within a stream reach:

1) Semi-quantitative sample collection of hard-bottomed streams that focuses collecting macroinvertebrates from riffle/run habitats. These samples are collected using a modified kick net.

2) Semi-quantitative sample collection of soft-bottomed streams that focuses collecting macroinvertebrates from non-riffle/run habitats, such as vegetated bank margins, submerged woody debris or snags and aquatic macrophytes. These samples are generally collected using a jab or sweeping technique that utilizes the same modified kick net.

Semi-quantitative sample collection methods are designed to collect the widest variety of aquatic macroinvertebrates available at the study reach. For these methods, it is not necessary to know the exact area sampled. Both procedures are suitable for use with both relative abundance and fixed count processing protocols from which a variety of species richness and relative abundance metrics (Stark et al 2001) and multimetric predictive model analysis can be calculated.

In hard-bottomed streams or those streams predominated by substrate greater than gravel size, a single sample shall consist of a one-minute timed sample collected over an area of one square meter (1 m^2). The investigator shall select a single riffle or run from within the study reach that represents the predominant velocity and substrate type.

In soft-bottomed streams or those streams predominated by substrate smaller than sand size, a single sample shall consist of several individual sweeps or jabs collected from a fixed area of approximately 1 m^2. The multihabitat sampling effort is limited to 1 minute. Time spent traversing from one habitat type to another is not included in the total time.

If the predominant habitat type expected to occur at the site does not occur along the defined study reach, then the investigator should specify some other stable and productive habitat type to sample. In circumstances where hard-bottomed or cobble substrates represent less than 20% of the study reach, multihabitat(s) will need to be sampled. Alternatively, in circumstances where hard-bottomed or cobble substrates represent greater than 80% of the study reach in plains/xeric streams, then a riffle/run sample will need to be collected.

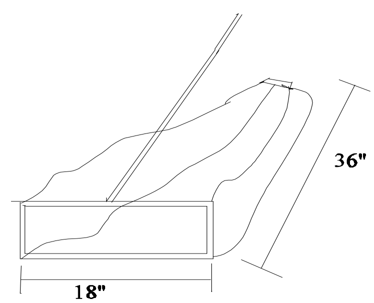
2.5 Equipment and Supplies

- Sampler with 500 to 600-µm mesh collection bag. Suggested: Kick-net with long handle, rectangular frame (18" x 8") dip-net, and 500-µm mesh nylon bag.
- Sieve dolphin bucket (504 µm mesh)
- 1-liter wide-mouth sample jars with screw tight lids
- 95% ethanol stored in sealed and labeled polyurethane carboys or bottles
- 1-liter rinse bottle
- 5-gallon bucket with handle
- Dissecting tray
- Rectangular "*Rite in the Rain"* labels
- Standard #2 pencil(s)
- Fine-tip forceps
- Waterproof stop watch
- Number 30 (600 µm) **or** 35 (500 µm) standard sieve
- Tape measurers (100 ft)
- 48 quart or larger ice chests or sealable Rubbermaid totes
- Geographic Positioning System (GPS) unit set to NAD 83 or WGS 84
- De Lorme Gazetteer map of Colorado
- Safety glasses
- Rubber gloves
- Hip or chest waders with wading boots
- Pertinent USGS topographic quad maps
- Applicable field sheets

2.5.1. Kick Net Specifications

The kick net is comprised of the following components:

1) 18" x 8" rectangular frame
2) 500 to 600 µm mesh nylon bag with canvas reinforced bottom and shroud reinforced opening
3) 1 or 2 piece long handle (≈ 70 inches long)
4) Sieve dolphin bucket (504 µm mesh)
5) Sieve bucket adaptor



3. Sample Collection

The following section discusses procedures used to collect benthic macroinvertebrate samples in perennial, wadeable streams.

3.1 Riffle or Run Habitat Method

1) Ensure that the sampling net and sieve bucket are clean prior to usage.
2) Select the dominant riffle or run habitat within the study reach according to Section 2.4.
3) Place the net frame flush to the streambed with the frame open to the upstream flow. Check that the nylon bag and sieve bucket are freely floating immediately downstream of the net frame. This will ensure that once the substrate is disturbed that specimens will be directed through the nylon bag and into the capture sieve bucket.

4) Carefully lower the handle forward in an upstream direction until the sampling net is nearly horizontal to the water surface but the net frame is still flush to the streambed. The point at which the tip of the handle extends along the streambed is the point at which the kicking activity will cease. This distance multiplied by the width of the net frame equals one square meter. Return the handle to its vertical position.
5) Position yourself next to sampling net and begin to disturb the substrate immediately upstream of the net. Disturb the substrate using the heel of your boot or entire foot by kicking to dislodge the upper layer of cobbles or gravel and to scrape the underlying bed. The area disturbed should extend no further than the point delineated in Step 4 and not exceed 1 minute. Approximately 0.25 meters should be disturbed for every 15 seconds.
6) Larger cobble may be scraped by hand, if necessary, to remove specimens. Cobble should be scraped clean quickly and efficiently as the scraping is counted within the one minute time frame.
7) Transfer material (matrix of specimens and insubstantial amount of stream substrate/detritus) from the interior of the net and sieve bucket into the sample jar and wash or pick all specimens off the net interior. Specimens that cling to the exterior of the net are not considered part of the sample. They may be removed and placed back into the stream.
8) Release back into the stream any fish, amphibians, reptiles or crayfish/rusty crayfish caught in the net.
9) If excessive or large debris items are present refer to Section 3.4.2.
10) The kick-net should be rinsed clean by backwashing with site water before collecting additional samples.
11) At this point refer to Section 3.4 Sample Processing.

3.2 Multihabitat Method

1) Ensure that the sampling net and sieve bucket are clean prior to usage.
2) Sample multiple habitats, as defined below, using the following procedures. The design is to sample an equivalent of a 1 meter sweep across multiple non-riffle/run habitats. Avoid dredging the kick net through mud or silt and clumps of leafy detritus or algal material. Also avoid hard-bottomed substrates as those habitats will be sampled separately according to Section 2.4.

   Woody Debris or Snags – Jab the kick net into an area of submerged and partially decayed woody debris to dislodge specimens, followed by 1-2 "cleaning" sweeps through the water column to capture specimens in the water column. Scrub larger debris by hand over the opening of the kick net. The area of the larger debris should be included in the one meter unit effort.

   Bank Margins – Locate an area of bank within the study reach. Jab the kick net vigorously into the bank for a distance of 1 meter to dislodge specimens, followed by 1 to 2 "cleaning" sweeps to collect specimens in the water column.

   Aquatic Macrophytes – Sweep the kick net through submerged or emergent vegetation for a distance of 1 meter to loosen and capture specimens, followed by 1 to 2 "cleaning" sweeps to collect specimens in the water column.

3) Transfer material (matrix of specimens and insubstantial amount of stream substrate/detritus) from the interior of the net and sieve bucket into the sample jar and

wash or pick all specimens off the net interior. Specimens that cling to the exterior of the net are not considered part of the sample. They may be removed and placed back into the stream.

4) Release back into the stream any fish, amphibians, reptiles or crayfish/rusty crayfish caught in the net.
5) If excessive or large debris items are present refer to Section 3.4.2.
6) The kick-net should be rinsed clean by backwashing with site water before collecting additional samples.
7) At this point refer to Section 3.4 Sample Processing.

3.3 Field Duplicates

One out of ten (10%) sample events shall include a duplicate field sample to ensure quality control (QC). For example, when a biosurvey consists of collecting benthic macroinvertebrates at 10 stations, then 1 out of the 10 stations shall include a duplicate field sample. It is acceptable to increase the rate of duplicate field samples (QC>10%). However, it is unacceptable for the rate to fall below 10%.

The duplicate field sample shall be collected within the same habitat type and in close proximity to the standard field sample and in a manner consistent with procedures set forth in Sections 3.1 or 3.2.

3.4 Sample Processing (On-site)

Sample processing is characteristically conducted in the field, generally on the bank of the stream being sampled. Sample processing consists of excessive material or large debris item removal and rinsing, elutriation (if necessary), preservation and storage.

3.4.1 Removing Excessive and Large Debris Items

Picking and rinsing should be performed in a Number 30 (600 µm) or 35 (500 µm) standard sieve. Rinse off and remove any excessive debris such as algal clumps or large debris items such as leaves, sticks, or rocks that will not fit into a 1-liter sample jar or will lessen the effectiveness of the preservative. Calmly rinse the debris with stream water over the sieve opening using care not to cause unnecessary splattering of material. Examine larger debris to ensure that all specimens have been thoroughly rinsed or scraped into the sieve. Discard the material.

Transfer the remaining sample matrix in the sieve to a 1-liter wide-mouth polyethylene sample jar. Each sample jar should be no more than 1/2 full of sample material. Consequently, splitting the sample into two or more sample jars is acceptable. See Section 3.4.4 for labeling split samples.

3.4.2 Elutriation

Elutriation is a technique used to extract specimens from excessive substrate that has been captured during the sample collection process. This technique works best when the substrate is comprised of fines, sands and pebbles and should be used in circumstances when the amount of substrate is disproportionate to the amount of the detritus/specimen matrix. This step follows the removal of large debris items detailed in Section 3.4.1.

Keeping the sample in the 5-gallon bucket, add stream water to the bucket. Gently swish the sample around in the bottom of the bucket to liberate organic material and macroinvertebrates from the substrate. Pour the water and all floating material and specimens into a Number 30 (600 µm) or 35 (500 µm) standard sieve. This process may not work for heavy invertebrates such as snails, larger annelids or case-building caddis flies that use sand. Continue rinsing in similar fashion 2-3 more times to maximize retention of specimens collected. If it appears that the heavy invertebrates are not being separated from the substrate, pour the remaining sample in the bucket into a tray and spread the sample homogenously across the bottom of the tray. Use forceps to remove remaining specimens and place them into the sieve.

Transfer the remaining sample matrix in the sieve to a 1-liter wide-mouth polyethylene sample jar. Each sample jar should be no more than 1/2 full of sample material. Consequently, splitting the sample into two or more sample jars is acceptable. See Section 3.4.4 for labeling split samples.

3.4.3 Sample Preservation

Sample preservation is very important to ensure the integrity of the benthic organisms collected from the site. The sample is preserved by decanting as much remaining water as possible and <u>completely</u> filling the sample container with 95% ethanol (ETOH). Gently invert the sample jar several times to thoroughly homogenize the sample and preservative. This will make certain that the entire sample is preserved. Poorly preserved specimens can impede the identification and enumeration process. Any liquid leaking from the jar lid with the bottle inverted indicates an incomplete seal.

Allowing for dilution with water remaining in the sample container, the minimum ethanol concentration should always be greater than 70%. If in doubt, or with samples containing a large amount of organic material, the ethanol should be decanted after initial preservation and replaced with fresh 95% ethanol. In general, the volume of the container should contain no more than 50% of the sample.

3.4.4 Labels

Add pre-printed, moisture resistant labels to both the inside and outside of the sample container. Affix the label to the outside using transparent packaging tape. The following information should be recorded with a pencil on each label and placed in each sample container:

- Site number
- Stream name
- Stream description
- Date
- Indicate if kicknet was used
- Habitat type sampled
- Collector's initials
- Indicate if sample is a duplicate
- Indicate if sample is split

If splitting the sample among several containers, label appropriately to indicate that the sample has been split (e.g., Sample 1 of 2 and Sample 2 of 2). If not, simply label sample as 1 of 1.

3.4.5 Storage

Place the sample jars in a hard-cased ice chest or equivalent container for transport to the laboratory. Ensure that jar lids are thoroughly tightened to eliminate leakage and fumes from developing inside vehicle cargo holds or truck camper shells.

4. Invasive Species

Precautions must be taken to avoid collecting invasive species from areas where the Colorado Division of Wildlife ("CDOW") has issued urgent closures to the taking of those species. Those species captured incidentally and prohibited under order of the Director of the Colorado Department of Natural Resources must either be immediately returned to the waterbody, where it was captured, or immediately killed.

Further precautions must be taken to avoid inadvertently transferring invasive species from one waterbody to another waterbody. This is best accomplished by following appropriate disinfection procedures of personal gear (i.e. waders/boots) as prescribed by CDOW.

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Appendix D

Development of Sediment Regions

All landscapes have natural rates of erosion, sediment delivery to the waterbodies and transport through the hydrologic system. When the rates of erosion and delivery exceed the rate of transport, sediment deposition occurs. The natural rates of erosion are influenced by land surface factors and climate. Erosivity of the landscape is governed by exposed geology and soil type, vegetative cover and steepness. Climate factors include annual precipitation and the form (rain or snow) and the intensity of rain fall. Colorado has a wide variety of landscapes and climate factors that result in a range of natural rates of erosion. Added to that, Colorado has a wide range of expected aquatic communities.

In order to increase the value of a sediment assessment tool, the state was divided or stratified into regions so that expected erosion/deposition rates varied less with a region that between regions. Level IV Ecoregions were selected as the stratification instrument because they based upon similar physical characteristics, including soil type and geology as well as climate and vegetation.

I. ECOREGIONS[1]

Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources; they are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. By recognizing the spatial differences in the capacities and potentials of ecosystems, ecoregions stratify the environment by its probable response to disturbance (Bryce and others, 1999). These general purpose regions are critical for structuring and implementing ecosystem management strategies across federal agencies, state agencies, and nongovernment organizations that are responsible for different types of resources within the same geographical areas (Omernik and others, 2000).

The approach used to compile this map is based on the premise that ecological regions can be identified through the analysis of the spatial patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Wiken, 1986; Omernik, 1987, 1995). These phenomena include geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology.

The relative importance of each characteristic varies from one ecological region to another, regardless of the hierarchical level. A Roman numeral hierarchical scheme has been adopted for different levels of ecological regions. Level I is the coarsest level, dividing North America into 15 ecological regions. Level II divides the continent into 52 regions (Commission for Environmental Cooperation Working Group, 1997). At Level III, the continental United States contains 104 ecoregions and the conterminous United States has 84 ecoregions (United States Environmental Protection Agency [USEPA], 2003). Level IV is a further subdivision of Level III Ecoregions. Explanations of the methods used to define the USEPA's ecoregions are given in Omernik (1995), Omernik and others (2000), Griffith and others (1994), and Gallant and others (1989, 1995).

[1] This section is taken from http://www.epa.gov/wed/pages/ecoregions/co_eco.htm (August 2014)

Colorado contains arid canyons, semiarid shrub- and grass-covered plains, alluvial valleys, lava fields and volcanic plateaus, woodland- and shrubland-covered hills, forested mountains, glaciated peaks, wetlands, and a variety of aquatic habitats. Ecological diversity is enormous. There are 6 Level III Ecoregions and 35 Level IV Ecoregions in Colorado, and many continue into ecologically similar parts of adjacent states.

The Level IV Ecoregion map was compiled at a scale of 1:250,000 and depicts revisions and subdivisions of earlier Level III Ecoregions that were originally compiled at a smaller scale (USEPA, 2003; Gallant and others, 1989; Omernik, 1987). This effort was part of a collaborative project primarily between USEPA Region VIII, USEPA National Health and Environmental Effects Research Laboratory (Corvallis, Oregon), Colorado Department of Public Health and Environment (CDPHE), Colorado Division of Wildlife (CDOW), United States Department of Agriculture – Forest Service (USFS), United States Department of Agriculture – Natural Resources Conservation Service (NRCS), United States Department of the Interior – Bureau of Land Management (BLM), and United States Department of the Interior – Geological Survey (USGS)–National Center for Earth Resources Observation and Science (EROS).

The project was associated with an interagency effort to develop a common framework of ecological regions. Reaching that objective required recognition of the differences in the conceptual approaches and mapping methodologies applied to develop the most common ecoregion-type frameworks, including those developed by the USFS (Bailey and others, 1994), the USEPA (Omernik, 1987, 1995), and the NRCS (U.S. Department of Agriculture–Soil Conservation Service, 1981). As each of these frameworks was further refined, their differences became less discernible. Regionally collaborative projects, such as this one in Colorado, where agreement has been reached among multiple resource management agencies, were a step toward attaining consensus and consistency in ecoregions frameworks for the entire nation.

ArcMap GIS shapefiles, metadata and illustrational maps of Colorado's Level IV Ecoregions are available on EPA's website at www.eps.gov/ecoregions/.

II. DEVELOPMENT OF COLORADO'S SEDIMENT REGIONS

There are 35 Level IV Ecoregions represented in Colorado. Most of the paired sediment and benthic macroinvertebrate data are from sites located in Ecoregion 21. Table 1 presents a summary of the distribution of Colorado's paired data by Level III Ecoregion.

Table 1. Distribution of Colorado's Paired Macroinvertebrate and Sediment Data

Level III Ecoregion Names		Level IV Ecoregions Represented in the Data	Number of Paired Sites in each Level III Ecoregion
18	Wyoming Basin	a, e	7
20	Colorado Plateau	a - e	57
21	Southern Rockies	a – j	279
22	Arizona/New Mexico Plateau	a, b, e	9
25	High Plains	b, c, d, l	32
26	Southwestern Table Lands	e - k	38

Because of the distribution of the paired data, Sediment Regions in Colorado's eastern plains (Ecoregions 25 and 26) were not developed. Table 2 presents a detailed summary of the characteristics of Level IV Ecoregions that were ultimately included in Colorado's Sediment Regions.

Table 2. Sediment Regions- Summary Characteristics of Level IV Ecoregions									
Level IV Ecoregion		Physiography	Elev/ Local Relief (feet)	Geology	Soil		Climate		Natural Vegetation
				Surface and Bedrock	Order (Great Group)	Temp/ Moisture Regimes	Precip Mean annual (inches)	Frost Free Mean annual (days)	
Sediment Region 1 - Level IV Ecoregions									
21a	Alpine Zone	Glaciated. High mountains with steep slopes, ridges, and exposed rocky peaks above timberline. Some wetlands and glacial lakes. High gradient headwater streams with boulder, cobble, and bedrock substrates.	10000-14400+/ 400-2500+	Quaternary rubble, glacial drift, and colluvium. Exposed bedrock. Tertiary andesitic lavas, basalts, breccia, tuffs, and conglomerates. Precambrian metasedimentary rocks: pelitic schist, amphibole schist, quartzite, diamictite, quartz-pebble conglomerate, and marble. Permian and Pre-Pennsylvanian Sangre de Cristo Formation: arkosic conglomerate, sandstone, and siltstone.	Inceptisols (Dystrocryepts)	Cryic/Udic	35-70+ Deep winter snowpack	Less than 30	Alpine meadows. Dominated by bistort, alpine timothy, alpine avens, alpine bluegrass, alpine clover, tufted hairgrass, and various sedges. Trees if present are krummholz (dwarf and/or prostrate shrubs) and include spruce, fir, and pine. Willow thickets occur in depressions and wet meadows.
21b	Crystalline Subalpine Forests	Glaciated. High mountains with steep slopes. High gradient perennial streams with boulder, cobble, and bedrock substrates.	8500-10000 in the north, 9000-12000 in the south/ 400-2500	Quaternary glacial till and colluvium. Tertiary intrusive rocks. Precambrian metasedimentary, metavolcanic, and intrusive rocks: pelitic schist, amphibole schist, quartzite, diamictite, quartz-pebble conglomerate, and marble. Precambrian granitic gneiss, felsic gneiss, amphibolite, and granitic rocks. Copper, silver, and gold deposits.	Alfisols (Glossocryalfs, Haplocryalfs),Mollisols (Argiustolls,Argicryolls, Haplustolls	Cryic, Frigid/ Udic, Ustic	30-58 Deep Winter snowpack	30-60	Subalpine forests dominated by Engelmann spruce and subalpine fir. Often interspersed with aspen groves, lodgepole pine forest, or mountain meadows, and with Douglas-fir at lower elevations. May include limber pine and Rocky Mountain bristlecone pine. Understory is dominated by dwarf huckleberry and grouse whortleberry .
21e	Sedimentary Subalpine Forests	Glaciated. High mountains with steep slopes. High gradient perennial	8500-10000 in the north, 9000-12000 in the south/	Quaternary drift and colluvium. Faulted and folded Tertiary sedimentary rocks of limestone, siltstone, shale,	Alfisols (Haplocryalfs,Glossocryalfs), Entisols	Cryic/ Udic, Ustic	28-50 Deep winter snowpack	30-60	Subalpine forests dominated by subalpine fir, Engelmann spruce, and lodgepole pine. Areas

Level IV Ecoregion		Physiography	Elev/ Local Relief (feet)	Geology: Surface and Bedrock	Soil: Order (Great Group)	Soil: Temp/ Moisture Regimes	Climate: Precip Mean annual (inches)	Climate: Frost Free Mean annual (days)	Natural Vegetation
		streams with boulder, cobble, and bedrock substrates.	400-1500	and sandstone. Permian arkosic conglomerate, sandstone, and siltstone of the Sangre de Cristo Formation. Flat Tops Mountains: Pre-Pennsylvanian Paleozoic limestone, sandstone, quartzite, and dolomite. Uncompahgre Plateau: Cretaceous sandstone and shale.	(Cryorthents), Inceptisols (Eutrocryepts), Mollisols (Haplocryolls,Argicryolls)				of Douglas-fir or aspen forests at lower elevations. Understory may include whortleberry, kinnickinnick, snowberry, sedges, mountain brome, and forbs.
21g	Volcanic Subalpine Forests	Glaciated. High mountains with steep slopes. High gradient perennial streams with boulder, cobble, and bedrock substrates.	9000-12000/ 600-1800	Quaternary drift and colluvium. Tertiary pyroclastic material, breccia, and volcanic ash fl ows, including basalt, andesitic lavas, and water-laid volcanics and conglomerates	Alfi sols (Haplocryalfs, Glossocryalfs), Inceptisols (Eutrocryepts), Mollisols (Argicryolls, Haplocryolls)	Cryic/ Udic, Ustic	28-50 Deep winter snowpack	30-60	Subalpine forests dominated by Engelmann spruce, subalpine fir, aspen and, in the north, lodgepole pine. Understory may include whortleberry, kinnickinnick, snowberry, sedges, mountain brome, and forbs.
Sediment Region 2 - Level IV Ecoregions									
21 c	Crystalline Mid-Elevation Forests	Partially glaciated. Low mountain ridges, slopes, and outwash fans. Moderate to high gradient perennial	7000-9000/ 400-1000	Quaternary glacial till, colluvium, and alluvium. Precambrian metasedimentary metavolcanic, and intrusive rocks: politic schist, amphibole schist, quartzite, diamictite,	Alfi sols (Haplustalfs, Glossocryalfs), Entisols (Cryorthents, Ustorthents),	Cryic, Frigid/ Udic, Ustic	20-32	60-90	Ponderosa pine forest with areas of Douglas fir forest. Understory may include mountain mahogany, bitterbrush, wax currant, skunkbush, woods rose,

Table 2. Sediment Regions- Summary Characteristics of Level IV Ecoregions

Level IV Ecoregion		Physiography	Elev/ Local Relief (feet)	Geology	Soil		Climate		Natural Vegetation
				Surface and Bedrock	Order (Great Group)	Temp/ Moisture Regimes	Precip Mean annual (inches)	Frost Free Mean annual (days)	
		streams with boulder, cobble, and bedrock substrates.		quartz-pebble conglomerate, and marble. Precambrian granitic gneiss, felsic gneiss, amphibolite, and granitic rocks. Copper, silver, and gold deposits.	Inceptisols (Dystrocryepts), Mollisols (Argicryolls, Haplocryolls)				mountain muhly, Junegrass, Arizona fescue, king spike-fescue, and various sedges.
21f	Sedimentary Mid-Elevation Forests	Partially glaciated. Low mountain ridges, slopes, and outwash fans. Moderate to high gradient perennial streams with boulder, cobble, and bedrock substrates.	7000-9000/ 400-1000	Quaternary drift and colluvium. Faulted and folded Tertiary sedimentary rocks of limestone, siltstone, shale, and sandstone. Uncompahgre Plateau: Cretaceous sandstone and shale	Alfi sols (Haplustalfs, Glossocryalfs, Haplocryalfs), Entisols (Ustorthents), Mollisols (Argicryolls, Haplustolls, Argiustolls, Haplocryolls), Inceptisols (Haplustepts)	Frigid, Cryic/ Udic, Ustic	20-32	60-90	Ponderosa pine forest, Gambel oak woodland, and aspen forest (especially on the Western slope). Areas of mountain mahogany and twoneedle pinyon pine. Shrub vegetation includes antelope bitterbrush, fringed sage, serviceberry, and snowberry. Understory grasses of Arizona fescue, bluegrass, Junegrass, needlegrasses, mountain muhly, pine dropseed, and mountain brome.
21h	Volcanic Mid-Elevation Forests	Partially glaciated. Low mountain ridges, slopes, and outwash fans. Moderate to high gradient perennial streams with boulder, cobble, and bedrock substrates.	7000-9000/ 400-1000	Quaternary drift and colluvium. Tertiary pyroclastic material, breccia, and volcanic ash fl ows, including basalt, andesitic lavas, and water-laid volcanics and conglomerates	Alfi sols (Haplocryalfs, Glossocryalfs), Mollisols (Argicryolls, Endoaquolls)	Cryic/ Ustic	20-32	60-90	Ponderosa pine, Douglas-fir, and aspen forests, with scattered areas of Gambel oak woodlands. Understory of dwarf juniper, western wheatgrass, Oregon grape, blue grama, sideoats grama, and needlegrasses.
Sediment Region 3 - Level IV Ecoregions									

Table 2. Sediment Regions- Summary Characteristics of Level IV Ecoregions

Level IV Ecoregion		Physiography	Elev/ Local Relief (feet)	Geology	Soil		Climate		Natural Vegetation
				Surface and Bedrock	Order (Great Group)	Temp/ Moisture Regimes	Precip Mean annual (inches)	Frost Free Mean annual (days)	
18d	Foothill Shrublands and Low Mountains	Footslopes, alluvial fans, hills, low mountains, ridges, and valleys	6000-9600/ 200-1000	Quaternary alluvium and colluviums derived from Tertiary sedimentary and older crystalline rocks of the surrounding mountains. Tertiary claystone, mudstone, sandstone, and oil shale. Precambrian quartzite, conglomerate, and shale.	Alfi sols (Glossocryalfs), Mollisols (Argicryolls), Inceptisols (Calciustepts)	Cryic/ Ustic, Xeric	10-20	60-90	Big sagebrush shrubland, with pinyon juniper woodland. Higher elevations may have areas of lodgepole pine, aspen, and subalpine fir. Associated vegetation may include rabbitbrush, mountain big sagebrush, pricklypear, bluebunch wheatgrass, and Idaho fescue on fine-textured soils. Rocky Mountain juniper, Utah juniper, and mountain mahogany woodlands occur on rock outcrops.
20c	Semiarid Benchlands and Canyonlands	Benches, mesas, cuestas, alluvial fans, hillslopes, cliffs, arches, and canyons. A few isolated peaks. Areas of low relief alternate with areas of high relief	5400-9200/ 100-1000	Quaternary alluvium and colluvium. Tertiary and Cretaceous siltstone, sandstone, claystone, oil shale, and marlstone. In deep canyons and cliffs: areas of Permian siltstone, sandstone, and shale, and Pre-Pennsylvanian Paleozoic shale, limestone, and sandstone.	Entisols (Torriorthents), Alfi sols (Haplustalfs), Mollisols (Argiustolls, Haplustolls, Argicryolls, Haplocryolls), Aridisols (Haplargids, Calciargids, Haplocambids, Haplocalcids), Inceptisols (Calciustepts)	Mesic, Frigid; Cryic on highest elevations/ Aridic, Ustic	Mostly 10–18, on highest sites 20-25	60-120	Pinyon-juniper woodland, Gambel oak woodland, and sagebrush steppe with black sagebrush, winterfat, Mormon tea, fourwing saltbush, shadscale, galleta grass, and blue grama.
20e	Escarpments	High, dissected cliffs, escarpments, mesa tops, and breaks with a wide elevational range. Includes the Book Cliffs and Roan Cliffs.	6000-9000/ 500-3000	Quaternary alluvium and colluvium. Tertiary and Cretaceous sandstone, shale, siltstone marlstone, limestone, and areas of oil shale. Rock outcrops are common.	Entisols (Torriorthents), Aridisols (Natrargids)	Mesic/ Aridic	Mostly 15-25, up to 32 at higher elevations	60-90	Pinyon-juniper woodland, mountain mahogany, aspen, and Douglas-fir forest at highest elevations.

Table 2. Sediment Regions- Summary Characteristics of Level IV Ecoregions									
Level IV Ecoregion		Physiography	Elev/ Local Relief (feet)	Geology	Soil		Climate		Natural Vegetation
				Surface and Bedrock	Order (Great Group)	Temp/ Moisture Regimes	Precip Mean annual (inches)	Frost Free Mean annual (days)	
21d	Foothill Shrublands	Unglaciated. Hills, ridges, and footslopes. Moderate to high gradient perennial, intermittent, and ephemeral streams with cobble, gravel, and sandy substrates.	Mostly 6000-8500, Small areas up to 10000/ 200-900	Quaternary glacial till, colluvium, and alluvium. Tertiary and Cretaceous shale and sandstone. Permian sandstone, limestone, and siltstone. Precambrian metasedimentary: sandstone, claystone, shale, siltstone, and conglomerates. Precambrian metamorphic rocks: amphibolite, schist, gneiss, quartzite, quartz-pebble conglomerate, and marble.	Alfi sols (Haplustalfs), Aridisols (Haplargids, Haplocalcids), Entisols (Torriorthents, Ustorthents), Mollisols (Argicryolls, Argiustolls, Haplustolls, Calciustolls)	Mesic, Frigid, Cryic/ Ustic, Aridic	12-20	75-100	Sagebrush shrubland, pinyon-juniper woodland, and foothill-mountain grasslands. Also includes areas of mountain mahogany shrublands and scattered Gambel oak woodlands. The woodlands are often interspersed with mountain big sagebrush, skunkbush, serviceberry, fringed sage,rabbitbrush, blue grama, Junegrass, western wheatgrass, Indian ricegrass, Scribner needlegrass, muttongrass, and blue grama.

GIS analysis was used to evaluate the characteristics of the Level IV Ecoregions. The percent fines data was compared to landscape characteristics and stream slope and elevation were found to be significant predictors of percent fines. For this reason, Level IV Ecoregions were grouped based upon similar slope and elevation range. This reduced the variability in the expected condition for percent fines. Hundreds of thousands of ArcMap GIS slope-calculated polylines, representing all stream segments, and a digital elevation model raster were summarized to characterize the distribution of stream slope[2] and elevation for each Level IV Ecoregion. It was determined that three distinct Sediment Regions could be established while maintaining a sufficient number of reference sites for each sediment region.

The Level IV Ecoregions were then combined based on similar elevation and stream slope. Ecoregion 18d was included in Sediment Region 3 because of its similarity to the rest of the region. Table 3 presents summary statistics on the regions and the reference sites located within those regions.

Table 3. Summary Statistics of Ecoregions and Reference Sites

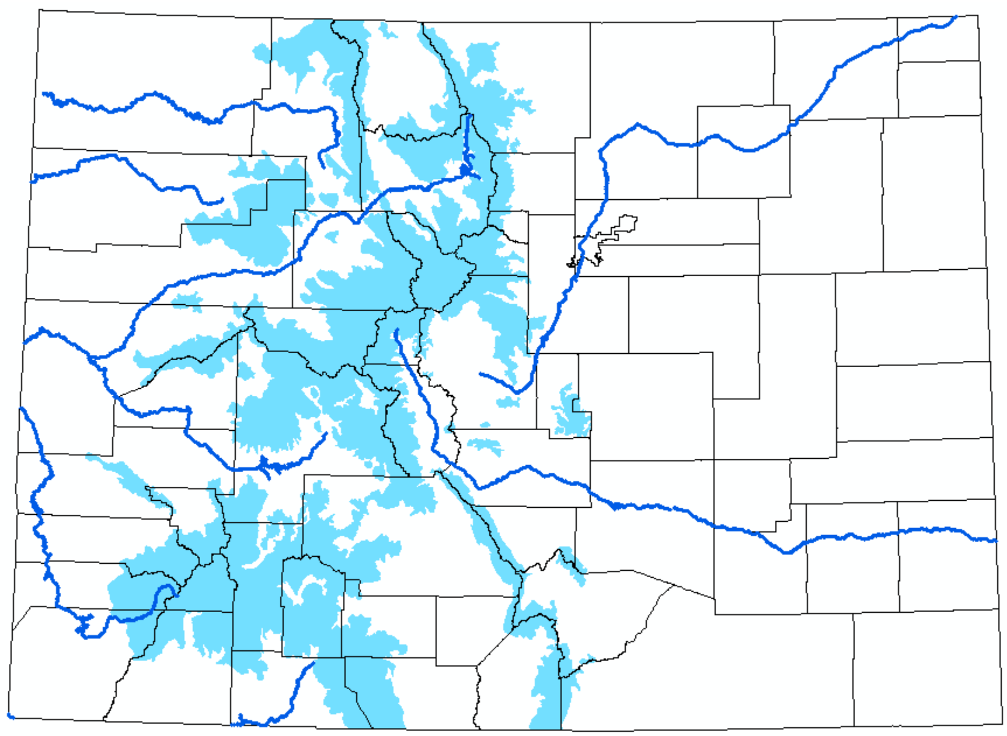
		Sediment Region 1	Sediment Region 2	Sediment Region 3
Description		High mountains with steep slopes. Glaciated. Alpine and subalpine forest.	Mid-elevation mountains. Partially glaciated. Mid-Elevation Forests	Low mountains, mid-elevation hills, ridges and foot slopes. Unglaciated. Woodland and shrubland,
Entire Region	Ecoregion IDs	21a, 21b, 21e, and 21g	21c, 21f, and 21h	18d, 20c, 20e, and 21d
	Elevation / Local Relief (ft)	6200 - 14400 / 400-2500	5200 - 12800 / 400-1000	4300 - 11200 / 200-1000
	GIS Stream course slope median (ft/ft)	0.1121	0.0721	0.0548
Reference Site Conditions	Number of Reference Sites	32	18	16
	Reference Site Range of % Fines <2 mm; median value	1 – 28%; 5%	4 – 52%; 9%	9 – 41%; 18%
	Reference Site Range of Stream Course Slopes (ft/ft); median value	0.008 – 0.235; 0.06	0.01 – 0.1; 0.05	0.004 – 0.1; 0.03
	Reference Site Elevation Range (ft); median value	7400 - 12000, 9600	6600 – 10200, 7800	4900 – 7800, 6200

[2] Slope shapefile developed by Utah State University to predict biotypes for WQCC Policy 10-1

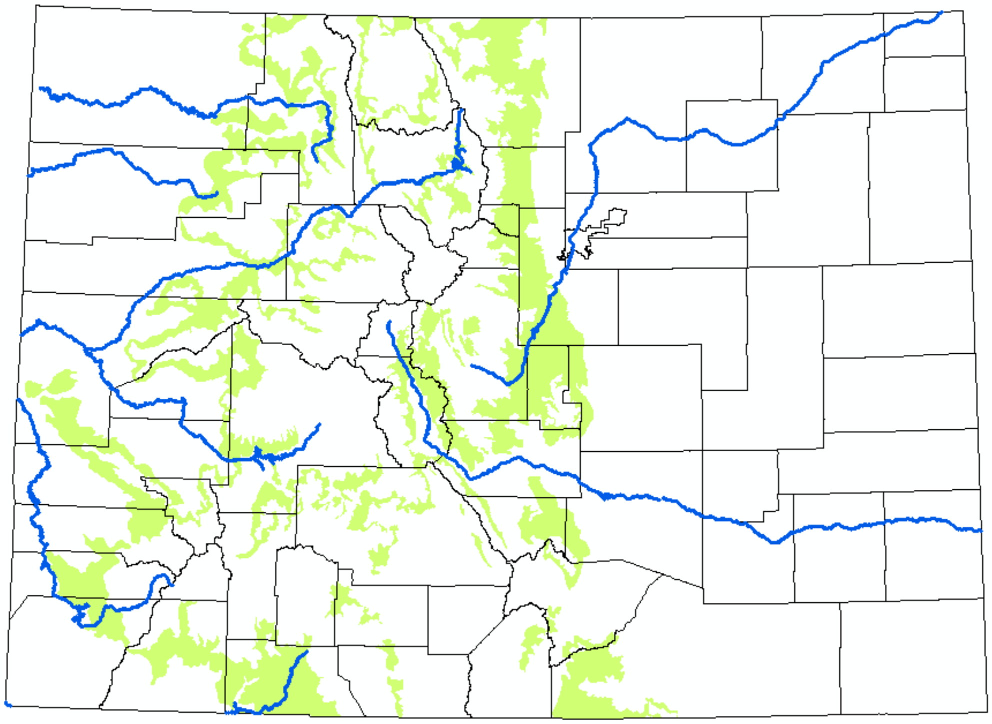
III. COLORADO'S SEDIMENT REGIONS

The result of the development process is three Sediment Regions, with numbering starting at the highest elevation. The Sediment Regions generally form concentric rings around the high peaks of the Rocky Mountains. Each region is described in the following sections and a map is provided. As more reference sites are identified and data collected, it may be possible to refine these regions and establish more regions for the rest of the state.

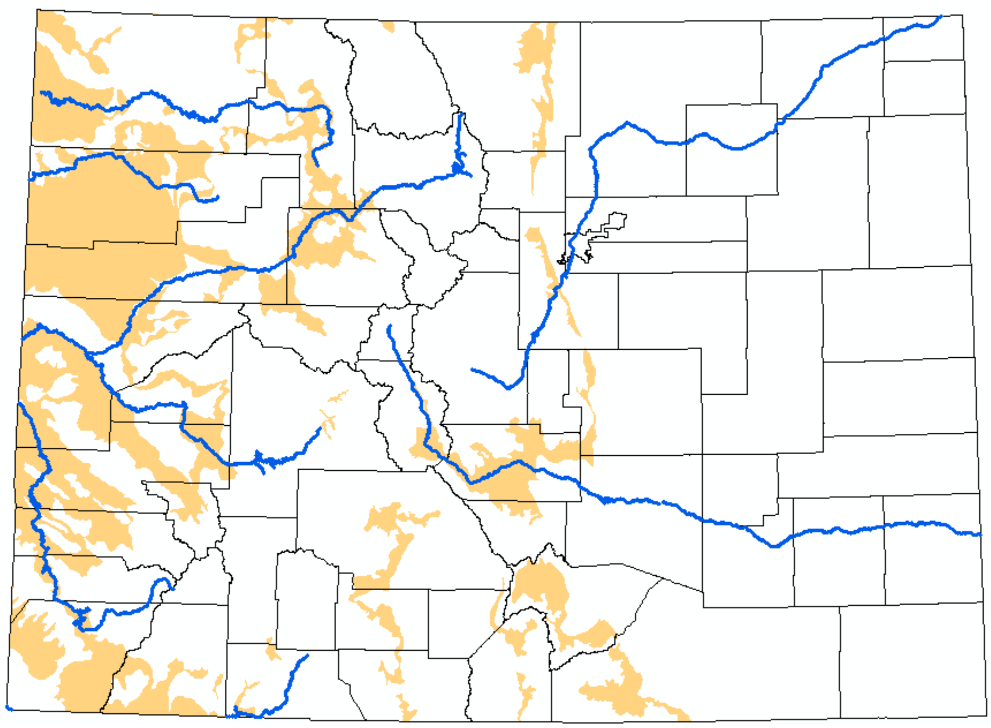
A. Sediment Region 1: High Mountains with steep slopes; glaciated; alpine and subalpine forest. This Sediment Region encompasses Colorado's central mountains with elevations down to approximately 8500 feet in the north, and approximately 9000 feet in the south. Stream courses are naturally steep.



B. Sediment Region 2: Mid-elevation mountains with moderate slopes; partially glaciated; mid-elevation forests of ponderosa pine with areas of Douglas fir, aspen and pinyon pine. This Sediment Region generally surrounds Sediment Region 1 on the mid elevation mountains. Elevations generally range from 7000 to 9000 ft. Stream courses are less naturally steep than those of Sediment Region 1.



C. <u>Sediment Region 3</u>: Low mountains, mid-elevation hills, ridges and foot slopes; unglaciated; pinyon-juniper woodland, mountain mahogany woodland, sage brush and rabbit brush lands. Elevations for this Sediment Region overlap with Sediment Region 2 with the lower elevations descending to 5000 ft. This Sediment Region has the most varied landscapes with a wide range of natural stream course slopes.



IV. HOW TO IDENTIFY THE CORRECT SEDIMENT REGION FOR YOUR TEST SITE

If the maps presented above do not provide enough detail, use EPA's website at http://www.epa.gov/wed/pages/ecoregions/co_eco.htm. Either use the maps as displayed or download the ArcMap GIS layers.

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APPENDIX E

Method for Calculating Sediment Weighted Average Tolerance Indicator Values

I. Introduction

The method at Section IV.A for assessing sediment impacts to macroinvertebrates includes assessment of the biological condition of a site using a sediment (percent fines) weighted average tolerance indicator value (TIV_{SED}). The methods for calculating TIV_{SED} were generally developed following the methods from the National Water Quality Assessment Program (Carlisle et al., 2007). The method was applied using paired macroinvertebrate and percent fines data from sites within each Sediment Region. The general steps are as follows:

- Identification of common genera in each Sediment Region;
- Calculation of an abundance-weighted average TIV (1-10) for each common genus in each Sediment Region; and
- Calculation of an overall TIV_{SED} score for the macroinvertebrate community at each site (1-10)

First, common genera were identified for each Sediment Region using all of the sites with paired macroinvertebrate and percent fines data. Macroinvertebrates that were present in samples from at least 9% of the sites within a Sediment Region were identified as "common" genera. The list of common genera for each Sediment Region is included in Section IV.

Second, a tolerance indicator value (TIV) was estimated for each macroinvertebrate on the common genus list. The TIV for each common genus is an index score (1 to 10) of the ranked abundance-weighted average percent fines value. The common genera were ranked from most-tolerant (TIV=10) to least-tolerant (TIV=1).

The relationship between the observed abundance of a common genus and the measured percent fines was modeled for all sites within each Sediment Region. The TIV for each common genus was calculated using the following equation:

$$WA_j = (Y_1X_1 + Y_2X_2 + ... + Y_nX_n) \ / \ (Y_1 + Y_2 + ... + Y_n)$$

where WA_j is the weighted average percent fines value of the common genus j, where Y is the abundance in samples 1, . . ., n, and X is the value of the percent fines variable in samples 1, . . ., n.

Common genera that are more abundant at sites with higher percent fines have higher WA_j scores. The TIV score (1–10) of each common genus was assigned based on its calculated WA_j. The 10% of common genera with the highest WA_j values were assigned a TIV score of 10, the next lowest 10% were assigned a TIV score of 9, and so on.

Third, TIV_{SED} scores were calculated for each site. The TIV_{SED} score is the abundance-weighted average TIV of all the common genera at the site. The calculation of the TIV_{SED} score uses the following equation:

$$TIV_{SED} = (Y_1X_1 + Y_2X_2 + \ldots\ldots + Y_nX_n) \;/\; (Y_1 + Y_2 + \ldots. + Y_n)$$

where TIV_{SED} is the score for the site, Y is the abundance of common genera 1, . . ., n, and X is the region-specific TIV for the common genera 1, . . ., n.

Overall, the TIV_{SED} score characterizes the sediment tolerance of the macroinvertebrate community as a whole. For example, a high TIV_{SED} score reflects both relatively low abundance of sediment-sensitive macroinvertebrates and relatively high abundance of sediment-tolerant macroinvertebrates, compared to other sites in the same Sediment Region. Conversely, a low TIV_{SED} score reflects both relatively high abundance of sediment-sensitive macroinvertebrates and relatively low abundance of sediment-tolerant macroinvertebrates, compared to other sites in the same Sediment Region.

It is important to note that TIVs are relative values. A genus with a TIV of "1" indicates that it is among the 10% of the most sensitive common genera within the specific Sediment Region. Compared to the list of common genera in another Sediment Region, the same genus might not be among the most sensitive. Similarly, a TIV_{SED} score for a site indicates the macroinvertebrate community's tolerance to sediment, relative to other sites within that Sediment Region. It is not directly comparable to TIV_{SED} scores calculated for sites in other Sediment Regions.

II. Step-by-Step Guide to Calculating Sediment Tolerance Indicator Values

The following sections provide a description of the steps for calculating a TIV_{SED} score for an individual site from macroinvertebrate data.

A. Data Requirements

The intention of this appendix is to describe the TIV_{SED} calculation rather than the field sample collection, laboratory method, and data management steps that are considered activity prerequisites relevant to this final step.

Accordingly, those prerequisite steps conducted prior to calculating TIV_{SED} will only be catalogued and referenced here, in Section A, so the user community can understand what is required to get to this point.

<u>Prerequisites</u>

- Collect and preserve benthic macroinvertebrate samples in the field using recommended Water Quality Control Division (Division) protocols
    - Reference: WQCC Policy 10-1 Appendix B - *Benthic Macroinvertebrate Sampling Protocols*
- Identify and enumerate benthic macroinvertebrate samples in a laboratory setting
    - Reference: WQCC Policy 10-1 Appendix C - *Standard Operating Procedures for Laboratory Identification and Enumeration*
- Upload taxon-harmonized benthic macroinvertebrate data and station predictor variable information into Colorado's Ecological Data Application System (EDAS)

- o Reference: WQCC Policy 10-1 Appendix D – *Methodology for Determining Biological Condition* (Pages 2-5)

- Randomly resample a single sample greater than 360 individuals to a fixed 300-count sub-sample using EDAS

  - o Reference: WQCC Policy 10-1 Appendix D – *Methodology for Determining Biological Condition* (Page 7)

The final prerequisite step of randomly resampling a larger, whole sample is consistent with the Division's standardized practice of sub-sampling all benthic macroinvertebrate samples in EDAS to a fixed 300-count (+/- 20%). The ensuing sub-sample effectively creates a one-time snapshot of the taxa and their final counts used to compute multi-metric index (MMI) metrics, auxiliary metrics, and ultimately the final MMI score. While the computation of these elements is not necessarily relevant to calculating TIV_{SED}, it is important to know because the same fixed 300-count sub-sample that contributes to metric and MMI calculations also serves as the data underpinnings from which TIV_{SED} will be calculated.

B. Software Requirements

This Appendix explains how to calculate a TIV_{SED} for a given sample using taxonomic identifications and counts queried from EDAS and Microsoft Excel® spreadsheets. The essential software for calculating the TIV_{SED}, as instructed in this Appendix, is as follows:

- Colorado EDAS – free software from WQCD
- Microsoft Windows XP or higher; although Window 7 or higher is preferred
- Microsoft Office with Access® and Excel®

<u>EDAS Query</u>

For those users familiar with EDAS's relational database structure, the fixed 300-count output is saved to EDAS's "Benthics" table once the sub-sampling macro is executed. In the Benthics table each organism's identification, shown as "BenTaxaID" in Figure 1, lists its corresponding original count (identified as "Individuals") and the subsample count (identified as "Ind_300"). If the two sets of values are equal, then the original count was less than 360 individuals and the sample was not sub-sampled. If the two sets of values are not equal, then the original count was greater than 360 individuals and the sample was sub-sampled.

BenTaxaID	Stage	BenSampID	RepNu	Individuals	Ind_300
8	X	3	1	3	3
96	X	3	1	1	1
191	X	3	1	90	90

Figure 1. Example of Original and Sub-sampled Counts

The taxonomic identifications and counts needed to calculate TIV_{SED} can be queried from EDAS's Benthics table and other related tables. See Figure 2 for a detailed query to match taxonomic final identifications with sub-sampled counts.

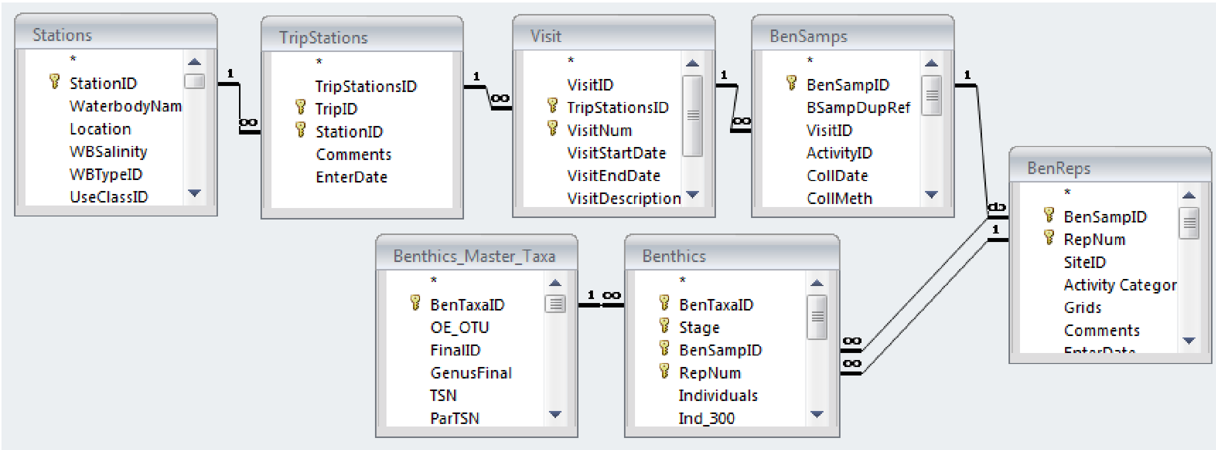

Figure 2. Example of EDAS Query Input

The query in Figure 2 will provide the necessary data to begin the process of calculating TIV_{SED}. The output from this query is illustrated in Figure 3 and can be copied and pasted into a Microsoft Excel® spreadsheet for further analysis.

StationID	WaterbodyName	Location	CollDate	FinalID	Individuals	Ind_300	RepNum
10160	Texas Creek	above Taylor Park Reservoir	08/13/1996	Acentrella	3	3	1
10160	Texas Creek	above Taylor Park Reservoir	08/13/1996	Ceratopogonidae	1	1	1
10160	Texas Creek	above Taylor Park Reservoir	08/13/1996	Enchytraeidae	90	90	1

Figure 3. Example of EDAS Query Output

The Division recommends using Microsoft Excel® to calculate TIV_{SED}. Accordingly, the step wise procedure to calculate TIV_{SED} will use Microsoft Excel® worksheets, formulas and PivotTables. While other methods may be explored to compute a TIV_{SED}, this document focuses only on calculations performed in Microsoft Excel®.

C. Taxonomic Hierarchy

TIV_{SED} for percent fines are based on the organisms genus rank relative to the taxonomic hierarchy. The hierarchy of biological classifications includes upwards to eight major taxonomic ranks, as shown below.

Domain > Kingdom > Phylum > Class > Order > Family > Genus > Species

Intermediate minor rankings are not shown.

Organisms identified coarsely at family or higher on the taxonomic hierarchy will not have a matching genus. Accordingly, those individuals identified at family or higher will not continue forward in the TIV_{SED} calculation process.

Conversely, when an organism is given a species name or identified to species, it is assigned to a genus, and the genus name is then part of the species name. For purposes of calculating the TIV_{SED} those organisms identified to the binomial nomenclature of "*Genus species*" will default to the genus rank only. For example, *Drunella doddsi* will default to *Drunella*.

D. TIV_{SED} Calculation Steps

The Division recommends following the procedural steps explained and illustrated in this section. Deviation from these steps may lead to an improperly computed TIV_{SED}.

Step 1: Formatting a Spreadsheet

Copy the query output as shown in Figure 3 from EDAS's Query window to a Microsoft Excel® spreadsheet to form the initial "data block" illustrated in Figure 4. Of note, the "RepNum" or replicate number shown in Figure 3 is not necessary unless multiple samples were taken on the same day at the same location. If, for instance, a duplicate sample was taken, then it will be necessary to add the "RepNum" column to the data block because a TIV_{SED} will be calculated separately for the routine and duplicate samples. For purposes of this demonstration, the RepNum column will not be considered.

	A	B	C	D	E	F	G
1	StationID	WaterbodyName	Location	CollDate	FinalID	Individuals	Ind_300
2	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Baetic tricaudatus group	63	63
3	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Bezzia group	1	1
4	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus	1	1
5	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Diamesa	2	2
6	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Dolophilodes	1	1
7	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Enchytraeidae	6	6
8	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella devonica group	22	22
9	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella gracei group	9	9
10	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Hesperoperla	8	8
11	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Heterlimnius	11	11
12	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Isoperla	4	4
13	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Leptophlebia	21	21
14	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micrasema	1	1
15	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micropsectra	4	4
16	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius	10	10
17	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius dorenus	24	24
18	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius mallochi	4	4
19	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Pagastia	25	25
20	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Parametriocnemus	1	1
21	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Plumiperla	7	7
22	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Polypedilum aviceps	5	5
23	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rheocricotopus	4	4
24	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila atrata/valuma	2	2
25	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila brunnea/vemna	3	3
26	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Simulium	20	20
27	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Stempellinella	1	1
28	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Sweltsa	3	3
29	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tanytarsus	1	1
30	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tvetenia bavarica group	7	7

Figure 4. Data Block Structure Shown in Excel® Spreadsheet Format

Step 2: Add Genus Identification

The next step requires matching an organism's genus identification to its corresponding final identification (FinalID).

Add a new column to the right of Column E (FinalID) and title the column "Genus". This will now be Column F. Open EDAS. From EDAS's front page, click "Access Database Structure". Locate and open the "Benthics_Master_Taxa" table in the Table of Contents to the far left of the Access® window. Copy the FinalID column and paste into spreadsheet Column K. Then copy the Genus column to spreadsheet Column L.

In the newly created Column F (Genus) type in the following match and index formula:

=INDEX($L$2:$L$3000,MATCH(E2,$K$2:$K$3000,FALSE),1)

Copy the formula down Column F to the last row cell within the data block. The genus rank for each FinalID will be matched and indexed into Column F. See Figure 5.

	A	B	C	D	E	F	G	H
1	StationID	WaterbodyName	Location	CollDate	FinalID	Genus	Individuals	Ind_300
2	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Baetic tricaudatus group	Baetis	63	63
3	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Bezzia group	Bezzia	1	1
4	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus	Cricotopus	1	1
5	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Diamesa	Diamesa	2	2
6	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Dolophilodes	Dolophilodes	1	1
7	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Enchytraeidae		6	6
8	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella devonica group	Eukiefferiella	22	22
9	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella gracei group	Eukiefferiella	9	9
10	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Hesperoperla	Hesperoperla	8	8
11	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Heterlimnius	Heterlimnius	11	11
12	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Isoperla	Isoperla	4	4
13	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Leptophlebia	Leptophlebia	21	21
14	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micrasema	Micrasema	1	1
15	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micropsectra	Micropsectra	4	4
16	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius	Orthocladius	10	10
17	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius dorenus	Orthocladius	24	24
18	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius mallochi	Orthocladius	4	4
19	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Pagastia	Pagastia	25	25
20	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Parametriocnemus	Parametriocnemus	1	1
21	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Plumiperla	Plumiperla	7	7
22	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Polypedilum aviceps	Polypedilum	5	5
23	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rheocricotopus	Rheocricotopus	4	4
24	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila atrata/valuma	Rhyacophila	2	2
25	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila brunnea/vemna	Rhyacophila	3	3
26	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Simulium	Simulium	20	20
27	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Stempellinella	Stempellinella	1	1
28	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Sweltsa	Sweltsa	3	3
29	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tanytarsus	Tanytarsus	1	1
30	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tvetenia bavarica group	Tvetenia	7	7

Figure 5. Genus Rank Added to Data Block

Genus rank matched and indexed to FinalID

Next, copy Column F and "Paste Special" back into Column F as "Values" to remove the match and index formulas. Delete Columns K and L as they are no longer needed.

In the example shown above, row 7 contains a FinalID at the family rank – *Enchytraeidae*. There is no matched genus, so the 6 individuals affiliated with family *Enchytraeidae* will not continue forward in the TIV_{SED} calculation process. Row 7 can be deleted.

<u>Step 3: Data Block Treatments</u>

The FinalID column may be removed from the data block since the operative identification is now "Genus". In the example, delete Column E. Columns F, G and H will then shift left to reform Columns E, F and G. See Figure 6.

Any rows of data without a genus rank can be deleted. See Figure 6.

	A	B	C	D	E	F	G
1	StationID	WaterbodyName	Location	CollDate	Genus	Individuals	Ind_300
2	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Baetis	63	63
3	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Bezzia	1	1
4	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus	1	1
5	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Diamesa	2	2
6	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Dolophilodes	1	1
7	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella	22	22
8	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella	9	9
9	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Hesperoperla	8	8
10	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Heterlimnius	11	11
11	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Isoperla	4	4
12	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Leptophlebia	21	21
13	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micrasema	1	1
14	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micropsectra	4	4
15	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius	10	10
16	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius	24	24
17	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Orthocladius	4	4
18	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Pagastia	25	25
19	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Parametriocnemus	1	1
20	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Plumiperla	7	7
21	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Polypedilum	5	5
22	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rheocricotopus	4	4
23	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila	2	2
24	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila	3	3
25	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Simulium	20	20
26	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Stempellinella	1	1
27	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Sweltsa	3	3
28	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tanytarsus	1	1
29	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tvetenia	7	7

Figure 6. FinalID Column and Non-Genus Rows Deleted

<u>Step 4: *Cricotopus/Orthocladius* Treatment</u>

The next step requires changing all Genus cases of "*Cricotopus*" and "*Orthocladius*" to "*Cricotopus/Orthocladius*" in Column E. Re-sort Column E alphabetically. See Figure 7.

	A	B	C	D	E	F	G
1	StationID	WaterbodyName	Location	CollDate	Genus	Individuals	Ind_300
2	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Baetis	63	63
3	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Bezzia	1	1
4	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus/Orthocladius	1	1
5	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus/Orthocladius	10	10
6	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus/Orthocladius	24	24
7	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus/Orthocladius	4	4
8	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Diamesa	2	2

Figure 7. Cricotopus/Orthocladius Genus Treatment

<u>Step 5: Condensing Genus</u>

The next step is to condense all like genera together. In some instances, the user will encounter multiple rows of the same genus. This is usually the result of the *Genus species* binomial nomenclature defaulting to genus only. In the example shown in Step 4, *Cricotopus/Orthocladius* must be condensed from four rows into a single row with all counts under Column G or “Ind_300” summed per genus.

This is best achieved by using a “SUMIFS” formula in Microsoft Excel® or by hand.

In the example in Figure 8, *Cricotopus/Orthocladius*, *Eukiefferiella*, and *Rhyacophila* have been condensed. Refer to Figure 6 to confirm that these genera have multiple rows.

	A	B	C	D	E	F	G
1	StationID	WaterbodyName	Location	CollDate	Genus	Individuals	Ind_300
2	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Baetis	63	63
3	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Bezzia	1	1
4	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus/Orthocladius	39	39
5	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Diamesa	2	2
6	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Dolophilodes	1	1
7	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella	31	31
8	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Hesperoperla	8	8
9	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Heterlimnius	11	11
10	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Isoperla	4	4
11	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Leptophlebia	21	21
12	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micrasema	1	1
13	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micropsectra	4	4
14	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Pagastia	25	25
15	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Parametriocnemus	1	1
16	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Plumiperla	7	7
17	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Polypedilum	5	5
18	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rheocricotopus	4	4
19	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila	5	5
20	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Simulium	20	20
21	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Stempellinella	1	1
22	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Sweltsa	3	3
23	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tanytarsus	1	1
24	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tvetenia	7	7

Figure 8. Genus Condensed

<u>Step 5: Identify Sediment Region</u>

The next step is to identify which Sediment Region the site (sample) falls within because the list of common genera varies among the three Sediment Regions. In the example demonstrated in this document, Middle Fork Cottonwood Creek is located in Level IV Ecoregion 21g. Table 1 lists the Level IV Ecoregions within each Sediment Region. Ecoregion 21g falls within Sediment Region 1.

	Sediment Region 1	Sediment Region 2	Sediment Region 3
Level IV Ecoregions	21a, 21b, 21g, and 21e	21c, 21f, 21h	18d, 20c, 20e, and 21d

Table 1. Level IV Ecoregions by Sediment Region

<u>Step 6: Identify Common Genus</u>

The next step is to identify which remaining genera in the data block are considered a Common Genus. In the example, Middle Fork Cottonwood Creek falls within Sediment Region

1, so the common genera from Sediment Region 1 are identified and will move forward in the TIV_{SED} calculation process.

The list of Common Genus for all three Sediment Regions is located in Appendix A to this document.

In Figure 9, the existing list of condensed genera is compared to the Common Genus for Sediment Region 1 listed in Appendix A to this document. Column H has been added to allow for tracking whether a genus is common or not. In this example, all genera are common, except for *Leptophlebia*. Accordingly, *Leptophlebia* will be removed from further TIV_{SED} calculation steps while the remaining common genera move forward to the TIV_{SED} calculation step. Delete row 11 and Column H may now be removed.

	A	B	C	D	E	F	G	H
1	StationID	WaterbodyName	Location	CollDate	Genus	Individuals	Ind_300	Common
2	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Baetis	63	63	YES
3	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Bezzia	1	1	YES
4	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus/Orthocladius	39	39	YES
5	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Diamesa	2	2	YES
6	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Dolophilodes	1	1	YES
7	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella	31	31	YES
8	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Hesperoperla	8	8	YES
9	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Heterlimnius	11	11	YES
10	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Isoperla	4	4	YES
11	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Leptophlebia	21	21	NO
12	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micrasema	1	1	YES
13	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micropsectra	4	4	YES
14	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Pagastia	25	25	YES
15	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Parametriocnemus	1	1	YES
16	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Plumiperla	7	7	YES
17	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Polypedilum	5	5	YES
18	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rheocricotopus	4	4	YES
19	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila	5	5	YES
20	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Simulium	20	20	YES
21	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Stempellinella	1	1	YES
22	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Sweltsa	3	3	YES
23	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tanytarsus	1	1	YES
24	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tvetenia	7	7	YES

Figure 9. Identification of Common Genus

<u>Step 7: Calculating the TIV_{SED}</u>

The next step adds the assigned TIV 1-10 rank for each Common Genus. Add a new Column H and title the column "TIV". Using either a Match and Index formula or a "SUMIF" formula, match the TIV to the Common Genus and add the equivalent TIV 1-10 rank to Column H.

Add a new Column I and title the column "Ind_300*TIV". In cell I2, enter the following formula: "=G2*H2". Copy the formula down Column I to the last cell. The resultant value is the product of multiplying the genus count (Column G) by the TIV (Column H). See Figure 10.

	A	B	C	D	E	F	G	H	I
1	StationID	WaterbodyName	Location	CollDate	Genus	Individuals	Ind_300	TIV	Ind_300 * TIV
2	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Baetis	63	63	4	252
3	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Bezzia	1	1	9	9
4	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Cricotopus/Orthocladius	39	39	7	273
5	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Diamesa	2	2	5	10
6	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Dolophilodes	1	1	1	1
7	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Eukiefferiella	31	31	9	279
8	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Hesperoperla	8	8	2	16
9	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Heterlimnius	11	11	6	66
10	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Isoperla	4	4	6	24
11	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micrasema	1	1	9	9
12	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Micropsectra	4	4	7	28
13	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Pagastia	25	25	9	225
14	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Parametriocnemus	1	1	10	10
15	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Plumiperla	7	7	2	14
16	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Polypedilum	5	5	10	50
17	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rheocricotopus	4	4	3	12
18	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Rhyacophila	5	5	5	25
19	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Simulium	20	20	7	140
20	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Stempellinella	1	1	4	4
21	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Sweltsa	3	3	2	6
22	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tanytarsus	1	1	10	10
23	CO154M	Middle Fork Cottonwood Creek		8/18/1995	Tvetenia	7	7	7	49

Figure 10. Adding Columns for TIV and Product of Ind_300 Multiplied by TIV

Next, highlight or select the data block range. In the above example, select A1:I23. Then go to Microsoft Excel's toolbar and insert a PivotTable. See Figure 11. Confirm the data block range and select "OK".

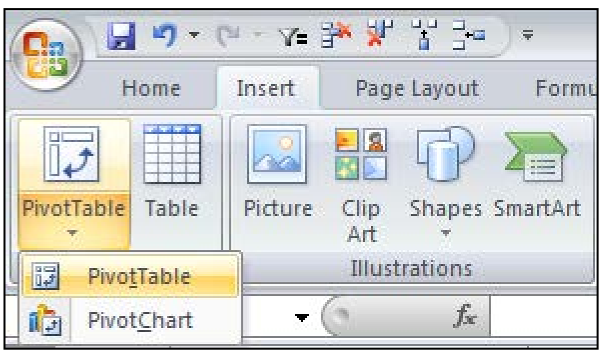

Figure 11. How to Insert a PivotTable

A new PivotTable tab will open with the PivotTable Field List showing up on the far right of the window. Select the Fields to add to the Row Labels window. The Division recommends adding "StationID", "WaterbodyName", "Location", and "CollDate". See Figure 12.

Next select "Ind_300" from the PivotTable Field List. This sums the overall count of common genera per sample in the "Values" window. See Figure 12.

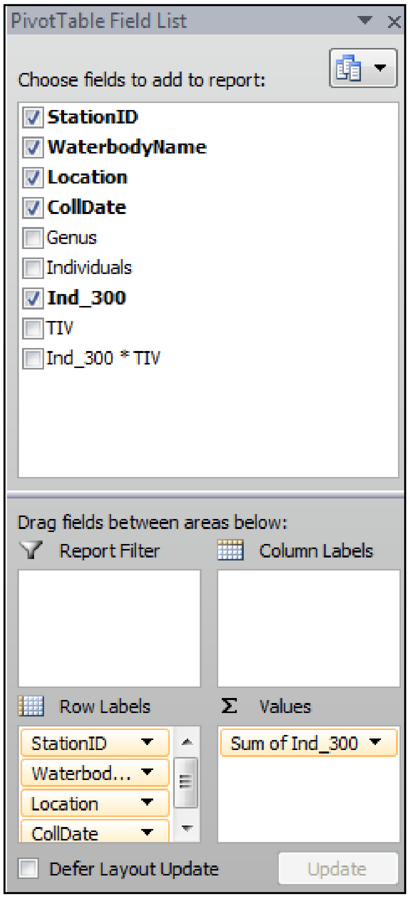

Figure 12. PivotTable Field List

Go to PivotTable Tools on the toolbar. Select "Design". Then select "Subtotals" and select the "Do Not Show Subtotals" option. See Figure 13.

Go to PivotTable Tools on the toolbar. Select "Report Layout". Then select "Show in Tabular Form" option. See Figure 14. These two intermediate steps will format the pivot table build to a tabular arrangement that can be easily copied and pasted into a new spreadsheet tab.

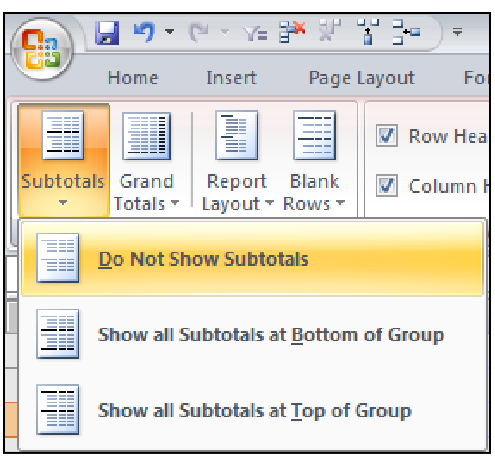

Figure 13. PivotTable Tools - Subtotals

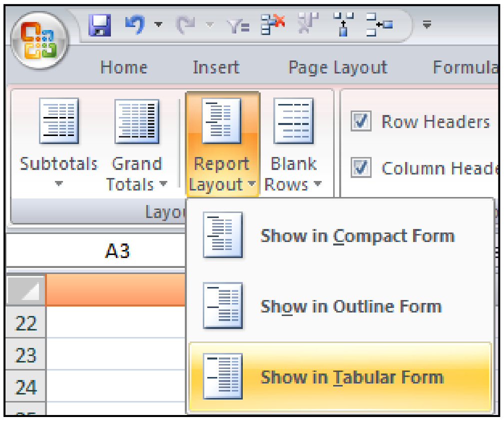

Figure 14. PivotTable Tools - Report Layout

Next go to PivotTable Tools and select “Options”. Go to “Formulas” and select “Calculated Field...” as shown in Figure 15.

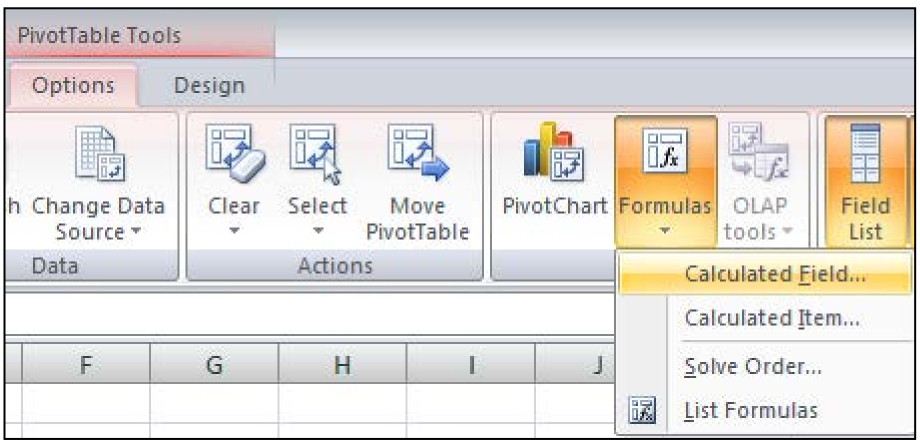

Figure 15. Pivot Table Tools - Formulas

In the “Insert Calculated Field” window, type “WA TIV” into the “Name” field. In the formula field, retain the “=” sign. Go to the “Fields” window and select “Ind_300*TIV”. Click the “Insert Field” button. In the formula field, type a “/” after “Ind_300*TIV”. Then go to the “Fields” window again and select “Ind_300”. Click the “Insert Field” button. See Figure 16 for the “Insert Calculated Field” example. Click “OK”.

The calculated TIV_{SED} will be added to the PivotTable as the “Sum of WA TIV” column. See Figure 17.

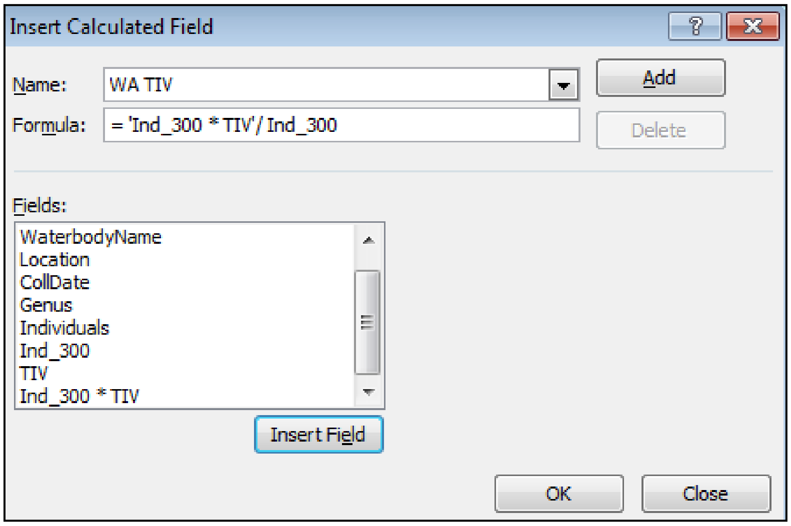

Figure 16. Example of Insert Calculated Field Window

	A	B	C	D	E	F
1						
2						
3					Values	
4	**StationID**	**WaterbodyName**	**Location**	**CollDate**	**Sum of Ind_300**	**Sum of WA TIV**
5	**CO154M**	**Middle Fork Cottonwood Creek**		8/18/1995	244	6.196721311
6	**Grand Total**				**244**	**6.196721311**

Figure 17. Example of PivotTable TIV_{SED} **Calculation**

In this example, the TIV_{SED} for the sample collected at Middle Fork Cottonwood Creek on August 18, 1995 is 6.20.

III. References

Carlisle, Daren M. et al. 2007. *Estimation and application of indicator values for common macroinvertebrate genera and families of the United States.* Ecological Indicators 7 (2007) 22–33.

IV. Common Genus by Sediment Region

Sediment Region 1

SEDIMENT REGION 1	TIV
Arctopsyche	1
Claassenia	1
Dolophilodes	1
Hygrobates	1
Lepidostoma	1
Oligophlebodes	1
Paraleuctra	1
Taenionema	1
Brachycentrus	2
Clinocera	2
Hesperoperla	2
Megarcys	2
Parorthocladius	2
Plumiperla	2
Rhithrogena	2
Sweltsa	2
Ameletus	3
Atractides	3
Epeorus	3
Polycelis	3
Rheocricotopus	3
Wiedemannia	3
Zapada	3
Baetis	4
Cinygmula	4
Paraleptophlebia	4
Protzia	4
Rheotanytarsus	4
Serratella	4
Sperchon	4
Stempellinella	4
Acentrella	5
Corynoneura	5
Diamesa	5
Drunella	5
Ephemerella	5
Hydrobaenus	5
Pseudodiamesa	5
Rhyacophila	5

SEDIMENT REGION 1	TIV
Atherix	6
Diura	6
Glossosoma	6
Heterlimnius	6
Isoperla	6
Skwala	6
Suwallia	6
Zaitzevia	6
Cricotopus/Orthocladius	7
Hydropsyche	7
Lebertia	7
Micropsectra	7
Potthastia	7
Simulium	7
Torrenticola	7
Tvetenia	7
Dicranota	8
Diphetor	8
Empididae	8
Hexatoma	8
Neothremma	8
Prosimulium	8
Pteronarcella	8
Bezzia	9
Brillia	9
Chaetocladius	9
Eukiefferiella	9
Kogotus	9
Micrasema	9
Pagastia	9
Pericoma	9
Chelifera	10
Chelifera/Metachela	10
Conchapelopia	10
Optioservus	10
Parametriocnemus	10
Polypedilum	10
Tanytarsus	10
Thienemannimyia	10

Sediment Region 2

SEDIMENT REGION 2	TIV
Arctopsyche	1
Atherix	1
Cardiocladius	1
Claassenia	1
Dolophilodes	1
Drunella	1
Megarcys	1
Rhithrogena	1
Acentrella	2
Cheumatopsyche	2
Epeorus	2
Glossosoma	2
Hesperoperla	2
Nais	2
Pericoma	2
Polypedilum	2
Protzia	2
Cinygmula	3
Ephemerella	3
Helicopsyche	3
Lepidostoma	3
Polycelis	3
Potthastia	3
Pteronarcys	3
Zaitzevia	3
Agapetus	4
Ameletus	4
Corynoneura	4
Neoplasta	4
Rhyacophila	4
Skwala	4
Sperchon	4
Suwallia	4
Antocha	5
Hexatoma	5
Hydropsyche	5
Lebertia	5
Microtendipes	5
Narpus	5
Stempellinella	5
Thienemanniella	5
Torrenticola	5

SEDIMENT REGION 2	TIV
Atractides	6
Baetis	6
Hygrobates	6
Paraleptophlebia	6
Pteronarcella	6
Serratella	6
Sweltsa	6
Tvetenia	6
Cricotopus/Orthocladius	7
Eukiefferiella	7
Lopescladius	7
Oligophlebodes	7
Optioservus	7
Simulium	7
Thienemannimyia	7
Zapada	7
Brachycentrus	8
Chaetocladius	8
Dicranota	8
Heterlimnius	8
Micropsectra	8
Ochrotrichia	8
Phaenopsectra	8
Rheocricotopus	8
Tanytarsus	8
Amphinemura	9
Brillia	9
Hydroptila	9
Micrasema	9
Pagastia	9
Parametriocnemus	9
Rheotanytarsus	9
Tricorythodes	9
Chelifera	10
Diamesa	10
Diphetor	10
Isoperla	10
Ophiogomphus	10
Pentaneura	10
Pisidium	10
Tipula	10

Sediment Region 3

SEDIMENT REGION 3	TIV
Arctopsyche	1
Cardiocladius	1
Lepidostoma	1
Leucotrichia	1
Nais	1
Rheocricotopus	1
Rhithrogena	1
Claassenia	2
Empididae	2
Hygrobates	2
Lopescladius	2
Paraleptophlebia	2
Pericoma	2
Phaenopsectra	2
Zaitzevia	2
Atherix	3
Diamesa	3
Helichus	3
Microcylloepus	3
Oecetis	3
Rhyacophila	3
Tipula	3
Atractides	4
Baetis	4
Brachycentrus	4
Epeorus	4
Pteronarcella	4
Tanytarsus	4
Tvetenia	4
Ambrysus	5
Dicranota	5
Ephemerella	5
Hesperoperla	5
Neoplasta	5
Pagastia	5
Simulium	5
Sperchon	5

SEDIMENT REGION 3	TIV
Bezzia/Palpomyia	6
Cinygmula	6
Drunella	6
Hydropsyche	6
Lebertia	6
Ochrotrichia	6
Optioservus	6
Acentrella	7
Cheumatopsyche	7
Corynoneura	7
Micropsectra	7
Pentaneura	7
Sweltsa	7
Thienemannimyia	7
Brillia	8
Eukiefferiella	8
Heleniella	8
Hemerodromia	8
Hexatoma	8
Polypedilum	8
Tricorythodes	8
Cricotopus/Orthocladius	9
Diphetor	9
Fallceon	9
Isoperla	9
Parametriocnemus	9
Paratendipes	9
Skwala	9
Thienemanniella	9
Argia	10
Cryptochironomus	10
Hyalella	10
Hydroptila	10
Ophiogomphus	10
Parakiefferiella	10
Rheotanytarsus	10

APPENDIX F

Reference Sites and Threshold Development

The Sediment Weighted Average Tolerance Indicator Value (WA TIV_{SED}) assesses the degree to which the macroinvertebrate community is tolerant to sediment, on a scale of 1 to 10. The numeric value characterizes the relative abundance of sediment tolerant species at a site. A WA TIV_{SED} score approaching 10 represents a highly tolerant community; a score approaching 1 represents a sensitive community. Establishing a threshold involves identification of a dataset of sites that characterize the expected condition for each region, and choosing a statistical method to identify the value that represents the upper end of the expected range of conditions for the region.

I. Reference Sites and Expected Condition

A common approach to evaluating potential impacts on aquatic systems is to compare the test site (candidate impaired site) to a site where those impacts are known to be absent. One of the keys to such a comparative approach is to identify an appropriate "reference" site. In previous versions of Policy 98-1, these sites were called "expected condition sites". One of the major changes in the 2014 version of Policy 98-1 is that rather than selecting an expected condition site for each test site, the new version of the policy established an expected condition for an entire sediment region. In order to describe the development of Colorado's sediment regions, the reference site data set must be described.

In Colorado, two Policies use a comparison of potentially impacted sites to the "expected condition" at minimally impacted reference sites in order to determine if impact has occurred to the degree that some regulatory action should occur. Policy 98-1, the Sediment Guidance, and Policy 10-1, Colorado's Aquatic Life Use Attainment policy, which contains the Multi Metric Index (MMI) tool, both use this concept.

A thorough reference site selection process was followed for development of the MMI tool and for development of the aquatic life thresholds. Appendix A to Policy 10-1 contains a discussion of the reference sites selection criteria.

Reference sites were selected using a GIS based approach that focused on using mapped human disturbance categories, delineated total watershed area polygons and delineated 5 km near-field polygons upstream of each candidate site. GIS was used to calculate the percent disturbed area or count within the total watershed or within the near-field zone. The disturbance factors were:

- Irrigated agriculture, total watershed
- Dryland agriculture, total watershed
- Urban land use, total watershed
- Number of permitted point sources within near field zone
- Number of headgate diversions within near-field zone
- Linear road miles within the near-field zone
- Number of abandoned mines, total watershed
- Oil and gas facilities, within near-field zone

- Number of confined animal feeding operations within near-field zone

The disturbance thresholds selection process is described in Water Quality Control Division (WQCC) Policy 10-1, Appendix A.

Refinement of Data Set for Policy 98-1

Many of the Policy 10-1 reference sites have not only macroinvertebrate information but also co-incident pebble count information, which makes them useful for Policy 98-1 as well as Policy 10-1. Where site-specific information was available, the reference sites were screened to evaluate their appropriateness for establishing the expected conditions specifically for sediment. Two sites were found not to be representative of reference conditions due to localized sediment impacts from beaver dams, road crossings and unstable riverbanks. Table 1 lists the sites in the reference data set. Sites with "na" in the Sediment Region column are outside the zones that became Sediment Regions 1, 2, and 3. See Appendix D.

Table 1. Reference Sites							
ID	**Site Name**	**Sample_ Replicate**	**Collection Date**	**Latitude**	**Longitude**	**MMI Biotype**	**Sediment Regions**
USFS Avalanche	Avalanche Creek	2936_0	9/7/2005	39.2311	-107.1992	BT-2	1
CO151M	Badger Creek	2285_0	8/22/1995	38.5942	-105.8364	BT-1	2
7630	Bear Creek	3016_1	5/2/2007	37.6138	-104.7738	BT-3	na
10262	Beaver Creek	3044_1	8/1/2007	38.5525	-107.053	BT-1	2
CO125M	Beaver Creek	2274_0	8/21/1995	37.9997	-108.1939	BT-1	3
10666	Billy Creek	3051_1	7/16/2007	38.2948	-107.702	BT-1	2
7164	Browns Creek	2682_1	7/27/2005	38.669	-106.161	BT-2	2
11206	Carr Creek	2885_1	9/13/2006	39.5665	-108.5017	BT-1	3
USFS Cataract	Cataract Creek	2951_1	9/26/2006	39.8285	-106.3272	BT-2	1
WCOP01-0777	Chacuaco Creek	2772_0	4/22/2003	37.4942	-103.6313	BT-3	na
7512	Chico Creek	3013_1	4/30/2007	38.3577	-104.3873	BT-3	na
WCOP03-R003	Chief Creek	2779_0	7/10/2003	40.1033	-102.3225	BT-3	na
5775	Cook Creek	3064_2	8/16/2007	39.1817	-104.8968	BT-1	na
7997b	Cottonwood Creek	2651_1	4/7/2004	37.1109	-103.0744	BT-3	na
USFS Cross 4	Cross Creek	2953_0	10/2/2006	39.4841	-106.5039	BT-2	1
USFS Cross 1	Cross Creek	2992_0	9/15/2005	39.5413	-106.4334	BT-2	1
WCOP99-0633	Crystal River	2762_0	6/18/2003	38.7239	-106.6725	BT-2	1
7595	Del Agua Arroyo	3014_1	5/29/2007	37.3472	-104.5742	BT-3	na
WCOP99-0597	Dyer Creek	2453_0	5/21/2002	38.5928	-107.4472	BT-2	1
7997a	East Carrizo Creek	2650_1	4/7/2004	37.1354	-103.0157	BT-3	na
7999a	East Carrizo Creek	2652_1	4/7/2004	37.1685	-103.0345	BT-3	na
USFS EFH Upper	East Fork Homestake Creek	2955_1	9/18/2006	39.3559	-106.454	BT-2	1

Table 1. Reference Sites							
ID	Site Name	Sample_ Replicate	Collection Date	Latitude	Longitude	MMI Biotype	Sediment Regions
WCOP03-R009	East Fork Piedra River	2785_0	8/8/2003	37.4817	-107.0971	BT-2	1
5779B	East Plum Creek	3043_1	8/14/2007	39.1843	-104.9307	BT-2	2
10551	Escalante Creek	2524_1	9/28/2004	38.7178	-108.2686	BT-3	3
CO162M	Fernleaf Gulch	2292_0	8/25/1995	38.4069	-105.6389	BT-1	3
CO153M	Fourmile Creek	2286_0	8/24/1995	38.9661	-106.1397	BT-2	2
5772A	Garber Creek	3062_1	8/16/2007	39.3552	-105.0272	BT-1	3
CO116M	Garner Creek	2271_0	8/28/1995	38.1897	-105.7764	BT-2	1
USFS Gore 1	Gore Creek	3001_0	9/27/2004	39.6277	-106.271	BT-2	1
7226	Hardscrabble Creek	3009_1	5/30/2007	38.3434	-105.0682	BT-3	na
7130	Hayden Creek	2736_1	9/14/2005	38.3356	-105.8022	BT-1	2
CO03RS	Hope Creek	2250_0	9/21/1995	37.5531	-106.8022	BT-2	1
5771	Jackson Creek	509_1	5/30/2003	39.3457	-104.9812	BT-1	2
CO072M	Junction Creek	2243_0	8/1/1994	37.3336	-107.9094	BT-1	2
10570	Kannah Creek	3049_1	7/19/2007	38.9612	-108.2297	BT-1	3
8337	La Jara Creek	2745_1	9/28/2005	37.1775	-106.2119	BT-1	2
8715	La Manga Creek	2753_1	9/29/2005	37.1164	-106.3778	BT-2	1
10906	La Sal Creek	3091_1	9/12/2007	38.3205	-108.977	BT-1	3
CO070M	Lime Creek	2242_0	8/4/1994	37.677	-107.7509	BT-2	1
12832	Little Bear Creek	2920_1	8/16/2006	40.6888	-107.4345	BT-1	3
CO04RS	Little Cimarron Creek	2224_0	8/16/1994	38.21	-107.4636	BT-2	1
11535	Lost Creek	292_1	6/7/2000	40.0506	-107.4687	BT-1	2
WCOP99-0503	Lost Man Creek	2419_0	7/27/2000	39.1595	-106.5718	BT-2	1
CO051M	Lottis Creek	2227_0	8/17/1994	38.7725	-106.6225	BT-2	1
USFS Meadow	Meadow Creek	3003_0	9/11/2003	39.5954	-106.1237	BT-2	1

Table 1. Reference Sites							
ID	Site Name	Sample_ Replicate	Collection Date	Latitude	Longitude	MMI Biotype	Sediment Regions
CO155M	Middle Fork Brush Creek	2288_0	9/6/1995	38.9542	-106.8583	BT-2	1
10559	Middle Fork Escalante Creek	3075_1	7/18/2007	38.5812	-108.4059	BT-1	3
WCOP99-0578	Middle Fork Little Snake R.	2448_0	8/14/2001	40.9715	-107.019	BT-1	2
CO038M	Middle Fork North Crestone	2214_0	8/11/1994	38.0361	-105.6425	BT-2	1
10834	Naturita Creek	3086_1	9/11/2007	38.1591	-108.4031	BT-1	3
EPA01-249	Newlin Creek	2175_0	7/19/2001	38.2662	-105.1898	BT-2	2
WCOP99-0649	Noname Creek	2466_0	7/23/2002	39.5817	-107.2881	BT-1	3
CO142M	North Anthracite Creek	2283_0	9/13/1995	38.9817	-107.1911	BT-2	1
10558	North Fork Escalante Creek	3074_1	7/18/2007	38.6369	-108.4272	BT-1	3
10917	North Fork Mesa Creek	3065_5	9/10/2007	38.5032	-108.7904	BT-1	3
CO113M	North St. Vrain Creek	2269_0	9/14/1995	40.2047	-105.4061	BT-2	2
USFS N Tenmile	North Tenmile Creek	2961_0	9/8/2005	39.573	-106.1722	BT-2	1
WCOP99-0518	Ouzel Creek	2433_0	7/10/2000	40.1998	-105.6258	BT-2	1
7170	Pine Creek	2686_1	7/26/2005	38.9988	-106.2318	BT-2	1
USFSPIKE1	Pine Creek	2663_1	11/3/2003	39.2406	-105.2826	BT-2	2
USFS Piney 2	Piney River	2964_0	9/28/2005	39.7504	-106.4713	BT-1	2
10350	Razor Creek	3047_1	8/2/2007	38.3846	-106.6733	BT-1	na
USFS Ripple	Ripple Creek	2976_0	8/12/2004	40.0746	-107.3028	BT-2	2
11208	Roan Creek	2887_1	9/13/2006	39.5096	-108.5248	BT-1	3
10980	Roc Creek	3093_1	9/10/2007	38.4418	-108.8774	BT-3	3
7284	Rock Creek	3011_1	5/1/2007	38.208	-104.7931	BT-3	na
7571	San Francisco Creek	2541_1	8/26/2004	37.1206	-104.2614	BT-3	na
CO174M	Scott Gomer Creek	2297_0	9/11/1995	39.5081	-105.7047	BT-2	1
CO067M	Silver Creek	2239_0	8/1/1994	37.4289	-106.7589	BT-2	1

Table 1. Reference Sites							
ID	**Site Name**	**Sample_ Replicate**	**Collection Date**	**Latitude**	**Longitude**	**MMI Biotype**	**Sediment Regions**
USFS Snowmass	Snowmass Creek	2978_0	9/8/2004	39.1801	-107.022	BT-2	1
12759	South Fork Fryingpan River	2861_1	9/12/2006	39.2372	-106.59	BT-2	1
CO122M	South Fork Saguache Creek	2273_0	8/23/1995	37.9192	-106.7153	BT-2	1
7560	Trinchera Creek	2540_1	8/26/2004	37.0446	-104.051	BT-3	na
CO133M	Trout Creek	2278_0	8/17/1995	37.6661	-107.07	BT-2	1
WCOP99-0634	Ute Creek	2462_0	8/13/2002	37.5955	-105.3989	BT-2	1
10922	Ute Creek	3092_2	9/13/2007	38.7237	-108.9097	BT-1	3
11485	Vermillion Creek	2897_1	8/15/2006	40.7197	-108.7518	BT-1	na
EPA01-240	Wahatoya Creek	2167_0	7/9/2001	37.4123	-104.964	BT-2	na
8116	West Alder Creek	2703_1	8/22/2005	37.705	-106.6478	BT-1	2
USFS West Lake	West Lake Creek	2991_0	9/27/2006	39.5395	-106.616	BT-2	1
10905G	West Paradox Creek	3090_1	9/12/2007	38.3827	-108.996	BT-1	3

II Percent Fines (<2mm) and WA TIV_{SED} Thresholds Derivation

Thresholds were developed to establish maximum values for percent fines and WA TIV_{SED}. The purpose of each threshold is to identify the upper end of the expected condition, using the range of variability of values observed at reference sites. The statistical method to calculate the thresholds is a 95% Upper Prediction Limit, which identifies whether a new observation is likely from the same distribution as the dataset. A new observation (i.e. the value at a new site) that exceeds the 95% Upper Prediction Limit is not within the range values in the reference population, with 95% confidence.

The Upper Prediction Limit is the upper end of the prediction interval, and is a function of the distribution of the data, the sample size and the specified confidence level. The Upper Prediction Limit takes into account the variability of single data points around the median or mean, in addition to the error in estimating the center of the distribution (Helsel and Hirsh, 2002). Also, a smaller reference dataset results in a wider prediction interval, and correspondingly, a higher upper prediction limit. There are methods for both parametric and non-parametric confidence intervals. The sediment datasets are lognormal distributed and the WA TIV_{SED} datasets are normally distributed. The thresholds for sediment and WA TIV_{SED} were calculated using a non-parametric UPL, which can be used on datasets with any distribution.

A one-sided nonparametric UPL is computed by the following m^{th} order statistic.

$$UPL = X_{(m)}, \text{ where } m = (n + 1) * (1 - \alpha).$$

Where n is the sample size and $(1 - \alpha)$ is the desired confidence level. Each observation in the data is ranked from lowest to highest, and m identifies the ranking order for each observation. For example $m = 1$ for the lowest value and $m = 2$ for the second lowest value, etc.

For example, for a nonparametric data set of size n=25, a 95% UPL is desired. Then m = 0.95 * (25 + 1) = 24.7 and a 95% UPL can be obtained by using linear interpolation between the 24th and 25th ranked values in the data set.

II. Salmonid Fish Spawning and <8 mm Sediment Thresholds Derivation

A threshold was developed to establish a maximum value for percent fines <8 mm that will be protective of salmonid spawning habitat. While the macroinvertebrate thresholds were developed using matched macroinvertebrate community and sediment data from Colorado streams, this type of matched data is not available for salmonids. Therefore, a literature-based approach was used to develop the salmonid spawning threshold.

Measurements of particles smaller than 6.35 mm are commonly used to describe salmonid spawning gravel quality (Chapman 1988). However, the WQCD's Pebble Count Standard Operating Procedure (see Appendix B) does not include a 6.35 mm size class. The procedure does include 5.6 mm and 8 mm size classes. Therefore, the salmonid spawning threshold is based on sediment particles <8 mm.

Several studies (including, but not limited to: Koski 1966; Phillips et al. 1975; Hausle and Coble 1976; Tappel and Bjornn 1983; Chapman 1988; McHenry et al. 1994; Kondolf 2000;

Jensen et al. 2009) have shown effects on embryo survival and fry emergence when the percentage of fine sediment exceeded 10-40%. Effects were most frequently reported as significant when fine sediment approached 20%; therefore, 20% was selected as the threshold for fine sediment <8 mm.

This methodology is applicable only at sites where salmonid fish spawning is expected. Therefore, the first step is to determine whether salmonid fish spawning is expected to occur at a site. If salmonid spawning is expected to occur, the percent of sediment particles that are < 8 mm within the wetted width of the stream should be determined. Because fish can be selective of microhabitat, it is important to measure sediment deposition at the location where spawning is expected. Therefore, transects should be completed only in the riffle portion of the study reach, where spawning habitat may be present.

References

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APPENDIX G

Salmonid Spawning Percent Fines Thresholds Literature Review

1. **Bennett, D.H., W.P. Connor, and C.A. Eaton. 1993. Substrate composition and emergence success of fall Chinook salmon in the Snake River. Northwest Science 77:93-99.**

   Bennett et al. (1993) conducted field and laboratory studies to evaluate the relationship between substrate composition and Chinook salmon emergence success. The authors studied seven spawning sites in the Snake River to create appropriate substrate mixtures for the laboratory study. In the laboratory portion of the study, the authors set up 48 troughs containing six replicates of eight substrate mixtures, which were similar to the mixtures observed at the field sites. Fifty fertilized Chinook salmon eggs were placed into each of two 25 cm depressions in each test trough. Mean emergence success was 7% when percent fines were 33:15% (i.e., 33% <6.4 mm with 15% <0.85 mm). Mean emergence success was 51% when percent fines was 2:0% (i.e., 2% <6.4 mm with 0% <0.85 mm). Mean emergence success decreased from 51% to 34% when percent fines <6.4 mm exceeded 24%.

   Possible threshold: 24% fines <6.4 mm

2. **Bjornn, T.C. 1969. Salmon and steelhead investigations. Job No. 5. Embryo Survival and Emergence Studies. Federal Aid in Fish and Wildlife Restoration. Job Completion Report, Project F-49-R-7. Idaho Fish and Game Department, Boise, Idaho. December 1969.**

   Bjornn (1969) conducted a laboratory study to evaluate the effects of different amounts of sand on the survival and emergence of steelhead trout and Chinook salmon. The study included both swim-up fry and green eggs. Bjornn (1969) placed 135-137 green and 50 swim-up steelhead trout fry into study troughs containing 0, 12, 17, 31, 36, 48, and 55% sand (<6.35 mm). One hundred green and 50 swim-up Chinook salmon fry were placed into study troughs with 0, 10, 20, 30, 40, 50, and 60% sand (<6.35 mm). Percent emergence for steelhead trout ranged from 12 to 96% for swim-up fry and 1.7 to 52% for green eggs. Percent emergence for Chinook salmon ranged from 6.5 to 87.7% for swim-up fry and 1.1 to 70.7% for green eggs. Potential causes of the low survival for green eggs were handling stress, low oxygen, natural causes, and toxic materials in the water supply. Emergence success in steelhead trout fry remained above 90% until the percentage of sand exceeded 31%, at which point emergence dropped to 74%. Similarly, emergence success in Chinook salmon fry remained near 90% until the percentage of sand exceeded 17%, at which point emergence dropped to 62%.

   Possible threshold: 20% fines <6.35 mm

3. **Burton, T.A., G.W. Harvey, and M.L. McHenry. 1990. Protocols for assessment of dissolved oxygen, fine sediment, and Salmonid embryo survival in an artificial redd. Idaho Department of Health and Welfare, Division of Environmental Quality, Water Quality Bureau. Boise, Idaho.**

Burton et al. (1990) conducted field studies to evaluate the relationships between intergravel dissolved oxygen and fine sediment and the survival of salmonid embryos in artificial egg pockets in the South Fork Salmon River, Idaho. Chinook salmon embryo survival decreased rapidly and was consistently low (<10-15%) when the percent fine sediments <6.03 mm exceeded 20-25%, and no survival occurred when fines exceeded 27%.

Possible threshold: <20% fines <6.03 mm

4. **Canadian Council of Ministers of the Environment. 2002. Canadian water quality guidelines for the protection of aquatic life: Total particulate matter. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.**

"The quantity of fine sediment in streambed substrates (i.e., percent fines) should not exceed 10% <2.00 mm, 19% <3.00 mm, and 25% <6.35 mm at potential salmonid spawning sites…. These guidelines… apply to actual and potential spawning sites in streams, and were derived based on the analysis of the available data and extrapolating the value that would produce a survival rate of 80% for egg-to-fry life stages (Caux et al. 1997)."

Possible thresholds: <10% fines <2 mm, <19% fines <3 mm, and <25% fines <6.35 mm

5. **Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117:1-21.**

Chapman (1988) conducted an extensive literature review and presented results from several studies showing effects of fine sediments on salmonid embryo survival. The review evaluated redd structure and development, internal characteristics of egg pockets, effects of sediment texture, embryo survival as related to fines, and salmonid emergence. Chapman (1988) said the evidence is clear that female salmonids clean fines from the redd during redd construction, but fines move back into the redd, sometimes to the depth of the egg pockets. The review did not recommend a threshold for fine sediments, but discussed results of other studies. Three relevant studies discussed by Chapman (1988) could not be located but provided useful thresholds: Tagart (1976) – 32% Coho salmon survival to emergence when fines <20% (0.85 mm), 18% when >20% fines; McCuddin (1977) – Chinook and steelhead survival and emergence decreased when fines 6-12 mm exceeded 10-15% or fines <6 mm exceeded 20-25%; NCASI (1984) – rainbow trout survival decreased 1.1-1.3% with each 1% increase in fines (<6.4 mm) over 10-40% fines.

Possible threshold: 20% fines <0.85 mm, 10-15% fines 6-12 mm, 20-25% fines <6 mm

6. **Hausle, D.A., and D.W. Coble. 1976. Influence of sand in redds on survival and emergence of brook trout (*Salvelinus fontinalis*). Transactions of the American Fisheries Society 105:57-63.**

   Hausle and Coble (1979) conducted a study using brook trout (*Salvelinus fontinalis*) to investigate the effect of sand in spawning gravel on emergence and estimate the survival rate from egg deposition to emergence. The laboratory portion of the study to assess fry emergence utilized substrate composed of gravel and 0 to 25% sand (<2 mm). Emergence time decreased with each increasing amount of sand, with fry in 0% sand emerging first, followed by fry in 5% sand, 10% sand, 15% sand, 20% sand, and finally 25% sand. Similarly, the percentage of fry that emerged decreased with increasing sand, with percent emergence decreasing from approximately 100% in 0% sand to approximately 80% in 25% sand. The authors concluded that "Emergence of salmonid embryos is likely to be reduced from spawning gravel containing more than about 20% sand."

   Possible threshold: 20% fines 1-3 mm

7. **Jensen, D.W., E.A. Steel, A.H. Fullerton, and G.R. Pess. 2009. Impact of fine sediment on egg-to-fry survival of Pacific salmon: A meta-analysis of published studies. Reviews in Fisheries Science 17:348-359.**

   Jensen et al. (2009) conducted a review of 96 studies which evaluated the effects of fine sediment on the egg-to-fry survival of steelhead trout and Chinook, chum, and coho salmon. Fourteen studies provided sufficient data for Jensen et al. (2009) to use in developing models that described the relationship between the proportion of fines and egg-to-fry survival. The authors found that, on average, each 1% increase in percent fines <0.85 mm results in a 17% decrease in the odds of survival for all of the species evaluated. Chinook salmon and steelhead survival was reduced to less than 10% when fines <0.85 mm exceeded 25% or fines <6.4 mm exceeded 50%. Chinook salmon and steelhead survival were approximately 90%, but decreased rapidly when percent fines <6.4 mm exceeded 20-25%.

   Possible thresholds: 20-25% fines <6.4 mm, 10% fines <0.85 mm

8. **Kondolf, G.M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129:262-281.**

   Kondolf (2000) conducted a review of literature on salmonid spawning gravel quality and presented recommendations for evaluating gravel quality. Kondolf (2000) recommended different thresholds and particle sizes for different phases of fish development, with 1 mm particles restricting gravel permeability and thus affecting incubation, and 3 to 10 mm particles affecting fry emergence. Mean percent fines thresholds resulting in 50% emergence success for bull trout, coho salmon, Chinook salmon, chum salmon, Kokanee, brook trout, cutthroat trout, steelhead trout, and rainbow trout, were 14% fines <1 mm (range: 7.5 to 21%), 10% fines <2 mm, 29.5% fines <3.35 mm (range: 25 to 36%), 30.3% fines <6.35 mm (range: 20 to 40%), and 28% fines <9.5mm (range 16 to 40%).

   Possible thresholds: 10% fines <2 mm, 30% fines <3.35, 6.35, or 9.5 mm

9. Koski, K.V. 1966. The Survival of Coho Salmon (*Oncorhynchus kisutch*) from Egg Deposition to Emergence in Three Oregon Coastal Streams. Thesis submitted to Oregon State University, June 1966.

Koski (1966) conducted a field study to assess the survival of coho salmon from egg deposition to emergence in three coastal Oregon streams. Koski (1966) measured substrate sizes in three samples taken from each redd. Survival to emergence ranged from 0 to 76%, with site means ranging from 13.6 to 54.4%. Percent fine sediments <3.327 mm, which ranged from 27 to 51% of the substrate, was the parameter most correlated to emergence success. Fine sediments were inversely related to survival, with a decrease in survival observed between the 27 to 51% fines at the study sites. Because the author did not include a low-fines control site in this study, it is not possible to derive a percent fines threshold.

Possible thresholds: None.

10. McHenry, M.L., D.C. Morrill, and E. Currence. 1994. Spawning Gravel Quality, Watershed Characteristics and Early Life History Survival of Coho Salmon and Steelhead in Five North Olympic Peninsula Watersheds. Lower Elwha S'Klallam Tribe, Port Angeles, WA. and Makah Tribe, Neah Bay, WA. Funded by Washington State Department of Ecology.

McHenry et al. (1994) conducted a study in five Olympic Peninsula watersheds to assess the impacts of sedimentation on coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*) spawning and early life history. The authors placed egg baskets in artificial redds in streams to assess eggs survival under relatively natural conditions. Most sites had high levels of fine sediment <0.85 mm, likely related to historic and current logging activities. Overall, survival was highly variable, ranging from 0 to 53%. Egg survival to the eyed stage was not highly correlated with percent fines <0.85 mm, but maximum survival to eyed stage was only 13% for sites containing 10% fines or greater, suggesting a threshold effect.

The authors also described how they selected sample sites in this study. "Preference was given to known spawning redd sites, but if unavailable, then areas that met the following habitat use criteria for spawning coho salmon (Reiser & Bjornn 1979) were sampled:

(a) Water depth 0.10 to 0.53 m
(b) unarmored gravel to cobble sized substrate
(c) pool tailouts or glide habitats

Areas of deposition generally occur in low-energy environments of less than 3% gradient, typically along the sides of the channel (bars), back eddies, and pools (Jackson & Beschta 1982). These areas, especially pool tailouts, are actively selected by salmonids for incubating their eggs."

Possible threshold: 10% fines <0.85 mm

11. Phillips, R.W., R.L. Lantz, E.W. Claire, and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104:461-466.

Phillips et al. (1975) conducted a laboratory study to evaluate the impacts of eight mixtures of sand and gravel on the emergence of coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*). Study substrates contained 0 to 70% fines (sand 1 to 3 mm). Fry were released below the gravel surface and the authors monitored survival of emergent fry in each mixture. Survival of steelhead trout ranged from 99% in the control groups (0% fines) to 18% in groups with 70% sand. Similarly, survival of coho salmon ranged from 96% in the control groups (0% fines) to 8% in groups with 70% sand. Survival in the 10% fines tests was approximately 99% and 85% for steelhead and coho, respectively. Survival in the 20% fines tests was approximately 70% and 65% for steelhead and coho, respectively. At 30% fines, survival decreased to approximately 50% and 40%, respectively. The authors note that this study did not include fines <1 mm, suggesting that survival would be even lower in natural systems. Additionally, because fry were evaluated, this study did not include fines-related mortality that would be expected to occur prior to hatching.

Possible threshold: 20% fines 1-3 mm

12. Sowden, T.K., and G. Power. 1985. Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates. Transactions of the American Fisheries Society 114:804-812.

Sowden and Power (1985) studied the relationship between spawning substrates and rainbow trout (*Oncorhynchus mykiss*) embryo survival in a groundwater-fed stream. The authors monitored 19 redds in Young Creek, a tributary of Lake Erie in southwestern Ontario. Embryo survival was low, ranging from 0 to 43.5%. Percent fines <2.0 mm in redds ranged from 13.4% to 64.9%. Survival was not significantly related to the percentage of sediments <2.0 mm or the geometric-mean particle size. However, embryo survival was highest (ranging from 1.1 to 43.5%, with an average of 18.4%) when percent fines was less than 25%. When fines exceeded 25%, survival ranged from 0 to 9.6%, with an average of 1.8%. The authors observed a relationship between survival and dissolved oxygen, with survival generally higher when dissolved oxygen was greater than 5 mg/L. The relationship between substrate composition and dissolved oxygen was variable.

Possible threshold: 25% fines <2 mm

13. Tappel, P.D., and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3:123-135.

Tappel and Bjornn (1983) conducted a laboratory study to evaluate the effects of 15 experimental gravel mixtures containing various proportions of fine sediment on the survival of salmonid embryos. Two hundred steelhead trout embryos (and 100 Chinook salmon embryos in a second experiment) were placed into each treatment, with two or three replicates per treatment. The 15 gravel treatments were mixtures containing between 0 to 55% fines <9.50 mm and 0 to 19.5% fines <0.85 mm. Survival to emergence for steelhead trout and Chinook salmon ranged from 6 to 99%, with survival decreasing as percent fines increased. Steelhead and Chinook fry in treatments with high percent fines tended to emerge before yolk sac absorption was complete, indicating the embryos were under stress. The authors pointed out the importance of looking at multiple particle sizes, and found that a geometric mean particle size of at least 10 mm resulted in survival of approximately 90%. Survival decreased rapidly with decreasing geometric mean particle sizes, dropping to nearly 0 when the geometric mean particle size was 5 mm. Steelhead and Chinook embryo survival were 93% and 96%, respectively, in the control treatments (0% fines) and decreased with increasing percent fines <9.50 mm and <0.85 mm.

Possible thresholds: <12% fines <0.85 mm, <35% fines <9.50 mm

14. Weaver, T.M., and J.F. Fraley. 1993. A method to measure emergence success of westslope cutthroat trout fry from varying substrate compositions in a natural stream channel. North American Journal of Fisheries Management 13:817-822.

Weaver and Fraley (1993) evaluated the relationship between emergence success of westslope cutthroat trout and the amount of fine sediments (<6.35 mm) in a natural stream in the Flathead River basin. The authors constructed test cells with varying amounts of fine sediments and placed 50 eyed embryos in each test cell, with three replicates per treatment. Emergence success in the control treatment (0% fines less than 6.35 mm) was significantly higher than all other treatments with ≥20% fines, with 76% emergence success in the control and 39% emergence success in the 20% fines treatment. Emergence success ranged from 4% to 76% in treatments containing 50% to 0% fines, respectively.

Possible threshold: 20% fines <6.35 mm

15. Witzel, L.D., and H.R. MacCrimmon. 1983. Embryo survival and alevin emergence of brook charr, *Salvelinus fontinalis* and brown trout, *Salmo trutta*, relative to redd gravel composition. Canadian Journal of Zoology 61:1783-1792. (only able to obtain abstract)

Witzel and MacCrimmon (1983) conducted a laboratory study to evaluate the impacts of different gravel sizes and mixtures on the survival and emergence of brook charr and brown trout. The authors tested three homogenous gravels (2.7, 6.2, and 9.2 mm) and five gravel mixtures (0, 20, 40, 60, and 80% sand). Survival ranged from 0 to 20% in the treatments with 100% fines <6.2 mm and when sand ≥60%. Survival ranged from 60 to 96% in the treatments with 100% fines 9.2 mm and in mixtures with ≤20% sand. Survival increased from 2 to 96% when sand was reduced from 60 to 20%. The authors observed premature emergence in alevins in the treatments with higher fine sediments.

Possible threshold: <20% fines <2 mm

16. Habitat Suitability Index models for brook trout, brown trout, cutthroat trout, and rainbow trout:

Hickman, T., and R.F. Raleigh. 1982. Habitat suitability index models: Cutthroat trout. U.S. Fish and Wildlife Service. FWS/OBS-82/10.5. 38 pages.

Raleigh, R.F. 1982. Habitat suitability index models: Brook trout. U.S. Fish and Wildlife Service FWS/OBS-82/10.24. 42 pages.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information: Rainbow trout. U.S. Fish and Wildlife Service FWS/OBS-82/10.60. 64 pages.

Raleigh, R.F., L.D. Zuckerman, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Brown trout, revised. U.S. Fish and Wildlife Service Biological Report 82(10.124). 65 pages. [First printed as: FWS/OBS-82/10.71, September 1984].

All four Habitat Suitability Index model reports present similar information for brook trout, brown trout, cutthroat trout, and rainbow trout. The authors repeat that the presence of fines in spawning areas can adversely affect embryo survival, food production, and cover for juveniles. 30% fines will cause low embryo survival and fry emergence. Optimal spawning gravel substrate is gravel 0.3 to 8 mm with ≤ 5% fines.

Possible threshold: Between 5-30% fines <3 mm

Summary of Salmonid Spawning Percent Fines Thresholds from Literature

Reference	Species	Endpoint Evaluated	Study Location	<Particle Size (mm)	% Fines Threshold
Bennett et al. (1993)	Chinook salmon	Emergence success	WA, ID, Lab	6.4	24
Bjornn (1969)	Steelhead trout and Chinook salmon	Embryo survival and emergence success	Lab	6.35	20
Burton et al. (1990)	Chinook salmon	Embryo survival	ID	6.03	20
Canadian Council of Ministers of the Environment (2002)	Salmonids	Results in 80% embryo survival	CAN	<2 3 6.3	10 19 25
Chapman (1988)	Coho salmon Chinook salmon and steelhead trout Rainbow trout	Embryo survival	Lit Review	0.85 6 6-12	20 20 10
Hausle and Coble (1976)	Brook trout	Embryo survival and emergence success	Lab	1-3	20
Jensen et al. (2009)	Pacific salmon	Embryo survival	Lit Review	0.85 6.4	10 20
Kondolf (2000)	Trout: bull, brook, cutthroat, steelhead, rainbow Salmon: coho, Chinook, chum, Kokanee	Results in 50% emergence success	Lit Review	2 3.35 6.35 9.5	10 30 30 28
McHenry et al. (1994)	Coho salmon and steelhead trout	Embryo survival		0.85	10
Phillips et al. (1975)	Coho salmon and steelhead trout	Emergence success	Lab	1-3 (sand)	20
Sowden and Power (1985)	Rainbow trout	Embryo survival	Ontario	2	25
Tappel and Bjornn (1983)	Steelhead trout and Chinook salmon	Embryo survival	Lab	0.85 9.5	<12 <35
Weaver and Fraley (1993)	Westslope cutthroat trout	Emergence success	MT	6.35	20
Witzel and MacCrimmon (1983)	Brook trout and brown trout	Survival and emergence	Lab	2	<20
U.S. FWS Habitat Suitability Index Models (1982, 1984, 1986)	Brook trout, brown trout, cutthroat trout, and rainbow trout	Survival and emergence	Lit Review	3	5-30%