Lake Merwin and Swift Creek Reservoir Tributary Streams Bull Trout Limiting Factors Analysis

Final Study Plan

Prepared for

PacifiCorp

Prepared by

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1.0 INTRODUCTION

As a component of the Lewis River Hydroelectric Project's Settlement Agreement (Settlement Agreement), PacifiCorp has agreed to conduct a limiting factors analysis (LFA) for bull trout (*Salvelinus confluentus*) occurring in the tributaries to Lake Merwin and Swift Creek Reservoir and to finalize this evaluation in consultation with the Aquatics Coordination Committee (ACC). Section 5.5 of the Settlement Agreement states:

> *By the second anniversary of the Effective Date, PacifiCorp shall provide a limiting factors analysis for bull trout occurring in Lake Merwin tributary streams and Swift Creek Reservoir tributary streams and finalize this evaluation in Consultation with the ACC. If the Licensees, in Consultation with the ACC and with the approval of USFWS, determines that one or more locations have the potential to provide long-term, sustainable habitat for critical life stages of bull trout, the ACC may implement enhancement measures through the use of the Aquatics Fund as described in Section 7.5 below [of the Settlement Agreement].*

According to the *Bull Trout LFA Scope of Work* issued by PacifiCorp in January, 2006, the LFA should seek to answer (at a minimum) the following key questions:

1) Other than known bull trout streams associated with Merwin and Swift Creek reservoirs, do other streams exist at either project that can potentially provide long-term spawning, incubation, and rearing habitat?

2) Are the habitat conditions in each potential stream suitable for any one of the critical life stages of bull trout?

3) Do bull trout reside in these other streams?

4) Of the potential streams that do exist, what are the limiting factors that can be attributable to the absence of bull trout?

5) Are there any physical changes that can be made to potential streams lacking bull trout to provide for colonization by existing bull trout stocks?

Therefore, this study plan is designed to answer each of these questions and to develop a list of habitat enhancement measures that could be implemented to address limiting factors in those streams that have the potential to provide long-term bull trout habitat.

The approach to completing the bull trout LFA is presented below, following a brief literature summary of important bull trout habitat requirements and Lewis River basin life history timing. The literature summary provides a background on the habitat factors (abiotic interactions) that may have the greatest influence on the distribution and abundance of bull trout in the Lewis River basin. More detailed information describing general bull trout life histories and habitat requirements is available in Appendix 1 (EDT Bull Trout Species-Habitat Rules) (note that due to specific Lewis River basin characteristics, bull trout life history and habitat usage within the Lewis River basin may be somewhat different from that described in Appendix 1 (Pers. comm. J. Byrne, WDFW, July 2006).

2.0 KEY BULL TROUT HABITAT REQUIREMENTS

It is well documented in the scientific literature that bull trout have more specific habitat requirements than most salmonids (USFWS 1998; Rieman and McIntyre 1993). Habitat components that particularly influence their distribution and abundance include water temperature, channel form and stability, cover, spawning and rearing substrate conditions, and migratory corridors (natural and man-made barriers) (Dunham et al. 2001; Watson and Hillman 1997; Fraley and Shepard 1989; Goetz 1989).

2.1 WATER TEMPERATURE

Bull trout is one the most thermally sensitive salmonid species in western North America and researchers recognize water temperature as the most consistent factor influencing their distribution and abundance (Dunham et al. 2001; Hass 2001; USFWS 1998; Rieman and McIntyre 1993; Buchanan and Gregory 1997). Optimal water temperatures for bull trout have been estimated at 2 to 10°C, while temperatures above 15°C are thought to provide a thermal limitation for most bull trout populations (Fraley and Shepard 1989; Rieman and McIntyre 1996).

According to the U.S. Environmental Protection Agency (EPA) (2003), optimal bull trout growth occurs at water temperatures ranging from 8 to 12°C, spawning initiation takes place at temperatures less than 9°C, and optimal bull trout egg incubation happens at temperatures ranging from 2 to 6°C (Table 1). Bull trout egg mortality is reported to increase dramatically as water temperatures begin to exceed 8ºC (McPhail and Murray 1979; Weaver and White 1995) (Table 1). A narrow range from 10 to 12°C represents the preferred water temperatures for spawning migrations (McPhail and Murray 1979; Buchanan and Gregory 1997).

Table 1. Summary of temperature considerations for bull trout life stages.

Life Stage	Temperature Consideration	Temperature & Unit
Spawning and Egg Incubation	Spawning initiation	<9ºC (constant)[1]
	Temperature at which peak spawning occurs	<7ºC (constant)[1]
	Optimal temperature for egg incubation	2-6ºC (constant)[1]
	Substantially reduced egg survival and size	6-8ºC (constant)[1]
Juvenile Rearing	Lethal temperature (1-week exposures)	22-23ºC (constant)[1]
	Optimal growth Limited food Unlimited food	 8-12ºC (constant) 12-16°C (constant)
	Highest probability to occur in the field	12-13ºC (daily maximum)[1, 2]
	Competition disadvantage	>12ºC[2]

1 McCullough, D.A., S. Spalding, D. Sturdevant, and M. Hicks. 2001. Issue paper 5: summary of technical literature examining the physiological effects of temperature on salmonids. EPA-910-D-01-005. U.S. Environmental Protection Agency, 114 pp.

2 Sauter, S.T., J. McMillian, and J. Dunham. 2001. Issue Paper 1: salmonid behavior and water temperature. Prepared as part of USEPA Region 10 temperature water quality criteria guidance development project.

Source: EPA 2003

Although numerous field studies conducted to date suggest that juvenile and adult bull trout are uncommon in streams and rivers where water temperatures exceed 16°C for extended periods (Haas 2001; Fraley and Shepard 1989; Goetz 1989; Donald and Alger 1993; and Rieman and McIntyre 1993), recent studies in the Puget Sound region (Snohomish River) and in eastern Washington have documented adult and juvenile bull trout residing in streams with maximum daily water temperatures approaching 18°C (Goetz et al. 2004, Dunham et al. 2003). Unfortunately, there is no information available describing how frequently water temperatures can exceed 16°C before streams loose their capacity to provide long-term, sustainable habitat for bull tout.

2.2 CHANNEL FORM AND STABILITY

In addition to cool water temperatures, juvenile and resident adult bull trout are usually associated with relatively stable, perennial stream channels containing complex forms of cover, including large woody debris, undercut banks, boulders and pools (Goetz et al. 2004; Fraley and Shepard 1989; Goetz 1989). Dambacher and Jones (1997) found that seven habitat variables were significant descriptors of the presence of juvenile bull trout: (1) high levels of shade; (2) high levels of undercut banks; (3) large woody debris volume; (4) high level of gravel in riffles; (5) large woody debris pieces; (6) low level of fine sediments in riffles; and (7) low levels of bank erosion. Watson and Hillman (1997) also found a direct relationship between bull trout density, maximum pool depth, and percentage of undercut banks. Although bull trout are often found associated with large woody debris, they are known to use other forms of cover, including cobble and boulders, when wood is limited (Mullan et al. 1992; Bonneau and Scarnecchia 1998; Watson and Hillman 1997).

2.3 SPAWNING AND REARING SUBSTRATE CONDITIONS

Bull trout spawn in a wide range of substrate sizes, including sand and fine gravel, loosely compacted gravel and cobble, and large cobble (Shepard et al.1984; Shellberg 2002). In general, an increased proportion of fines in the substrate is inversely related to bull trout egg survival and emergence (Watson and Hillman 2002). However, when spawning occurs in upwelling groundwater areas, the adverse effects of sediment on eggs and emerging fry are largely negated, resulting in high survival (Bjornn and Reiser 1991; Waters 1995; Lestelle et al. 2002). Following emergence from the gravel, juvenile bull trout are found in close association with the channel bottom, often using substrate for cover (Rieman and McIntyre 1993). Low levels of fine sediments in riffles (embeddedness) and low levels of bank erosion are considered significant descriptors of the presence of juvenile bull trout (Dambacher and Jones 1997; Goetz 1997).

2.4 MIGRATORY CORRIDORS AND STREAM GRADIENT

Bull trout typically spawn in relatively low gradient stream channels (less than 2 percent) (McPhail and Baxter 1996; Shellberg 2002), though spawning has been documented in reaches with channel gradients as high as 15 percent or greater (USFWS 2000). In Rush Creek (Lewis River basin), bull trout use reaches up to approximately 11.5 percent for spawning and rearing, although the accessible reach averages approximately 8 percent (PacifiCorp and Cowlitz PUD 2004). In general, stream channel gradients in excess of 20 percent are thought to limit the distribution of all resident and anadromous salmonids, including bull trout (DNR 2002).

3.0 LEWIS RIVER BULL TROUT LIFE HISTORY TIMING

In the Lewis River basin, bull trout residing in Swift Creek Reservoir migrate into tributary streams from late May through early-August, and are believed to spawn from early August through the middle of September(PacifiCorp and Cowlitz PUD 2004; Faler and Bair 1992; Graves 1982), possibly spawning until the end of November (Pers. comm. J. Byrne, WDFW, July 2006). The population of bull trout living in Yale Lake migrates into tributary streams from the middle of August through late-September. Throughout their range, bull trout fry usually emerge from the gravel from mid-January to late February. Emigration of juveniles from the tributaries to Swift Creek Reservoir and Yale Lake is believed to occur primarily from late April to Mid-June.

4.0 STUDY PLAN APPROACH

The Lewis River bull trout LFA will include an initial “office phase” (Task 1) intended to collect and evaluate published habitat and water temperature data for the tributaries to Lake Merwin and Swift Creek Reservoir, followed by a “field phase” (Task 2) designed to fill any data gaps, further evaluate aquatic habitat conditions, and determine bull trout presence/absence in a short list of candidate streams. Then in Task 3, we will use Mobrand / Jones & Stokes’ Qualitative Habitat Assessment (QHA) analysis as a means to identify limiting factors in those streams that are found to have the greatest potential to support bull trout. A more detailed description of each of these study plan components is presented below.

4.1 TASK 1: DATA COLLECTION AND ANALYSIS (OFFICE PHASE)

During the Task 1 office phase, an initial short list of potential bull trout streams entering Lake Merwin and Swift Creek Reservoir will be developed using existing streamflow, migration barrier, and channel gradient, as these habitat factors appear to be some of the best predictors of potential bull trout use (Dunham et al. 2003; Goetz et al. 2004, Goetz 1989). The goal of this task is to minimize the amount of field work needed to identify streams that can potentially provide long-term spawning, incubation, and rearing habitat. Primary sources of information will include the data sheets developed during the *Assessment of Potential Anadromous Fish Habitat Upstream of Merwin Dam* (AQU 4) (PacifiCorp and Cowlitz PUD 2004), existing DNR stream typing information, USFS habitat surveys and water temperature data, WDFW Salmon and Steelhead Analysis Inventory and Analysis Program (SHIAPP) data, and other relevant sources.

Using this existing information and what is known about bull trout habitat requirements, each stream entering Lake Merwin and Swift Creek Reservoir will be categorized as having “optimal”, “marginal”, or “poor” bull trout potential (Table 2). A fourth category "unknown" will be applied to perennial streams that have no available habitat and water temperature data. All streams ranking from "optimal" to "marginal" and those ranking as "unknown" for a particular parameter will be carried forward to the field phase (Task 2). Only streams ranking “poor” for at least one parameter will be eliminated from further consideration and deemed not suitable for bull trout use under any habitat restoration scenario. We assume that if “optimal” and “marginal” criteria for flow, temperature, and gradient parameters are not met, there is little chance that restoration efforts will create suitable habitat for bull trout over the long term.

Table 2. Initial bull trout habitat ranking categories.

Habitat Parameter	Optimal	Marginal	Poor
Flow	Perennial	Perennial	Seasonal[1]
Gradient	≤12% (same as Rush Creek)	<20%	≥20%[2]
Water temperature (spawning) - by mid-November[3]	≤10°	≤13°	>13°C
Maximum water temperature (rearing)	≤16°C	≤18°C	>18°C

1 Based on AQU-4 study results and anecdotal information (Pers. comm. J. Byrne, WDFW, July 2006), accessible reaches for all streams listed in Table 3 are likely perennially flowing.

2 Based on AQU-4 study results, accessible reaches for all streams listed in Table 3 are <20% in gradient.

3 Spawning may occur in Lewis River tributaries through November (Pers. comm. J. Byrne, WDFW, July 2006).

It should be noted that the “optimal” water temperature and flow criteria used in Table 2 are the same as those currently being used by the U.S. Fish and Wildlife Service (USFWS) to model and map potential bull trout spawning and early rearing “habitat patches” in the Lewis River basin[1]. The more conservative “marginal” ranking included in Table 2 is designed to capture those streams that have sub-optimal habitat conditions but may be capable of supporting at least some limited bull trout spawning and rearing through enhancement. To be conservative, streams meeting both the “optimal” and "marginal" criteria will be carried forward and further assessed during the field phase (see Task 2). As stated previously, only streams ranking as “poor” for at least one parameter listed in Table 2 will be eliminated from further assessment during the field phase.

Based on a preliminary assessment of available flow, gradient, and barrier data (PacifiCorp and Cowlitz PUD 2004, AQU-4), there are at least 7 independent tributaries to Lake Merwin and 5 independent tributaries to Swift Creek Reservoir that are both accessible to bull trout and that have the potential to support long-term spawning, incubation, and rearing habitat (i.e. perennial stream channels) (Table 3). Water temperature will be monitored in all streams listed in Table 3 to further classify each

1 The USFWS was driven to use elevation and basin size as surrogates for water temperature and streamflow due to the lack of available data for most streams.

stream as "optimal", "marginal", or "poor" based on the water temperature criteria listed in Table 2 (see Task 2, Field Survey, for temperature monitoring methods).

Table 3. Independent tributaries to Lake Merwin and Swift Creek Reservoir, not known to contain bull trout, to be evaluated as part of the bull trout LFA.

Reach Name	Length of Accessible Habitat (ft)	Length of Accessible Habitat (miles)	Average Wetted Width (ft)	Average Bankfull Width (ft)	Average Gradient (%)
LAKE MERWIN					
Cape Horn Creek	1,744	0.3	13.1	23.3	6.5
Jim Creek	3,140	0.6	11.7	21.5	3.4
Indian George Creek	4,760	0.9	9.7	21.9	5.0
Buncombe Hollow Creek	4,168	0.8	6.7	10.9	3.9
M4	3,900	0.7	6.1	11.5	10.0
Brooks Creek	5,714	1.1	14.8	19.5	4.0
M14	6,507	1.2	12.0	35.7	2.5
SWIFT CREEK RESERVOIR					
Swift Creek	1,639	0.3	29.8	NS	8.4
Range Creek	3,486	0.7	19.0	45.1	8.9
S10	1,855	0.4	5.3	24.7	6.8
Drift Creek	8,506	1.6	26.7	48.1	11.2
S15	6,680	1.3	13.4	29.7	6.7

NS = not surveyed

M4, B1, M14, S10, and S15 represent code names given to tributaries that were not assigned names on USGS topographic maps (7.5 minute quadrangles).

Source: PacifiCorp and Cowlitz PUD 2004

There are four smaller tributaries entering these reservoirs (identified in the AQU- 4 Study) that ranked "poor", and are not included in Table 3. Table 4 lists streams assessed in the AQU-4 study that will be dropped from further limiting factors analysis and describes the rational for eliminating these streams.

Table 4. Streams assessed in Study AQU-4 that rank as "poor" and will be dropped from further analysis in the bull trout LFA study.

Reach Name	Length of Accessible Habitat (ft)	Average Wetted Width (ft)	Average Bankfull Width (ft)	Average Gradient (%)	Reservoir Tributary
Marble Creek[1]	40	8.2	15.2	2.0	Merwin
Rock Creek[2]	320	15.0	47.5	6.1	Merwin
Canyon Creek[3]	0	not surveyed	not surveyed	not surveyed	Merwin
Diamond Creek[4]	655	4.1	20.8	10.0	Swift

1 Marble Creek contains only 40 feet of accessible habitat downstream from a 40 foot high falls. It is highly unlikely that only 40 feet of accessible habitat, at a relatively low elevation (240 feet above sea level), would support long-term spawning and rearing habitat for bull trout.

2 The lowermost 200 feet of accessible habitat in Rock Creek has an average gradient of <1% , the remaining 150 feet of accessible habitat has an average gradient of approximately 20%. It is highly unlikely that only 200 feet of accessible habitat, at a relatively low elevation (240 feet above sea level), would support long-term spawning and rearing habitat for bull trout.

3 Numerous waterfalls located at the mouth and throughout the lower 1,000 feet of Canyon Creek block fish access into Canyon Creek from Lake Merwin.

4 Diamond Creek is a high gradient tributary to Lake Merwin (16.5% for first 200 feet, and 8% for the remaining 455 accessible feet from the mouth). Fish habitat in the accessible portion of Diamond Creek is dominated by shallow, high gradient riffles with occasional pocket pools. Cobble and small boulder are the dominant substrate types. Gravel is extremely limited. Because of its relatively short length, high gradient, and low summer flow of 0.5 cfs (observed during the AQU-4 Study, Diamond Creek appears to contain only a limited amount of salmonid habitat, and would not likely support long-term spawning and rearing habitat for bull trout.

4.2 TASK 2: FIELD SURVEY OF OPTIMAL, MARGINAL, AND UNKNOWN STREAMS

Water temperature data loggers will be deployed in all streams listed in Table 3. In relatively small tributaries (accessible habitat lengths that are less than one mile), one temperature logger will be placed at the mouth of the stream. In tributaries with accessible reaches greater than one mile in length, two temperature loggers will be deployed: one at the mouth of the stream and one in the middle of the accessible reach. The temperature loggers will be deployed in the selected tributaries in July of 2006 and data will be collect through mid-November of 2006. Temperature loggers will be set to record data once every half-hour (i.e. 48 measurements per day). Each data logger will be downloaded on a monthly basis. In addition, in the late summer, a cold water refugia survey will be conducted in each stream that will involve walking the accessible reaches and taking hand-held thermometer readings (approximately every 100 to 200 feet) to determine if any cold water refugia are present and to generally determine how the thermograph data compares with the stream temperature profile during the warmest period in late summer.

If water temperature data indicates that a stream is too warm during the summer bull trout rearing period (i.e. exceed the 18°C daily maximum “marginal” criteria), the stream will be dropped from further analysis. The stream will also be dropped from further analysis if water temperatures remain high (over 13°C daily maximum) throughout the bull trout spawning period (mid-September to mid-November).

For all streams that remain in the “optimal” and “marginal” categories, field data will be gathered on a suite of other habitat factors (environmental attributes) that could potentially be addressed to promote long-term spawning, incubation, and rearing habitat. Besides temperature, habitat components that particularly influence bull trout distribution and abundance include cover, channel form and stability, spawning and rearing substrate conditions, and migratory corridors (Fraley and Shepard 1989; Goetz 1989; Watson and Hillman 1997). The environmental attributes evaluated in the field will be the same as those needed to populate a QHA. A qualitative assessment of potential limiting factors will also be completed for each candidate stream and the percentage of the stream in which the factor is limiting will be documented. Appendix 2 identifies the environmental attributes that will be assessed in the field for all streams initially ranked as “optimal” and “marginal”. In addition, prior to the field habitat surveys, we will have a brief meeting with agency participants to identify the final habitat attributes to survey in the field and to include in the QHA analysis of limiting factors.

Habitat surveys will be scheduled for late-September/early-October, coinciding with the peak bull trout spawning period in the Lewis River basin. An added benefit associated with the timing of these surveys is that they may lead to identification of bull trout redds in candidate streams not previously known to support bull trout. A barrier survey will also be conducted during the fall in the drawdown zone portion of stream channels to determine if any barriers are exposed that would preclude adult bull trout from migrating upstream to spawn in particular creeks that may be suitable for spawning and rearing.

In addition to completing the Task 2 habitat surveys, bull trout presence/absence surveys will be conducted in the candidate streams. The presence/absence surveys will be based on guidance presented in the Western Division of the American Fisheries Society's document "Protocol for Determining Bull Trout Presence" (Peterson et al. 2002), and will be designed to meet the desired 80 percent power of detection. The level of effort and the sampling method will be similar to that used in Siouxon Creek in September of 2003. Each individual tributary system will be considered an individual sample frame. For the presence/ absence surveys, night snorkeling will be used; however, if a stream is generally too shallow to snorkel or if night snorkeling presents safety concerns, then electrofishing will be used following the AFS (2002) protocol methods. During the presence/absence survey, as soon as one bull trout is encountered in a particular stream, the survey will cease as presence will have been established.

4.3 TASK 3: QHA ANALYSIS

Following completion of the field phase, the QHA technique, led by Mobrand / Jones & Stokes (see Appendix 2), will be used to conduct a limiting factors analysis on each stream examined with "optimal" or "marginal" potential. QHA provides a structured, "qualitative" approach to analyzing the relationship between a given fish species and its habitat. It does this through a systematic assessment of the condition of several aquatic habitat attributes (sediment, water temperature, etc.) that are thought to be key to biological production and sustainability. Habitat attribute findings are then considered in terms of their influence on a given species and life stage.

QHA relies on largely qualitative habitat survey data combined with the expert knowledge of natural resource professionals with experience in a given local area to describe physical conditions in the target stream and to create an hypothesis about how the habitat would be used by a given fish species. The hypothesis is the "lens" through which physical conditions in the stream are viewed. The hypothesis consists of weights that are assigned to life stages and habitat attributes, as well as a description of how reaches are used by different life stages. These result in a composite weight that is applied to a physical habitat score in each reach. This score is the difference between a rating of physical habitat in a reach under the current condition and a theoretical "reference" condition. Ratings for life stages and habitat attributes will be developed in consultation with the agency participants, as the rating process relies heavily on local expert knowledge.

QHA produces a series of tables that (1) describe the physical habitat, (2) establish an hypothesis concerning how species interact with the natural environment, and (3) identify where restoration and/or protection activities may be the most productive. Taken as a whole, these tables offer a means to focus the attention of biologists and planners and track the decision process.

The ultimate result is an indication of the relative restoration and protection value for each reach and habitat attribute. QHA also provides a means to compare restoration and protection ratings to other biological and demographic information of the user's choosing. QHA includes features for documenting the decision process and describing the level of confidence that users have in the various ratings.

A complete description of the QHA method is included as Appendix 2.

4.4 TASK 4: PREPARE DRAFT AND FINAL BULL TROUT LFA REPORT

The information collected in tasks 1 through 3 will be compiled in draft and final reports that will be distributed to the ACC for review and comment. The reports will include a brief introduction, a detailed methods description, the results of each task, and a discussion that includes the categorization of each stream, a ranked list of limiting factors in the "optimal" and "marginal" streams, the results of the bull trout presence/absence surveys, and a description of potential restoration and/or protection activities that may be the most productive. In addition, the final report will include a discussion of how this bull trout LFA is related to the bull trout habitat assessment conducted on Yale Lake tributary streams. Both the draft and final reports will be submitted to the ACC according to the schedule presented in Section 5.0 of this study plan.

5.0 PROPOSED SCHEDULE

The proposed schedule for the Lewis River bull trout LFA is presented in Table 4.

Table 5. Proposed bull trout LFA schedule.

Action	Date (YR 2006)
1. Draft study plan to the ACC	April 13
2. Final study plan to the ACC	May 15
3. Meeting with agency participants to finalize attributes of habitat survey	September 29 (tentative)
4. Data collection and analysis	May 20 – November 30
5. Meeting with agency participants to rate QHA parameters	October 15 (tentative)
4. Draft report to the ACC	December 15
5. Final report to the ACC	January 31 (2007)

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Appendix 1

*Ecosystem Diagnosis and Treatment (EDT)
Bull Trout Species-Habitat Rules*

MOBRAND BIOMETRICS, INC.

Species-Habitat Rules

Bull Trout

In Ecosystem Diagnosis and Treatment (EDT)

2004

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Species-Habitat Rules for Bull Trout in Ecosystem Diagnosis and Treatment (EDT)

By Lawrence C. Lestelle, Gregory R. Blair,
Lars E. Mobrand, and Willis E. McConnaha

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Chapter 1
Introduction

Natural resources managers need to understand the ways in which the quality and quantity of different habitats affect the performance of salmonid populations. Concerns about salmonid species and stocks at risk have prompted wide consideration of the effects of land use practices on habitat. While broad patterns of land use and environmental conditions can generally be correlated with population abundance (Pess and others 2002; Feist and others 2003), this knowledge is often inadequate for the needs of decision makers and watershed planners.

Those charged with managing watersheds and fish populations need far more specific information about fish population responses to different actions within a watershed. Specific information on spatial and temporal variation in habitat quality and quantity is necessary if managers are to effectively evaluate the outcomes of different strategies and actions. They must weigh trade-offs between different scenarios involving future development and devise scientifically accountable and cost effective solutions to management of freshwater systems.

Ecosystem Diagnosis and Treatment (EDT) was developed to provide such information for decision makers. EDT provides a diagnosis of current environmental constraints in a system and allows managers to explore alternative habitat restoration strategies. The method uses species-specific rules that relate environmental conditions in freshwater to life stage survival responses of salmonid fishes. The rules are one part of the modeling procedure to characterize habitat conditions in a stream and to assess how anthropomorphic changes to the environment constrain species performance. The general process for application of the EDT to watershed planning is explained in Lichatowich and others (1995). EDT species-habitat rules have been developed for most anadromous species of Oncorhynchus (Lestelle and others 2004). Using these rules, EDT has been successfully applied to most streams in the Columbia River and western Washington.[1]

This document explains the rules and information structure for EDT with specific application to bull trout (*Salvelinus confluentus*). It is divided into four major chapters:

[1]/ Go to http://www.mobrand.com/MBI/edt.html for more information on EDT.

1. Introduction
2. Review of Bull Trout Performance in Relation to Biotic and Abiotic Factors
3. Conceptual framework
4. Highlighted survival factors and examples of rules

Chapter 2 provides a brief overview of bull trout biology and life history, followed by summaries of the major biotic and abiotic issues affecting bull trout performance described in the literature. The species-habitat rules for bull trout presented in this document were formulated to address these issues.

Chapter 3 describes the framework used in EDT—how knowledge (information) is structured in the form of rules that assess species-specific survival responses to environmental conditions. The rules, which are based on knowledge contained in the literature, should be thought of as hypotheses about the ways in which biotic and abiotic components of habitat affect survival.

Chapter 4 contains descriptions of the rules associated with selected life-stage survival factors for bull trout. The complete rule set is large; therefore, only a subset of those rules is presented here—specifically, those rules that address key issues that are raised in Chapter 2. Examples of expected survival responses are included.

The rules presented in this document address survival responses of bull trout to conditions in riverine environments; they are not intended for lake environments, particularly large lakes and reservoirs. The unique issues confronting bull trout in the large lakes of Idaho and Montana would best be addressed through a specially formulated rule set—similar to the set of Chinook and coho rules that were developed specifically for application in the Lake Washington system.

The rules in EDT are hypotheses based on the scientific literature and expert knowledge. Their ability to produce useful and accurate representations of salmonid habitat potential has been demonstrated throughout the Pacific Northwest. The documentation of the EDT rules is intended to encourage a continued dialogue between EDT practitioners and scientists regarding species-habitat relationships for salmonid fishes, resulting in review and refinement of the rules and EDT structure.

Chapter 2
Review of Bull Trout Performance in Relation to Biotic and Abiotic Factors

The biological rules were formulated to address key issues that affect bull trout (*Salvelinus confluentus*) performance, as identified in the literature. This chapter begins with a brief overview of bull trout biology and life history to provide context. The key issues are grouped for description into biotic and abiotic factors. And, finally, a synthesis of issues is presented in order to inform an understanding of the rule examples given in Chapter 4.

2.1. The Effect of Scale and Stream Size

It is helpful to consider different scales at which habitat affects salmonid performance. A hierarchy of spatial scales for stream habitat, reflecting different processes and controls on channel morphology, includes (from largest to smallest) geomorphic province, watershed, valley segment, channel reach, and habitat or channel unit (e.g., pool-riffle) (Frissell and others 1986; Montgomery and Buffington 1998). Each level in the hierarchy corresponds to a distinct spatial scale—from hundreds of square kilometers, to kilometers, to meters, to centimeters.

The biological rules within EDT are formulated for the valley segment and channel reach scales within a framework of the river continuum concept (Vannote and others 1980).[2] The EDT biological rules allow for rule shifts along the continuum of stream sizes.

2.2. Distribution, Biology, and Life History

The range of bull trout extends from the upper Klamath Lake basin in southern Oregon to the headwaters of the Yukon and Mackenzie rivers in the Alaskan panhandle and northern British Columbia and Alberta (Behnke 2002). In Pacific Coast drainages, bull trout occur in rivers in British Columbia, Puget Sound, and the Olympic Peninsula; they occur in the Columbia River basin where conditions are suitable.

The biology and general life history of bull trout are characteristic of chars (Rieman and McIntye 1993). Bull trout are found in habitats similar to those used by Dolly Varden and introduced brook trout. Bull trout spawn in August

[2] The river continuum concept proposes that structural and functional characteristics of the river system progressively shift in a downstream direction with increasing stream size.

through November (when falling water temperatures reach 5–9 °C); embryos incubate over winter; hatching occurs in late winter or early spring; and following emergence, the fry remain closely associated with the substrate for an extended period.

Like other char, bull trout exhibit multiple life history forms and complex age structures, behavior, and maturation schedules; they have one of the most diverse sets of life histories among salmonids. Two distinct forms exist throughout their range—resident and migratory—that are further categorized (after Leary and others 1991; WDFW 2000):

- *Anadromous* – A sea-run form occurs in coastal areas with spawning and juvenile rearing in coldwater tributaries; most growth occurs in salt water after initial juvenile rearing of several years in freshwater. Subadults and adults make frequent migrations into and out of lower mainstem rivers and estuaries. Mature adults range from 45 to 76 cm in length.
- *Adfluvial* – This form is similar to the anadromous form, although major growth occurs in lakes and reservoirs instead of the marine environment following emigration from tributaries. Mature adults range from 50 to 81 cm in length.
- *Fluvial* – Spawning and early rearing in this form occur in smaller tributaries, with major growth and maturation in mainstem rivers. Individuals typically move randomly throughout a river system (although the opposite has been found in some rivers—see below), and then congregate near spawning streams in the summer. Mature adults are somewhat smaller than the other migratory forms, ranging from 40 to 66 cm in length.
- *Resident* – All life stages in this form are spent in small headwater streams, often upstream of impassable barriers. Mature adults vary from 15 to 38 cm in length, although they are seldom larger than 30 cm. They have been found in some cases to mix and interbreed with migratory forms unless physically separated by barriers. Some authors distinguish between a resident-residual form (the result of population fragmentation) and a true resident form that is non-migratory (e.g., Shellberg 2002).

Although, resident and migratory forms can co-exist, it is not clear whether they represent single or multiple populations (Rieman and McIntrye 1993).

The evidence for homing in bull trout is contradictory, according to McPhail and Baxter (1996) who suggest that the degree of homing may be variable—related to stream size and stability (or presence) of habitat and flow from year to year. Bull trout that spawn in larger, more stable, streams may home with a higher degree of fidelity. Others (e.g., Costello and others 2003) have concluded on the basis of evidence, including DNA variation, that bull trout show strong spawning site fidelity. Except for spawning migrations, fluvial bull trout adults in some rivers have been found to occupy relatively small home ranges to which they appear to have strong fidelity prior to and following their spawning migration, e.g., Blackfoot River, Montana (Swanberg 1997) and McLeod River, Alberta (Carson 2001).

Food abundance is an important influence on life history. Growth can vary dramatically depending on form, strongly affecting population productivity. The resident form matures as early as age 3, while the other forms typically mature when they are between 5 and 7 years of age (Rieman and McIntyre 1993). Once mature, they may spawn each year or in alternate years. The larger life history forms can be long-lived—often living to 10 years and, under exceptional circumstances, 20 years or more (McPhail and Baxter 1996).

Bull trout are considered to be particularly vulnerable to human-induced factors. The influence of species introductions and habitat perturbation on population structure is an on-going topic of research (e.g., Dunham and Rieman 1999; Costello and others 2003).

2.3. Biotic Interactions

Biotic interactions can be grouped into five factors: interspecific competition, intra-specific interactions, hybridization, availability of forage, and harvest. This section describes the primary issues associated with each factor.

2.3.1. Inter-specific competition

Although there is evidence that bull trout compete with other native salmonids for food and living space, the extent of interactions is likely low due to resource partitioning (Rieman and McIntyre 1993). Underwood and others (1995), however, found that supplementation with steelhead and spring Chinook negatively affected growth of bull trout juveniles in southeast Washington; we assume that this, in turn, affected survival.

The extent of competitive interactions with non-native species present can be high (Rieman and McIntyre 1993). Introduced rainbow trout and brown trout have been associated with a decline of bull trout populations in some areas. Lake trout, introduced into large lakes of northern Idaho and western Montana, adversely affected native bull trout through both competition and predation.

Non-native brook trout compete for the same food and space utilized by bull trout. The habitats and prey of both species closely overlap when they inhabit the same area. Gunckel and others (2002) found that brook trout dominated bull trout in 75% of the enclosures used to study inter-specific competition. The aggressive behavior and shorter generation time of brook trout, in combination with hybridization, suggest that brook trout will eventually outnumber and dominant bull trout in many streams where they co-exist.

2.3.2. Intra-specific interactions

A large body of literature demonstrates the importance of intra-specific competition among stream dwelling salmonids (e.g., Chapman 1966; Allen 1969; Grant and Kramer 1990), including bull trout (e.g., Paul 2000). Our highlighting intra-specific interactions here is not due to our use of the concept of intra-specific competition represented through an asymptotic (Beverton-Holt) stock-production relationship. We apply that concept as a standard feature in EDT modeling of salmonid performance.

Evidence exists for inter-cohort interactions within bull trout populations (i.e., between age groups) (McPhail and Baxter 1996; Paul 2000; Paul and others 2000). These interactions, which appear to be associated with competition for food but may also be due to cannibalism by older fish on younger fish, result in a cyclic pattern of abundance—the stock-production relationship exhibiting a spiraling pattern of abundance, as one age group is affected by others (Figure 1, from Paul and others 2000). In contrast, a standard Beverton-Holt stock-production model produces dynamics in which the population approaches an equilibrium monotonically leading to a single asymptotic curve. Paul and others (2000) suggest that three or more years of juvenile development is needed to produce this effect and they hypothesize that bull trout spawned in small unproductive systems, where juveniles typically rear for three or more years, experience such an effect. Evidence from field studies is given.

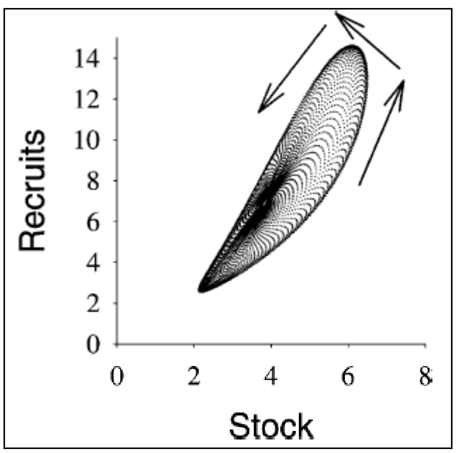

Figure 1. Stock-recruit (or stock-production) relationship reflecting effects of inter-cohort interactions in a bull trout population. The original equilibrium (center) spirals outward, following perturbation, until the outer stable orbit is reached. Taken from Paul and others (2000).

2.3.3. Hybridization

Hybridization between bull trout and brook trout appears to be a problem when distributions overlap, with both species likely to spawn at approximately the same time and place. Most bull trout–brook trout hybrids are males and may be sterile (McPhail and Baxter 1996). Hybridization could eliminate a bull trout population, particularly for resident populations (migratory bull trout may have a reproductive advantage over resident brook trout) and for populations of small bull trout, which tend to have high hybridization rates.

Bull trout and Dolly Varden also hybridize in areas of geographic overlap, as seen in some parts of the Skagit River system. In these cases, there is evidence of introgression (fusion of genomes) between the two species, tending to favor one species or the other depending on habitat conditions. McPhail and Baxter (1996) describe these situations as "complex."

2.3.4. Forage availability

Bull trout diet varies widely between life stages and life history forms. Small juvenile bull trout feed primarily on aquatic insects near the stream bottom and in the water column. As they grow, juveniles shift their diet, consuming fish typically when they reach about 110 mm in size (Shepard and others 1984b). McPhail and Baxter (1996) reported that a 90 mm bull trout in a small Skagit River tributary contained a 45 mm rainbow trout.

Bull trout grow rapidly once they emigrate to areas with abundant forage that include fish. Fish eating bull trout within streams feed on a variety of native and introduced species, appearing to have a propensity for sculpins, mountain whitefish, and salmonids. And as noted previously, they are also cannibalistic.[3] Anadromous and adfluvial forms encounter abundant fish prey when they enter the marine or lake environment. The distribution of bull trout in rivers is associated with the distribution of potential prey. Vigorous populations require abundant fish prey; the decline of bull trout in some areas followed the decline of forage species, such as salmon (Rieman and McIntyre 1993).

2.3.5. Harvest, harassment, and poaching

Bull trout have a reputation for being particularly vulnerable to angling and poaching due to their voracious nature and tendency to aggregate near spawning tributaries during summer (McPhail and Baxter 1996; Long 1997). They can be extremely easy to catch compared to other native and non-native species (author's personal observations). Sullivan (1997) describes an example of their vulnerability in a sub-alpine Alberta lake having a 10.3 ha surface area. He reported that 21% of the population could be caught with an effort of 1 angler-hour/ha. He concluded that such vulnerability in area lakes would result in over harvest even under catch-and-release regulations.

2.4. Habitat Relationships (Abiotic Interactions)

The primary habitat relationships (abiotic interactions) that affect bull trout performance can be categorized into seven groups of factors: channel stability, sediment, cover and structure, habitat types, water temperature, flow, and migration barriers. Following our review of these groups, we note several others factors, grouped simply as "Other Issues."

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[3]/ This author (L.C. Lestelle) cannot avoid telling a fishing story here to illustrate the cannibalistic nature of bull trout. While angling in the upper Queets River on the Olympic Peninsula in extremely turbid water due to glacial melt, I hooked and was retrieving a small bull trout approximately 225 mm in length. Heralded by a sudden, large surface disturbance, a much larger bull trout adult attacked and consumed the fish I was retrieving. Now retrieving the large fish, I had it nearly captured when it coughed up the smaller fish and swam away. I finished retrieving the smaller fish, still alive. I measured it and released it. I estimated the larger fish to be in excess of 700 mm in length.

2.4.1. Channel Stability

Bed scour and channel instability can affect survival of incubating and young bull trout. Incubation, which begins in late summer, is often prolonged due to very low water temperatures throughout the winter. After emergence, fry remain in close association with the substrate, hidden in gravel interstices. This prolonged period of association with the substrate during fall, winter, and spring suggests that the species can be particularly vulnerable to bed instability. Rieman and McIntyre (1993) anticipated that watershed disturbance leading to changes in flow rates and loss of habitat complexity would increase bull trout losses through channel instability.

Shellberg (2002) reported that for streams in western Washington having high flows during fall and winter, bull trout redds were scoured in reaches lacking features that protect against instability (e.g., side channels and stable LWD). He also found bull trout redds to be more vulnerable to scour in areas where timber harvest practices and road building have influenced runoff rates. He concluded that loss of LWD and channel simplification have increased the probability for redd scour in some streams.

Schuett-Hames and Adams (2003) found the depth of bed scour in salmonid spawning tributaries of the upper White River (western Washington) to be a function of peak flow (Figure 2). They projected significant egg losses for spring Chinook due to bed scour. They also reported that channel simplification and loss of stable LWD appears to have increased the extent of bed scour at specific flow levels in those streams. Furthermore, peak flows appear to have increased as a result of timber harvest and road building.

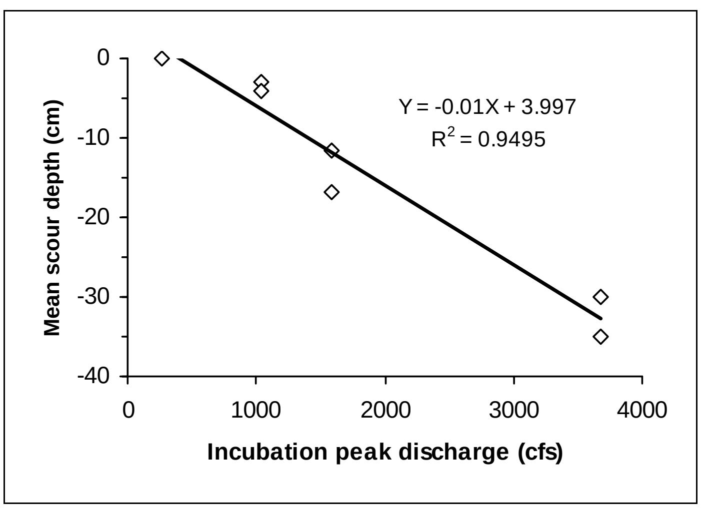

Figure 2. Relationship between mean scour depth at spring Chinook redd sites (averaged by reach) and peak flow during incubation period in a spawning tributary of the upper White River, western Washington. The White River drains the north slopes of Mt. Rainier. Adapted from Figure 6 in Schuett-Hames and Adams (2003).

2.4.2. Sedimentation

Increased sediment loading can increase the amount of fine sediment within and on the streambed and reduce pool depth, which can, in turn, affect the survival of incubating eggs and alevins within the substrate and of rearing bull trout. Early work on the effects of sediment on bull trout eggs and alevins suggested that bull trout might be less sensitive than salmon species (Shepard and others 1984a; Weaver and White 1985); however, subsequent research indicates otherwise.

Weaver and Fraley (1991) found that increasing fine sediment within the substrate reduced survival to emergence for bull trout (Figure 3). Research on other salmonid species found survival remaining high across a range of low percentages of fines in field studies (e.g., Koski 1966; Koski 1975; Tagart 1984) and lab studies (e.g., Tappel and Bjornn 1983; Irving and Bjornn 1983). Weaver and Fraley's (1991) findings suggest that bull trout are generally more sensitive to fine sediment intrusion during incubation than other salmonids at low concentrations of fines (at least when the dominant fine sediment size is sand sized, i.e., 1-6 mm).

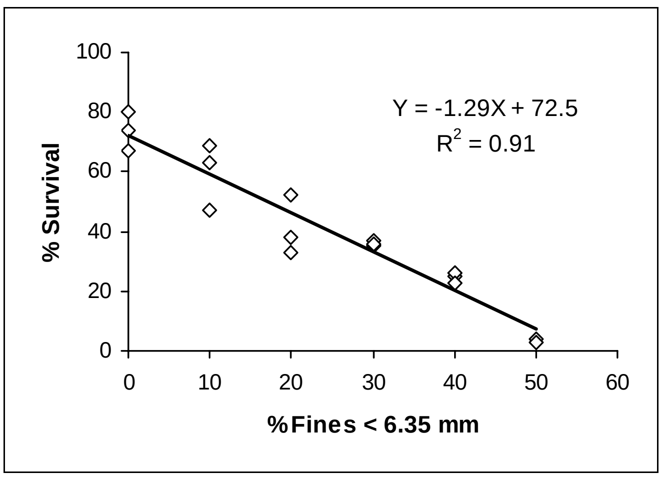

Figure 3. Relationship between percent of substrate <6.35 mm in size and percent survival to emergence of bull trout in a field experiment in the Flathead River basin, Montana. Adapted from Figure 4 in Weaver and Fraley (1991).

It should be noted that the relationship in Figure 3 is linear across the range of fine sediment composition values shown. The relationship published by Tagart (1984) for coho salmon in streams of the Olympic Peninsula, on the other hand, is curvilinear across the range of fines examined (Figure 4). The EDT biological rules for salmon and steelhead have drawn heavily on Tagart's relationship.

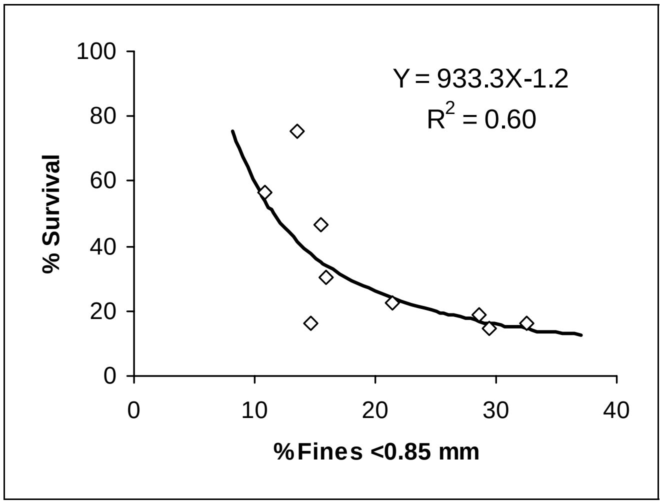

Figure 4. Relationship between percent of substrate <0.85 mm in size and percent survival to emergence of coho salmon in the Clearwater River, Washington. Adapted from Figure 2 in Tagart (1984).

The difference in the biological factors represented by these two relationships (shown in Figures 3 and 4) warrants closer attention.

Weaver and Fraley, whose linear relationship is tied to particle sizes <6.35 mm, reported that entombment appeared to cause the majority of losses in their study. Entombment occurs when sediment particles sufficiently block interstitial voids in the substrate, impeding fry emergence to the water column above. Sand sized particles (1-6 mm in diameter) are apparently more difficult for fry to move through than smaller fines when attempting to emerge (studies cited in Kondolf 2000). For bull trout in sand affected substrates, therefore, it appears that entombment operates linearly as a function of sand concentration until virtually 100% loss occurs. Similarly, linear relationships between percent sand sized particles and survival to emergence have been reported for naturally spawning coho salmon, with little or no reduction in survival occurring until a threshold in sand percentage was reached (Koski 1966), and chum salmon (Koski 1975).

Tagart (1984), whose relationship is tied to fines <0.85 mm, found that mortality was likely due to poor oxygenation resulting from sedimentation. He suggested that dissolved oxygen within redds is inversely related to intragravel fines: small increases in fines within the intermediate range of values (12-20%) produced a rapid decline in survival. At higher levels of fines, the rate of decline in survival slowed substantially, suggesting that egg pocket structure affords some protection against further degradation as fines (<0.85 mm) within the surrounding redd environment increase to higher levels. Chapman (1988) also predicted that egg pocket structure within natural redds would afford such protection.

Bed scour prior to fry emergence can ameliorate the effects of sand sized particles on survival to emergence.[4] Entombment can be reduced if the top stratum of gravel (above the egg pocket) is scoured, removing sand laden substrate that could potentially prevent fry from emerging.

The relationship given by Weaver and Fraley is useful for characterizing survival to emergence for bull trout in streams where the dominant size fraction of fines is sand sized. In streams where most fines are smaller (i.e., <1 mm), a relationship like that presented by Tagart is probably more representative of survival. Kondolf (2000) recommended differentiating survival patterns in streams dominated by fines <1 mm versus those with sand sized particles (1-6 mm) due to different mechanisms of mortality.

Gravel cleaning by adult salmonids building redds may complicate assessment of the effects of fine sediment on survival to emergence (Chapman 1988). And, in many streams in managed watersheds of the Pacific Northwest, fine sediment appears to reinvade redds of fall spawning species so that percentage fines attain levels comparable to pre-spawning conditions. This situation has been described for Kennedy Creek, a Puget Sound lowland stream (Peterson and others 1994) and for the Grande Ronde River in northeast Oregon (Rhodes and Purser 1998). Timing of runoff affects the likelihood of reinvasion by fine sediments (Kondolf 2000).

The relationships between fines and survival described above apply where flow through the redd is downwelling. None of the study streams (including those reported by Koski) are strongly influenced by springs; therefore, downwelling would characterize flow through the redds in all of the studies discussed earlier (see Bjornn and Reiser 1991; Waters 1995; Baxter and Hauer 2000).

In streams fed largely by springs, salmonid spawning is usually associated with upwelling due to the groundwater influx occurring through a reach (Figure 5). When spawning occurs in upwelling groundwater, the adverse effects of sediment on eggs and emerging fry are largely negated, resulting in high survival, provided the groundwater is not low in dissolved oxygen (Bjornn and Reiser 1991; Waters 1995; Garrett and others 1998). Spawning areas at these locations can be very high in fines. Both brook trout (Waters 1995) and bull trout (Shellberg 2002) are known to spawn sometimes at very sandy sites; we assume these are upwelling sites. If springs fed streams are available, bull trout apparently spawn there at a higher rate than in other areas (Shepard and others 1984; Goetz 1997b; James and others 1997). Survival benefits in such areas would accrue due to reduced effects of fine sediment, cold water temperature amelioration, and reduced potential for scour.

[4]/ The role of bed scour on ameliorating sediment effects on STE was discussed at the bull trout biological rules workshop held in Missoula, MT on November 21, 2002, attended by Brad Shepard, Tom Weaver, Clint Muhlfeld, Chris Frissell, Craig Barfoot, and Larry Lestelle.

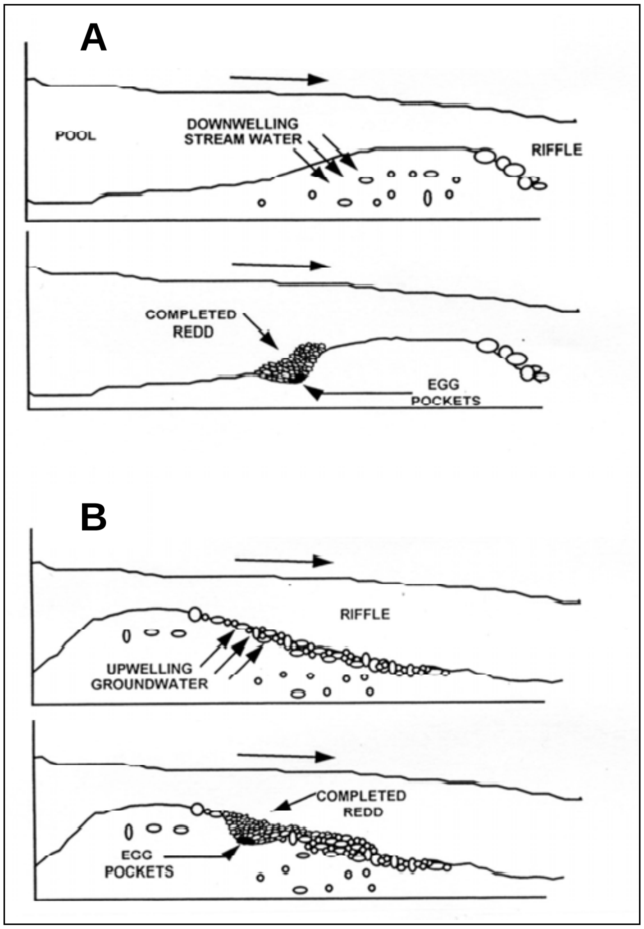

Figure 5. Salmonid redd construction in relation to sites of downwelling and upwelling. Taken from Waters (1995).

The factors that affect the choice of spawning location by bull trout, relative to downwelling or upwelling sites, are not clear, aside from the fact that spawning occurs where springs are abundant. Some additional consideration of these factors is needed because of the significant differences that can occur in incubation survival between the two types of flow through redds.

Upwelling of hyporheic (subsurface) flow can occur at various locations along a stream channel depending on underlying bedrock formations and encroaching canyon walls. The hyporheic zone is generally defined as the interface between surface channel water and groundwater (Edwards 1998).[5] Hyporheic water is a mixture of the two; the relative quantities of each within the zone vary depending on location, river hydrology, and geomorphology.

When a stream channel contains alternating confined and unconfined segments associated with knickpoints (sudden changes in gradient), the hyporheic zone has been described as resembling a giant string of pearls (Stanford and Ward

[5]/ Definitions of groundwater and surface water for defining the hyporheic zone for this discussion are taken from Edwards (1998): groundwater is subsurface water that has not yet entered a surface flow channel, and surface water is water that has entered the stream channel directly, as rainfall or surface runoff, or indirectly as groundwater.

1988). The size of the zone alternates between large and constricted along the segments. A large volume of hyporheic downwelling occurs where the channel changes from confined to unconfined. The reach in this area loses surface flow. At the downstream end of the unconfined valley segment, water upwells into the surface causing the reach to gain flow. The entirety of the unconfined segment, which is bounded at both the upstream and downstream ends, has been called a bounded alluvial valley segment (BAVS). These valley segments possess complex patterns of hyporheic exchange with surface flow and extensive upwelling zones.

Baxter and Hauer (2000) found that bull trout tended to select reaches for spawning within zones of hyporheic groundwater discharge within BAV segments. These reaches possess relatively stable thermal and flow regimes believed important to incubation success. However, at the pool-riffle scale instead of the larger reach scale, they found that bull trout selected sites of downwelling flow. These sites, located on pool tailouts formed at the heads of riffles, possessed localized downwelling conditions despite existing within an upwelling zone seen at a larger scale.

The extent of bounded alluvial valley segments within a drainage is influenced by past glaciation (Baxter and Hauer 2000). These features create deep hyporheic flow pathways that can influence the distribution of bull trout spawning, as seen in alluvial river systems of the northern Rocky Mountains and the intermountain west. In contrast, hyporheic exchange in non-glaciated stream systems of northeastern Oregon appears to occur only at shallow, small spatial scales (Baxter and Hauer 2000), and hence may not be as influential on distribution and incubation success as in those with stronger hyporheic interactions.

Fine sediment can affect other life stages besides egg and alevin incubation. Embeddedness describes the extent that interstitial spaces between cobble and gravel on the substrate surface is filled with fine particles. Juvenile bull trout use the voids between cobbles as hiding cover during both summer and winter. It is well documented that the capability of the substrate to hold juvenile salmonids as hiding cover diminishes as the substrate becomes more embedded (Bjornn and Reiser 1991), implying that overall habitat quality during associated life stages declines with sedimentation. Rieman and McIntyre (1993), Dambacher and Jones (1997), and Goetz (1997a) list embeddedness has having the potential for significantly affecting bull trout performance.

Fine sediment carried in suspension can also affect bull trout juveniles, sub-adults, and adults. High amounts of suspended sediment can affect behavior and physiology, resulting in poor feeding conditions, stress, and reduced survival (Newcombe and Jensen 1996). High suspended sediment loads occur naturally in many glacial river systems, as well as being caused by some land use practices, notably mining.

2.4.3. Cover and Structure

Bull trout are often associated with complex forms for cover and with pools. In drainages along the Cascade Mountains of Washington and Oregon, Goetz (1997b) found bull trout juveniles most often associated with in-channel wood, substrate, or undercut banks (Goetz 1997b). He found the highest densities in larger, complex habitat units. The highest pool and side channel densities occurred in complex units with a large amount of woody debris cover. Bull trout have been reported to be associated with complex cover by Shepard and others (1984b), Rieman and McIntyre (1991), Johnson (1991), McPhail and Baxter (1996), Bonneau and Scarnecchia (1998), and Rich and others (2003). Both juveniles and adults have been found in close association with cover. Bull trout juveniles are associated with cover during summer and winter.

Although bull trout are often found associated with wood, they can use other forms of cover, especially cobbles and boulders, when wood is lacking (Mullan and others 1992; Bonneau and Scarnecchia 1997; Watson and Hillman 1997).

A number of recent multiscale studies demonstrate that factors operating at both local and landscape scales interact to influence the suitability of habitat for stream biota (e.g., Baxter and Hauer 2000; Rich and others 2003). The influence of different scales led Watson and Hillman (1997) to conclude that there was a high degree of variability in the habitat factors, including types of cover, that affect bull trout performance between basins based on correlation analysis. A problem with this type of analysis performed by Watson and Hillman is that many remaining populations of native salmonids occur as fragmented populations isolated in headwater tributaries (Rich and others 2003). Many of these populations exist at low population densities and likely have uneven distributions within the inhabited streams. Rich and others (2003) assessed the influence of local scale habitat factors in conjunction with several large-scale watershed factors, including presence of brook trout and connectivity to neighboring bull trout populations. They found that bull trout occurrence was strongly associated with certain local habitat factors (channel width, large woody debris, and channel gradient), as well as the presence of a "strong" neighboring mainstem population of bull trout and presence of brook trout (negatively affected).

2.4.4. Habitat Type

Bull trout, like other salmonids, demonstrate preferences for different habitat types in different life stages. Preferences are described below for the spawning, fry, rearing, and sub-adult/adult life stages.

Bull trout spawn in a variety of habitat types, substrate sizes and gradients. Habitat types include pool tailouts and runs (Pratt 1992; Shellberg 2002), glides (Shellberg 2002), and riffles (James and Sexauer 1997; Shellberg 2002). Side channels appear to be preferred when present, at least in the coastal region (Johnson 1991; Shellberg 2002). Spring-fed tributaries (eastern Washington; James and Sexauer 1997) and wall-based channels (western Washington, Johnson 1991) also may be preferred if present; both of these stream types are groundwater fed.

Bull trout spawn in a wide range of substrate sizes, including sand and fine gravel (Shellberg 2002), loosely compacted gravel and cobble (Shepard and others 1984a; Shellberg 2002), and large cobble (100-200 mm in size, Shellberg 2002). The manner that large cobble is used is noteworthy. Shellberg (2002), in describing his own observations and those of Johnson (1991) in western Washington, states that veneers of gravel are scrapped of the cobble; eggs are deposited in the exposed gravel pores; then, the eggs are thinly covered with small gravel. While a range of substrates can be used, Shellberg (2002) reports that the majority of redds in western Washington are constructed in gravel substrate similar to that used by other salmonids of comparable size. We conclude from our literature review that Shellberg's finding can be applied to the intermountain region as well.

Bull trout spawn across a wide range of gradients, when seen at the reach scale. They typically spawn in relatively low gradient reaches (<2%, McPhail and Baxter 1996; Shellberg 2002), though spawning is known to occur in reaches as high as 15% or greater (USFWS 2000). At lower gradients, habitat types used are those described above. In high gradient reaches, redds are typically located in gravel pockets downstream from large boulders or logs or in side channels or braided channels where the gradient lessens (Johnson 1991).

Newly emerged fry use areas of low velocity, particularly side channels and stream margins (Goetz 1997b).

Juveniles will use all types of habitat, although they are most often found in slow-water habitats (Watson and Hillman 1997; Fraley and Shepard 1989; Goetz 1997b, Sexauer and James 1997). Watson and Hillman (1997), sampling streams in Washington, Idaho, and Montana, reported that the highest densities of bull trout were found in areas with the deepest pools. Goetz (1997b), sampling in Metolius River tributaries (Deschutes basin in Oregon), found juveniles strongly preferred pool habitat (Figure 6), though they also used other habitat types. Bull trout selected side channel habitat at the highest rate when it was present. Figure 6 shows densities found both during day and night sampling; nighttime sampling is clearly more representative of the actual number of fish present. Goetz reported similar patterns for the aggregate of several streams, including some in Washington and western Oregon. Sexauer and James (1997), sampling at night, reported that juvenile bull trout usually occupied areas of shallow, low velocity water. Fish occupied pools, glides, and riffles although they were found along the channel margins and backwaters of riffles. In streams in Alberta, Earle and McKenzie (2001) found juvenile bull trout to use all habitat types, though the majority were associated with pools (40%) and runs (36%). Considerably fewer were found in riffles and boulder gardens. Martin (1992), sampling streams in southeast Washington, also reported that highest densities generally occurred in pools and runs, though in some cases, riffles contained high densities, particularly for age-0 fish. He also found that plunge pools appeared to be used at a much lower rate than scour pools by juvenile bull trout.

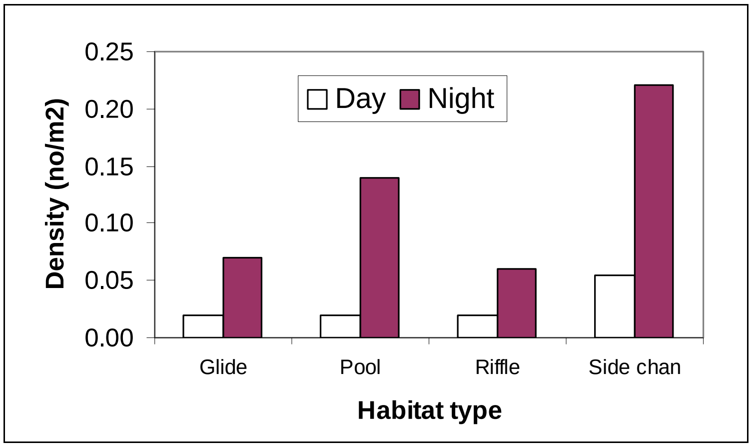

Figure 6. Density (no./m^2) of bull trout (fry and juveniles) found during day and night in Metolius River tributaries. Taken from Goetz (1997b).

Subadults and adult bull trout are usually found in pools and runs (Pratt 1984; Muhlfeld and others 2003).

2.4.5. Temperature

Water temperature is often reported to be the most important factor affecting bull trout distribution and abundance (Dunham and others 2003). The species is believed to be among the most thermally sensitive species in coldwater habitats in western North America (Rieman and McIntyre 1993; Buchanan and Gregory 1997; Hass 2001; Selong and others 2001). Species so dependent on coldwater habitat are likely especially vulnerable to increases in water temperature that can result from land use practices (Poole and Berman 2001).

Dunham and others (2003) found that the maximum daily temperatures for sites with small bull trout (<150 mm) was 17.5 °C and 26.2 °C in Washington data sets and Pacific Northwest regional data sets respectively. Their model predicted higher probabilities of occurrence with the regional data set at warmer (>12 °C) maximum temperatures. They hypothesized that this was due either to a larger amount of data in the regional data set (hence the Washington set was biased low) or that bull trout at the warmest sites in the regional set were using localized refugia. Regardless of which data set is more appropriate, the model predicts that as water temperature exceeds a single daily maximum of 20 °C, it becomes increasingly unlikely that juvenile bull trout will be present (Figure 7). McCullough and Spalding (2002) referred to the data sets used in the Dunham and others analyses as "the most current and extensive database and analysis of juvenile bull trout distribution relative to temperature."

Gamett (2002) analyzed relationships between 18 temperature metrics and bull trout presence, density, and composition (in conjunction with other species) in 39 sections of Little Lost River, Idaho. The metric that performed the best for each of the three response variables was mean water temperature. Two other metrics that performed well, among others, were maximum temperature and the number of days that temperature exceeded 15 °C. The association between maximum temperature for all sites between July 1 and September 30 was similar to the relationships presented by Dunham and others (Figure 7). In this case, however, bull trout were present at all sites where maximum temperature was less than 17 °C. The relationship predicted that probability of occurrence drops rapidly with increasing temperature, with only a 10% probability of occurrence at a maximum temperature of 21 °C. Bull trout densities were found to be highest when maximum temperature was less than 14.9 °C, but dropped rapidly with increasing temperature.

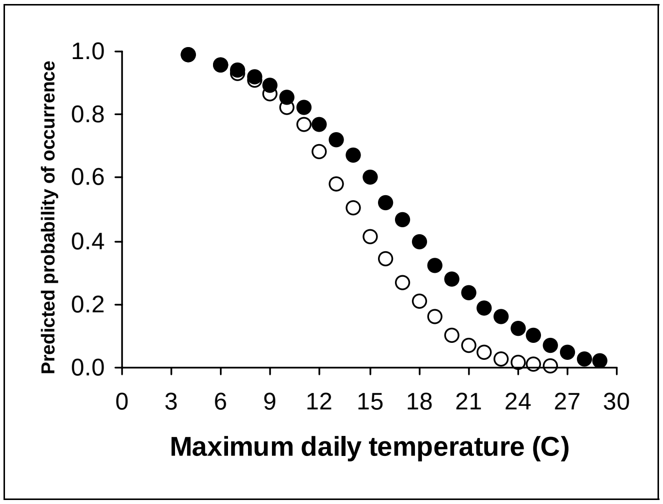

Figure 7. Predicted occurrence of small bull trout (<150 mm) in relation to maximum daily temperature for regional (solid circles) and Washington data (open circles) sets. Adapted from Dunham and others (2003).

Haas (2001) reported from field studies in British Columbia that bull trout were not found above a maximum daily temperature of 16 °C, giving an even more restrictive picture than the one for the Washington data set using Dunham and other's model. In sympatry with rainbow trout, bull trout did not gain numerical dominance and have higher condition factors until maximum temperatures dropped to 12 C or less.

The results of Haas (2001), Gammet (2002), and Dunham and others (2003) are consistent with laboratory studies of thermal tolerance. Selong and others (2001) reported that the temperature-survival curve developed for bull trout from lab experiments indicates that the species can survive temperatures up to 20 °C for up to 60 days but that survival decreases rapidly with exposure to even small increases above that level. Their calculated upper incipient lethal temperature (UUILT) of 20.9 °C at 60 d is about 1-5 °C lower than those reported for other salmonids (Table 1). The calculated UUILT for bull trout was most similar to that of Arctic char. Selong and others noted that even relatively small differences in upper lethal temperature can mean substantial differences in thermal tolerance, performance, and regional distribution.

Selong and others (2001) found that age-0 bull trout had slightly greater temperature tolerance than yearlings.

Selong and others (2001) reported that the growth rate of bull trout fed to satiation was maximized at 13.2 °C. This temperature is in the lower portion of the maximum-growth range of most other salmonids and is closest to the temperature optimum of Arctic char. Based on distributions of other sympatric salmonids, bull trout may be disadvantaged in their competition with other salmonids at temperatures that are nearer to the maximum-growth temperatures for those species. For example, McMahon and others (1999, 2001) suggest that as water temperatures rise above 12 °C bull trout begin to loose their ability to compete with brook trout. Haas (2001) concluded that where rainbow trout and bull trout coexist that rainbow trout are dominant when maximum temperatures greater than 14 °C occur and that bull trout dominant when they are less than 14 °C.

The temperature when growth is maximized can be used to define what has been called the fundamental thermal niche (FTN)(Magnuson and others 1979; Christie and Regier 1988). Christie and Regier (1988) considered the FTN as –3 and +1 °C around the optimal growth temperature. For bull trout, the FTN would be 10.2-14.2 °C (Selong and others 2001). The upper range of maximum-growth temperatures likely represents the upper limit of suitable habitat for salmonids (McCullough 1999). These projections, based on lab studies, are consistent with the results of field studies reported by Hass (2001), Dunham and others (2003), and Gamett (2002).

Hicks (2002) reviewed available research on the effects of elevated temperature on bull trout spawning and egg incubation. We rely largely on his review. Field observations reported in various studies showed strong concurrence that spawning behavior (pairing and redd construction) does not be begin until the 7-day average of the daily maximum temperatures (7DADMax) falls below 8.45-9.45 °C and spawning itself does not begin until the daily maximum temperature falls below 7.45-8.45 °C.

Hicks' (2002) review of the effects of elevated temperature on incubation success showed that bull trout eggs are capable of surviving at very high rates (90-97%) when water temperatures were in the range 3.1-6.5 °C. At temperatures 8-10 °C, survival can drop precipitously to 0%.

Table 1. Representative summary of ultimate upper incipient lethal temperatures (UUILTs), critical thermal maximums (CTMs), and maximum-growth temperatures for juvenile salmonids. Reproduced from Selong and others (2001).

Species	UUILT (°C)	CTM (°C)	Acclimation temperature (°C)	Maximum-growth temperature (°C)	Reference
Bull trout		26.4-28.9	8-20		Selong and others 2001
	20.9 (60 d)			13.2	Selong and others 2001
	23.5 (7 d)	24.8-26.2	5-20		Selong and others 2001
Arctic char	20.8-22.1				Baroudy and Elliott 1994
Arctic grayling	25		20		Lohr and others 1996
Dolly Varden	24.5				Takami and others 1997
Whitespotted char	26.5				Takami and others 1997
Brook trout	24.5				McCormick and others 1972
		28.3-30.8	8-20		Selong and others 2001, unpublished data
		29	10		DeStaso and Rahel 1994
				14.4-16	Dwyer and others 1983
Rainbow trout	25.6		16		Hokanson and others 1977
	26.2		24.5		Kaya 1978
		28.0-29.8	10-20		Currie and others 1998
				17.2	Hokanson and others 1977
Cutthroat trout		28	10		DeStaso and Rahel 1994
	25				Dickerson and Vinyard 1999
Brown trout	24.7				Elliott 1981
		29.9	20		Elliott and Elliott 1980
		28.9-29.8	10-20		Lee and Rinne 1980
				13.9	Elliott and Hurley 1999
Lake trout				10-12	O'Conner and others 1981
Sockeye salmon	24.5				Brett and others 1969
				15	Brett 1952
Coho salmon	23.7			15	Edsall and others 1999
		25.3-28.7	5-15		Becker and Genoway 1979

Relatively little is known about the temperature preferences and requirements of migratory sub-adult and adult bull trout that use mainstem rivers as migration corridors (Hicks 2002). Swanberg (1997) reported that sub-adult and older bull trout migrated out of the lower Blackfoot River (Montana) when temperatures reached 18-20 °C. Non-spawning subadults began to return once maximum temperatures declined to 12 °C. A few fish did not migrate from the mainstem but they were found in close association with small coldwater tributary. In Washington State, anadromous bull trout are found migrating upstream through mainstem rivers during mid summer, when maximum daily temperatures in lower reaches commonly reach 20 °C (author's personal observations).

2.4.6. Other Issues

Many other environmental issues can affect bull trout than those reviewed above. These tend to be watershed-specific issues associated with unique land use patterns that exist there. Ratliff and Howell (1992) list migration barriers and entrainment or injury associated with unscreened or inadequately screened diversions as issues in some streams. Loss or change in habitat due to creation of reservoirs has occurred in a number of watersheds (McPhail and Baxter 1996). Water quality issues related to mining (such as persistent effects of heavy metal pollution) and agriculture can be important issues in some streams (Montana Bull Trout Scientific Group 1995). Changes in flow regimes due either to dewatering associated with irrigation withdrawals or changes in runoff patterns can be significant factors in some areas (Montana Bull Trout Scientific Group 1995).

2.5. Issue Synthesis

We summarize here our conclusions regarding the primary issues affecting bull trout performance over broad areas of the coastal and interior regions of Washington, Oregon, Idaho and Montana. Our conclusions are listed in Table 2. Those issues, or factors, selected to illustrate how the habitat rules were formulated (Chapter 4) are shown with an asterisk.

Table 2. Conclusions regarding the most important issues affecting bull trout performance over broad areas of coastal and interior regions. Issues, or factors, selected to illustrate how the habitat rules were formulated (Chapter 4) are shown with an asterisk.

Issue	Conclusions	Life stages affected
Biotic Relationships		
Inter-specific competition *	• Competition with introduced species, mainly brook trout, is a major factor • Competition with other native species occurs but is not a major factor; supplementation of native species is likely to increase level of interaction	Juvenile stages
Intra-specific competition	• Interactions (competition and predation) between bull trout age classes occurs; effects on population dynamics may be significant, particularly for resident populations, likely creating cyclical patterns of abundance in age class strength • Modeling of effects best done using a population model, not with existing EDT tools	All stages
Hybridization *	• Hybridization with brook trout can be a major factor • Hybridization with Dolly Varden is limited to few areas; significance is unknown	Spawning and incubation stages
Forage availability	• Food availability for small juveniles??? • Abundance of fish prey, such as abundance of sculpins, juvenile whitefish, and juvenile salmonids, is important for fluvial, adfluvial, and anadromous life history forms	Age-2 and older juvenile, sub-adult and adult stages
Harassment and poaching	• Vulnerability to fishing pressure, whether by poaching, hook and release, or directed harvest, can be a major factor where easy access to streams exist and bull trout congregate	Sub-adult and adult stages
Habitat Relationships		
Channel stability *	• Bed scour and channel stability can severely affect incubation success and survival during younger juvenile life stages, particularly during inactive (overwintering) stages • Land use practices that increase peak flows, remove or reduce large wood in streams, or reduce the number of stable side channels can increase bed scour depth and channel instability	Incubation and younger juvenile stages
Sedimentation *	• Survival of eggs, alevins, and pre-emergent fry are highly susceptible to mortality due to fine sediment, apparently more so than many other salmonid species • Survival to emergence is linearly related to quantity of sand sized sediment (1-6 mm); mortality occurs even at small amounts of this sediment size; effects are primarily due to entombment • Some amount of bed scour prior to fry emergence can ameliorate the effects of sand sized sediment by removing the top stratum of sand-laden substrate • Survival to emergence is curvilinearly related to quantity of fines <1 mm; mortality increases sharply as fines exceed 11% but the rate of increase slows at levels >18% due to protection by egg pocket structure; effects are primarily due to reduced oxygenation of eggs and alevins • Spawning at sites of upwelling and ground water influence can dramatically ameliorate effects of fine sediment – both sand sized and smaller • Effectiveness of gravel cleaning by spawning adults is largely negated	All stages but primarily incubation and younger juvenile stages

Table 2. Conclusions regarding the most important issues affecting bull trout performance over broad areas of coastal and interior regions. Issues, or factors, selected to illustrate how the habitat rules were formulated (Chapter 4) are shown with an asterisk.

Issue	Conclusions	Life stages affected
	by re-invasion of fine sediment where timing of runoff occurs during the period prior to fry emergence • Embeddedness, an issue primarily in gravel bedded streams with moderate to high loads of sand-sized particles, can be a major factor affecting survival of younger age classes, particularly during overwintering • Suspended sediment can be a major factor in streams with unusually high sediment concentrations, either due to heavy glacial runoff or land-use such as mining	
Cover and structure	• The amount of cover and structure can be a major factor affecting survival, particularly when a stream channel is simplified and little cover remains • Wood, stream margin cover (roots, overhanging vegetation, and undercut banks) and cobbles are preferred sources of cover	Juvenile and older stages
Habitat type *	• Pool-tailouts, riffles, and glides are used for spawning • Pools are used more than other types by juveniles, sub-adults, and adults, though other types are also used, particularly by smaller juveniles	All life stages
Temperature *	• Water temperature during summer and fall is in many streams the most important factor affecting abundance and distribution • Bull trout are among the most thermally sensitive salmonid species in western North America • In streams with bull trout, juvenile densities are highest when the maximum daily temperature is < 15 °C; densities drop rapidly as maximum temperatures increase; a very low probability of presence occurs when a single daily maximum temperature exceeds 20 °C. • Age-0 juveniles have a slightly higher temperature tolerance than yearlings • Relatively little is known about temperature preferences and tolerances of adult bull trout; fluvial and anadromous adult migrants can cope, at least for brief periods, when temperatures exceed 20 °C. • Relatively little is known about tolerances to periods of extreme cold, though it is assumed that bull trout are much more tolerant than most other salmonid species	All life stages
Water quality	• Pollution, past and present, can pose significant health risks to bull trout in some watersheds	All life stages
Flow alterations	• As noted above, increases in peak flows can result in greater bed scour depth, affecting incubating eggs and alevins • Water diversions, such as those associated with irrigation, can dewater reaches and thereby reduce amount and quality of rearing and adult habitat—this can be a major factor in streams with significant withdrawals	All life stages
Obstructions to migration	• Barriers to fish migration caused by dams, water diversion structures, and culverts are a major factor affecting movements and distributions of bull trout in many watersheds	Migratory stages
Reservoirs	• Dams can convert riverine habitat to reservoirs, causing significant loss in spawning area and other changes in habitat features—this can be a major factor in some streams	All life stages

Chapter 3
Conceptual Framework

This section describes the key concepts for understanding how knowledge is structured in EDT in the form of rules to assess species-specific survival responses to environmental conditions. The description is provided in three parts: Components of Population Performance, EDT Information Structure, and Rule Structure.

In Chapter 4, we illustrate how the different types of rules for estimating productivity, key habitat, and food are formulated for the primary issues affecting bull trout performance.

3.1. Components of Population Performance

EDT is an approach for characterizing the quality and quantity of aquatic habitat in relation to species-specific survival. Its underlying premise is that biological capacity and productivity of a fish population are functions of the environment; therefore, environmental conditions are reflected in the shape of its production function (Reisenbichler 1989). Specifically, we assume that habitat based estimates of capacity and productivity create a Beverton-Holt production function (Beverton and Holt 1957) that serves as an index of potential biological performance of the species in the modeled environment (Figure 8).

Capacity defines the "size" of the environment with respect to a species while productivity is the survival rate without any density effects (density independent survival). Moussalli and Hilborn (1986) showed that a Beverton-Holt function for a population can be disaggregated into similar functions describing survival and capacity of the environment at different life stages. In EDT, capacity and productivity are calculated for each life stage at a stream reach scale and then integrated to estimate overall population capacity and productivity.

Productivity in EDT is equivalent to the concept of intrinsic productivity discussed in McElhany and others (2000) to describe viable salmonid populations with respect to the Endangered Species Act. It is survival without density dependence effects, i.e., the approximate rate that would occur when competition for resources is eliminated. As abundance increases, survival is increasingly modified by density dependent factors of the environment to the point that the quantity of resources becomes limiting and abundance approaches the capacity. In Figure 1, productivity is the slope of the abundance curve at its origin. Productivity is a function of the quality of the environment (Moussalli and Hilborn 1986).[6] The definition of productivity as applied here is consistent with its use by Hilborn and Walters (1992) in population dynamics modeling.

Environmental capacity limits how large a population can grow given finite space and food resources, depicted by the asymptote in Figure 1. It controls the extent that density dependence is operative at different population (or density) levels. Capacity is a function of the quantity of key habitats and food resources available.[7] The term key habitat here refers to those habitat types that are the primary types utilized by the species in a life stage—they are the types that are preferred or required by the species in the life stage. Given steady-state condition, abundance will increase toward the capacity and will equilibrate at a point below capacity where the Progeny/Spawners is equal to 1.0 (Figure 8). This equilibrium abundance, or Neq, is a function of both capacity and productivity.

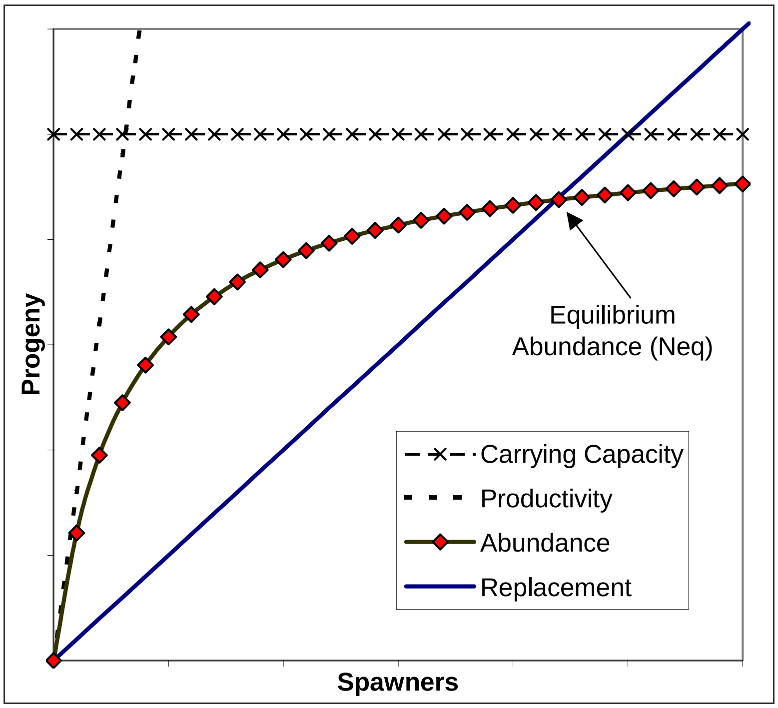

Figure 8. Features of a Beverton-Holt production function. Productivity is the density independent survival, which, along with density dependent factors of the environment, determines abundance limited by the total capacity of the environment. Replacement is the minimum number of spawners required to maintain a given abundance. Under steady-state environmental conditions, the population abundance equilibrates at Neq, the point where abundance crosses the replacement line.

6/ Productivity measured across the full life cycle also incorporates sex ratio, fecundity, and fitness.

7/ Environmental carrying capacity illustrated in the stock-production relationship is actually a function of both quantity of resources (ones that are competed for) and environmental quality—easily seen in a disaggregated production function, see Moussalli and Hilborn (1986) and pages 284-285 in Hilborn and Walters (1992).

Using the recursive property of the Beverton-Holt function highlighted by Moussalli and Hilborn (1986), the population level production function can be decomposed in EDT into similar functions for each life stage. Life stages for bull trout as applied in EDT are defined in Appendix A.

From the scientific literature we can estimate maximum productivity (survival rate) and capacity (density) conditions under optimal conditions that occur in nature. We refer to these survival and density values as reference benchmarks.[8] Benchmarks provide us with a set of descriptions for performance under optimal conditions expressed as survival and maximum densities for each life stage. Benchmarks are the theoretical natural limits on survival and density for a species. These conditions constitute what can be thought of as "as good as it gets" for survival of the species in nature. Estimated benchmark survivals and densities applied to bull trout in EDT are provided in Appendix B.

The biological rules are used to adjust the maximum benchmark performance to account for habitat conditions in a specific stream. The EDT rules adjust the theoretical benchmarks downward to reflect local conditions that typically are less ideal for survival than those associated with the benchmarks, due either to natural or anthropogenic constraints. As a result, fish performance will almost always be less than the benchmark maximum levels. The EDT rules provide a systematic way of quantifying survival conditions for any reach by computing performance in the local environment relative to the benchmarks. This procedure ensures that productivity and capacity values computed for each life history segment are: a) bounded by the biological limits of the species, b) scaled consistently across time, space, and life stage, and c) scaled consistently with the benchmark values. While the rules are based on knowledge contained in the literature, they should be thought of as hypotheses about how survival is affected by environmental conditions.

It is important to distinguish the benchmarks from the historic or pristine conditions (often referred to as the Template or Reference condition in EDT). Maximum performance of fish in a particular stream is almost always less than the benchmarks because even pristine conditions are not "perfect." The benchmark descriptions serve as a point of reference for both the present-day and historic conditions and for all watersheds.

3.2. EDT Information Structure

Information used to derive biological performance parameters in EDT is organized through the hierarchical EDT Information Structure. It structures information through three levels of organization. Together, these levels can be thought of as an information pyramid in which each level of information builds

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8/ Benchmark values for productivity and capacity are theoretical, derived within a theoretical construct for how members of a population interact with one another within their environment. The values serve as working hypotheses about the natural limits on survival and density for a species.

on information from the lower level (Figure 9). As we move up through the levels, we take an increasingly organism-centered view of the ecosystem.

Levels 1 and 2 together characterize the environment as it can be described by different types of data. This provides the characterization of the environment needed to analyze biological performance for a species. Level 1 and Level 2 information is not specific to a species but instead forms a species-independent description of the aquatic environment. The Level 3 category of information, on the other hand, is a characterization of that same environment from a different perspective: "through the eyes of the salmon"(Mobrand and others 1997). This category describes biological performance in relation to the state of the environment described by the Level 2 information.

The Information Structure begins with a wide range of environmental data (Level 1 input data) such as flow, sediment load, temperature, physical habitat, land use and ownership, elevation, slope, and so on. Included is information on the spatial and temporal structure of the data (Figure 10). These data exist in a variety of forms and pedigrees. Some watersheds are data rich, others might be comparatively data poor. Level 1 information includes empirical measurements as well as conclusions of expert observers. These data are the basis for the more refined description of the environment in Level 2.

Level 2 factors are referred to as Environmental Attributes (Table 3). Level 2 information creates a generalized depiction of the aquatic environment, essentially as a set of conclusions derived from the Level 1 information (Figure 10). Level 2 Environmental Attributes are <u>measurable</u> characteristics of the environment that relate to salmonid performance. They are the main input to EDT, which is organized in the Stream Reach Editor application. EDT Environmental Attributes are similar to the concept of environmental attributes used by (Morrison and others 1998) to describe species-habitat relationships for terrestrial environments. In concept, a set of Level 2 Attributes can be described for analyzing the environment with respect to any species. The EDT Environmental Attributes (Level 2) are defined more fully in Appendix C.

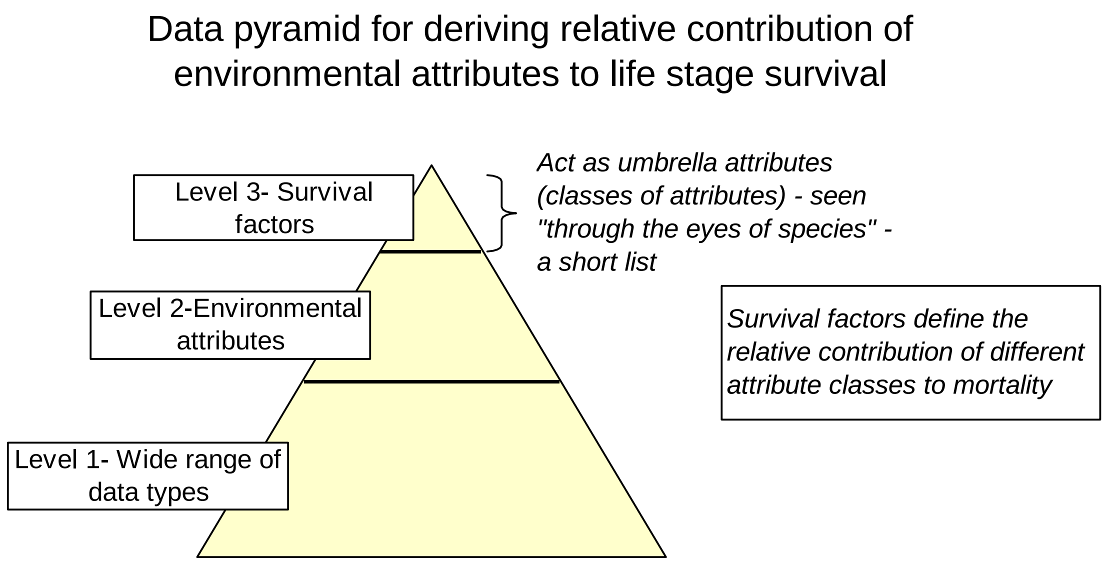

Figure 9. EDT Information Structure can be visualized as a "data pyramid." Information begins as raw data and observations (Level 1), is organized into a species-neutral description of the environment (Level 2) and then characterized as performance of a particular species (Level 3).

It is important to note that the list of Level 2 attributes presented in this document includes several additional attributes not previously used in EDT. New attributes are:

New Level 2 Attributes
Hydrologic regime - groundwater rating
Habitat type - side channel factor
Habitat type - side channel type
Fine sediment - >1 and <6 mm particles
Fine sediment - <1 mm particles
Fish community composition

The two fine sediment attributes take the place of the fine sediment attribute used previously which encompassed the two size fractions now being distinguished. The attribute "Fish community composition" actually includes two attributes – a list of fish species present in the drainage and an accompanying attribute that identifies the relative status of each species. This level of characterization of the fish community composition is needed to address how bull trout can be affected by the status of other fish species through competition.

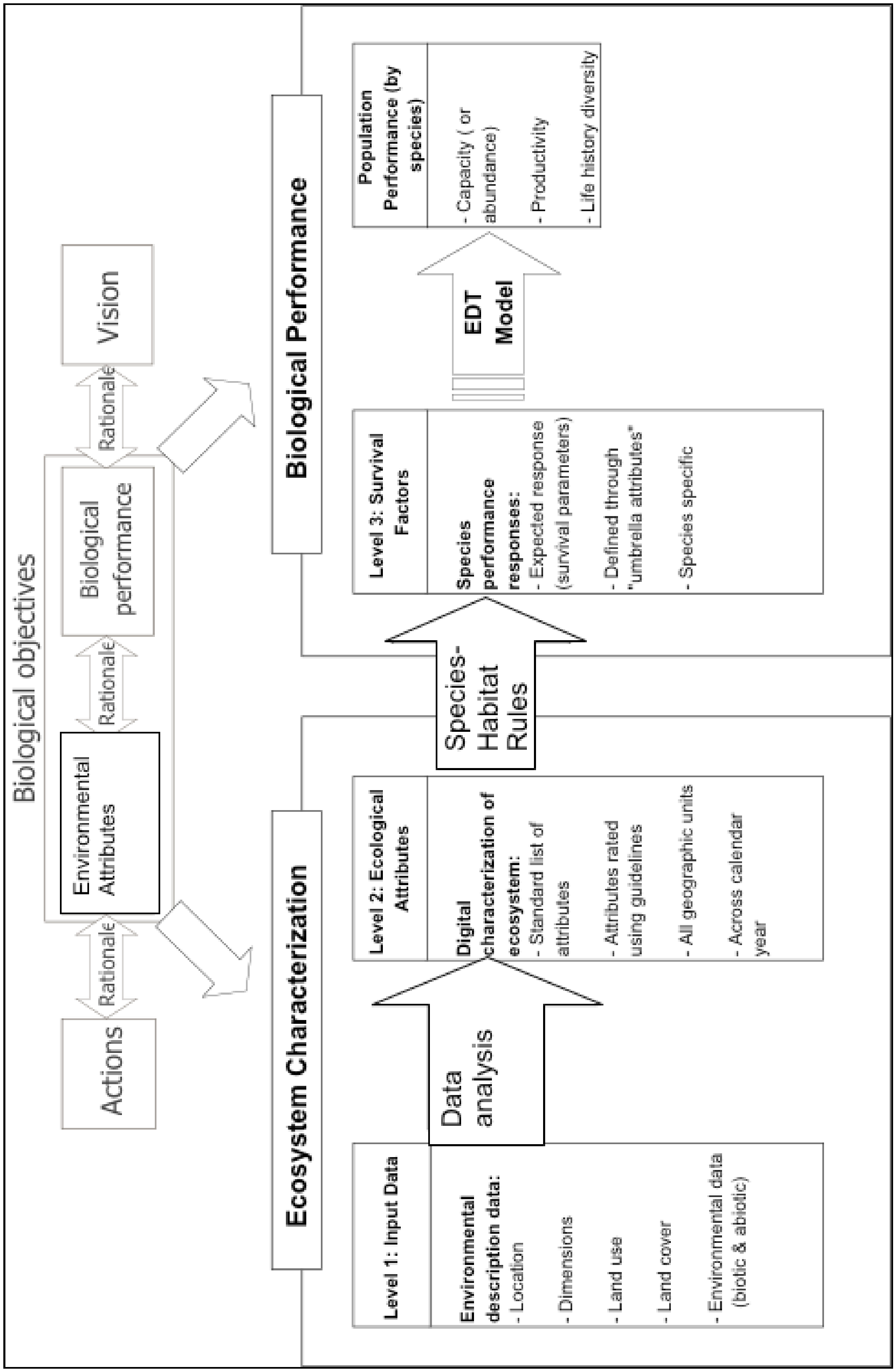

Figure 10. EDT Information Structure. Species-Habitat rules relate characteristics of the environment to potential performance of the focal species.

Table 3. Organization of Level 2 Environmental Attributes by categories of major stream corridor features. Salmonid Survival Factors (Level 3) are shown associated with groups of Level 2 attributes. Associations can differ by species and life stage. See Appendix F for association matrices for bull trout.

Environmental Attributes (Level 2)		Related Survival Factors (Level 3)
1 Hydrologic Characteristics		
1.1 Flow variation	Flow - change in average annual peak flow	Flow
	Flow - change in average annual low flow	
	Flow - Intra daily (diel) variation	
	Flow - intra-annual flow pattern	
1.2 Hydrologic regime	Hydrologic regime - natural	
	Hydrologic regime - regulated	
	Hydrologic regime - groundwater rating	
2 Stream Corridor Structure		
2.1 Channel morphometry	Channel length	Channel length Channel stability Channel width Habitat diversity Key habitat Obstructions Sediment load Withdrawals (entrainment)
	Channel width - month maximum width	
	Channel width - month minimum width	
	Gradient	
2.2 Confinement	Confinement - hydromodifications	
	Confinement - natural	
2.3 Habitat type	Habitat type - backwater pools	
	Habitat type - beaver ponds	
	Habitat type - glides	
	Habitat type - large cobble/boulder riffles	
	Habitat type - off-channel habitat factor	
	Habitat type - pool tailouts	
	Habitat type - primary pools	
	Habitat type - small cobble/gravel riffles	
	Habitat type - side channel factor	
	Habitat type - side channel type	
2.4 Obstruction	Obstructions to fish migration	
	Withdrawals (entrainment)	
2.5 Riparian and channel integrity	Bed scour	
	Icing	
	Riparian function	
	Wood	
2.6 Sediment type	Embeddedness	
	Fine sediment - <1 mm particles	
	Fine sediment - >1 and <6 mm particles	
	Turbidity (suspended sediment)	
3 Water Quality		
3.1 Chemistry	Alkalinity	Chemicals (toxics) Oxygen Temperature
	Dissolved oxygen	
	Metals - in water column	
	Metals/Pollutants - in sediments/soils	
	Miscellaneous toxic pollutants - water column	
	Nutrient enrichment	
3.2 Temperature variation	Temperature - daily maximum (by month)	
	Temperature - daily minimum (by month)	
	Temperature - spatial variation	

Table 3. Organization of Level 2 Environmental Attributes by categories of major stream corridor features. Salmonid Survival Factors (Level 3) are shown associated with groups of Level 2 attributes. Associations can differ by species and life stage. See Appendix F for association matrices for bull trout.

Environmental Attributes (Level 2)		Related Survival Factors (Level 3)
4 Biological Community		
4.1 Community effects	Fish community richness/composition	Competition with hatch fish Competition with other fish Food Harassment Pathogens Predation
	Fish pathogens	
	Fish species introductions (by species)	
	Harassment	
	Hatchery fish outplants	
	Predation risk	
	Salmon carcasses	
4.2 Macroinvertebrates	Benthos diversity and production	

The Level 2 characterization describes conditions in the watershed at specific locations (reaches along a stream), times of year (specific months), and by scenario (template, current[9], or a future scenario). Thus values assigned for each Environmental Attribute represent conclusions about the stream by site, month, and scenario based on the Level 1 data and observations. These assumptions become operating hypotheses for these attributes under specific scenarios. Where Level 1 data are sufficient, Level 2 conclusions can be derived directly or through simple algorithms. However, where Level 1 data are incomplete, experts are needed to provide knowledge about geographic areas and attributes. Regardless of the types of information used to derive the Environmental Attribute ratings, the Level 2 Environmental Attributes are measurable characteristics of the environment that can be monitored and ground-truthed over time through an adaptive process.

Most Level 2 Attributes are characterized using ratings on a scale of 0 to 4, spanning a spectrum of conditions. Generally, there is a consistent direction to the attribute ratings, where 0 or low values will tend to correspond with pristine environmental conditions and higher values tend toward more degraded conditions. This pattern varies for several attributes, however. Table 4 gives examples of the index values for three Environmental Attributes, all addressing a different aspect of sediment load within the stream system. Integer values represent the midpoint of conditions for attributes when a range of conditions is associated with one value.[10] The indexing system allows users to specify either continuous or integer values for the attributes, depending on the appropriate level of precision for particular stream reach given the available data. Conditions associated with index values for all Level 2 Environmental Attributes are described in Appendix D.

9/ The Current condition in EDT is often referred to as the Patient condition reflecting the terminology of Lichatowich and others (1995)

10/ When generating Level 2 attribute values for the basin, integer values frequently mean that only a broad categorical conclusion can be reached about an environmental attribute, as reflected in the range of values shown for the sediment examples. In these cases, the rule would interpret an integer to represent the midpoint.

Some Level 2 Attributes do not use the rating scale of 0-4. Instead they employ the appropriate metric for the attribute. These attributes are wetted channel width (maximum and minimum width in feet), channel length (miles), channel gradient (% slope) and percent of the wetted area of a reach represented by specific habitat types (e.g. pools, riffles and glides).

The species-habitat rules translate the species-neutral Level 2 characterization of the environment into a species-specific depiction of habitat in terms of Level 3 Survival Factors by life stage. The Level 3 Factors are listed and defined in Appendix E. The Survival Factors act as "umbrella attributes", grouping the effects of Environmental Attributes into broader synthetic concepts of habitat conditions for the species (Figure 11). The purpose of grouping effects of classes of attributes in this manner is to allocate mortality by the types of factors that biologists typically refer to in environmental analysis (e.g., limiting factors analysis). Table 3 illustrates general relationships between Level 2 Environmental Attributes and Level 3 Survival Factors. Specific associations of Level 2 Attributes and Level 3 Factors for bull trout are found in Appendix F.

In most cases, a single rule exists for one life stage-Level 3 Survival Factor combination. However, in some cases more than one rule exists to account for likely differences in biological sensitivity between stream sizes (by channel width) and hydrologic regime (accounting for source of flow, e.g., groundwater vs. rain fed).

Table 4. Rating indexes used for three Level 2 Environmental Attributes that address different characteristics of sediment load in a stream system.

Embeddedness	
Rating	Rating definition
0	≤ 10% embedded
1	> 10% and ≤ 25% embedded
2	> 25% and ≤ 50% embedded
3	> 50% and ≤ 90% embedded
4	> 90% embedded
Fine sediment (intragravel) - < 1 mm particle size	
Rating	Rating definition
0	≤ 6% fines < 1 mm
1	> 6% and ≤ 11% fines < 1 mm
2	> 11% and ≤ 18% fines < 1 mm
3	> 18% and ≤ 30% fines < 1 mm
4	> 30% fines < 1 mm
Suspended sediment (from SEV index - after Newcombe and Jensen 1996)	
Rating	Rating definition
0	≤ 4.5 scale of severity (SEV)
1	> 4.5 and ≤ 7.5 scale of severity (SEV)
2	> 7.5 and ≤ 10.5 scale of severity (SEV)
3	> 10.5 and ≤ 12.5 scale of severity (SEV)
4	> 12.5 scale of severity (SEV)

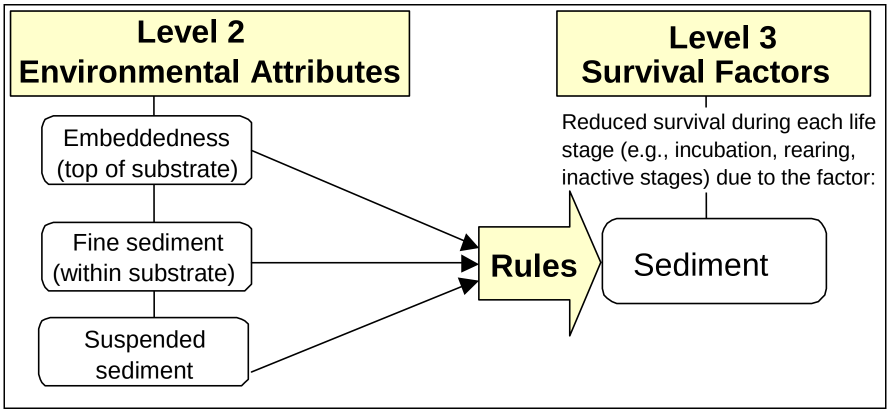

Figure 11. Concept of EDT rules relating Level 2 Environmental Attributes to Level 3 Survival Factors. Rules derive (as hypotheses) effects of Level 2 Attributes on species performance by life stage (example shows effects of sediment attributes on life stage productivity).

3.3. Rule Structure

In the this section, we describe the structure of rules for three types of Level 3 Survival Factors:

- factors that estimate productivity survival
- factors that estimate the amount of key habitat and
- factors that estimate the effects of food on productivity and capacity

The rules that define these survival factors are quite different and need to be described separately.

3.3.1. Estimating Productivity

Productivity in EDT is a measure of the quality of the environment with respect to the focal species. The life stage productivity value associated with a specific stream reach is defined as the density independent survival rate expected if the entire life stage occurred under the conditions in that reach.[11]

The rules presented here assume that productivity, P , can be partitioned into a set of sixteen independent multiplicative survival factors F_i , i.e.

$$P = P_0 \cdot F_1 \cdot F_2 \cdot F_3 \cdots F_{16}$$

where $0 < F_i < 1$ are relative productivity values and P_0 is the benchmark survival (Appendix B and discussion above).. Each $F_i < 1$ acts to reduce P from the benchmark productivity due to habitat conditions that are less than optimal corresponding to that F_i in the given reach. When the reach has

11/ Differences in conditions between months are handled within EDT by modeling life history trajectories to capture how groups of fish experience changes in environmental conditions in space and time.

optimal conditions corresponding to all factors, i.e, F_i = 1 for all Level 3 factors, then $P = P_0$.

We then assume that each Level 3 Survival Factor F_i can be estimated as a function of the Level 2 Environmental Attributes for the reach. The functional form that we applied in formulating the present rule set assumes that a Level 3 Survival Factor will principally be driven by a single dominant, or primary, Level 2 Attribute, though other Level 2 Attributes can act to modify the overall effect. We refer to this rule structure as the **Synergistic Form**.

In this form for rule structure, we refer to the dominant Environmental Attributes as the **Primary Level 2** Attribute for that specific life stage-Level 3 factor. When the Primary Level 2 attribute (p) alone affects the Level 3 (i.e. there are no secondary Level 2 attributes in the rule) survival factor F_i, it is defined as:

$$F_i = 1 - S_{P,i}$$

where $S_{P,i}$ is the sensitivity of survival of the species to the Primary Level 2 Attribute, here without other contributing Level 2 Attributes. The $S_{P,i}$ values for each rating (0 – 4) of the Primary Level 2 are estimated based on published studies, available data or where data is sparse, expert opinion.

In most cases the sensitivity to the Primary Level 2 Attribute is affected by one or more **Modifying Level 2** Attributes. These attributes modify overall sensitivity associated with the Primary Level 2, either increasing it or, in some cases, decreasing it. The functional form used (unless otherwise specified) to capture this modifying effect is:

$$F_i = 1 - \left[\sum_j S_{j,i}{}^g \right]^{1/g}$$

where $S_{j,i}$'s are the sensitivities of all contributing Level 2 Attributes *j* (including the Primary) operating on factor *i*, and *g* is a "synergy parameter."

In all rules where this synergistic form is used the value of *g* is 0.4. This value of *g* derives from the way the 0 – 4 rating scale for Level 2 attributes was defined. The synergistic form shapes the overall combined effect of multiple Level 2 Attributes affecting a single Level 3 factor *i* consistent with the way in which ratings have been defined for Level 2 Attributes. In general, the rating system was devised so that values of 1 or 2 would have little effect on survival, whereas values between 3 and 4 tend to reflect severe conditions for survival. Use of *g* = 0.4 in the equation retains a minor effect on relative productivity when adding multiple Level 2 modifiers with low ratings, but rapidly increases sensitivity at higher values for modifying attributes. As more data and information become available this function should be tested against observations.

An alternative to the synergistic rule described above is to assume that Level 2 Attributes operate independently of each other. The **Independent Form** of the rule would assume a simple multiplicative effect:

$$F_i = \prod_j (1 - S_{j,i})$$

All rules for bull trout used to estimate life stage productivity use the synergistic form except those associated with interspecific competition. These use the independent form.[12]

It is important to recognize that those sensitivities ascribed to Level 2 Attributes for each factor *i* in the existing rules database formulated using the synergistic form should not viewed in isolation of the contributing effects of other attributes. These sensitivities were defined by considering how they act in concert with other attributes to affect the Level 3 Survival Factors. Any sensitivities for those Environmental Attributes identified as being "modifiers" would need to be adjusted upward to be recast into a rule that uses the independent form.

Chapter 4 describes the basis for specific life stage productivity rules for bull trout.

3.3.2. Estimating Key Habitat

Key Habitat is defined as the primary habitat type(s) utilized by a species during a particular life stage. It is a Level 3 Survival Factor that affects how density-dependent survival operates together with the survival factor Food. Preference for habitat types changes with life stages. Some life stages, like egg incubation, occur almost entirely within three habitat types (i.e., pool-tailouts, glides and riffles), while other life stages, like actively migrating fish, use all habitat types. Level 2 Attributes for habitat types are those in Table 3 that begin with the words "Habitat type."

The use of habitat types by individual life stages is not necessarily "all or nothing", however. For example, sub-yearling bull trout are commonly found rearing in several habitat types, though pools and low gradient side channels are used most (Figure 6).

The rules for Key Habitat were formulated by assigning weights to the different in-channel habitat types, as well as to the different channel types defined in EDT. The estimation procedure involves four steps for each life stage:

12/ A special set of rules have been developed for use in large lakes that use the Independent Form of the rules. This document does not address those rules.

1. Estimation of the total amount of in-channel habitat, unadjusted for preferences for side-channel habitats;
2. Estimation of total amount of in-channel habitat, adjusted for preferences for side-channel habitats;
3. Estimation of additional habitat available for the life stage in off-channel areas; and
4. Estimation of the total amount of Key Habitat for the life stage within a reach.

Step 1 – Amount of in-channel Key Habitat, unadjusted for side-channel preferences:

Percent Key Habitat (*%ChHabUnadj*) unadjusted for side-channel preferences for a life stage is computed as the sum of the weighted percentages of habitat types *i* within a reach's channel network, excluding off-channel areas, as follows

$$\%ChHabUnadj = \sum \%HabType_i * Weight_i$$

where $\%HabType_i$ is the percent of the wetted in-channel surface area (including side channels) comprised of habitat type *i* and $Weight_i$ is the preference weight for habitat type *i* in the appropriate life stage. These preference weights do not consider whether a habitat type is located within the main channel or a side channel—hence this computation is not adjusted for preferences that might exist for side channels. The habitat weights are easily derived from densities measured empirically for different habitat types, such as data on fish per square meter obtained by electrofishing in different seasons.

Step 2 – Amount of in-channel Key Habitat, adjusted for side-channel preferences:

This step adjusts the quantity of Key Habitat obtained in Step 1 by the amount and kind of side channels that exists within the reach, based on whether side channels are more or less preferred by the life stage relative to main channel habitats. For example, Figure 6 illustrates that low gradient side channels are preferred by juvenile bull trout for rearing comparing to habitat types in the main channel.

Percent Key Habitat (*%ChHabAdj*) adjusted for side-channel preferences in a life stage is computed applying a preference weight for side channels as a function of the type of side channel, i.e., whether the side channel is a low, moderate, or high energy channel. This step incorporates two additional Level 2 Attributes, besides those that define habitat types; these are:

- Side channel factor—expressed as a percent, which identifies the percentage of the wetted channel comprised of side channels; and

- Side channel type—expressed as a Level 2 Attribute rating between 0-4, where 0 is a very low energy side channel and 4 is a high velocity, high energy channel.

The amount of in-channel habitat adjusted for side channels is computed as follows:

$$\%ChHabAdj = \%ChHabUnadj + \%ChHabUnadj * \%SideCh * E * Weight_{SideCh}$$

where $\%SideCh$ is the percentage of the wetted channel comprised of side channels, $Weight_{SideCh}$ is a preference weight for side channels for fish in a life stage, and E is the side channel energy coefficient, computed as:

$$E = 1 - \frac{SideChType}{4}$$

The computation of E converts the 0-4 rating for this attribute into a 0-1 scale, where a value of 0 would indicate that the side channel is a high energy type having no utilization and a value of 1 would indicate that it is a very low energy type having the potential for full utilization.

Step 3 – Amount of off-channel Key Habitat, based on preference for off-channel habitat within a life stage:

This step computes the quantity of off-channel Key Habitat $\%OffChHab$, i.e., habitat used by the life stage contained in off-channel areas. It uses the Level 2 Attribute "Off-channel habitat factor", which identifies the amount of off-channel wetted areas that are frequently connected to the flowing channel network. The attribute specifies the amount of off-channel area as an amount relative to the size of the wetted active channel. For example, an Off-channel factor of 0 indicates no off-channel area, whereas a factor of 2 would indicate that there is twice the amount of off-channel area as contained in the wetted active channel. The computation of off-channel Key Habitat estimates how much of the off-channel wetted area serves as Key Habitat for the life stage of interest as follows:

$$\%OffChHab = OffChFctr * Weight_{OffCh}$$

where $OffChFctr$ is the off-channel factor as explained above and $Weight_{OffCh}$ is a preference weight for off-channel area by fish in the life stage of interest.

Step 4 – Total amount of Key Habitat used by the species within a life stage:

This step computes the total quantity of Key Habitat $\%TotHab$ as a percentage of the total wetted areas contained both in the active channel and in off-channel areas as follows:

$$\%TotHab = \%ChHabAdj + \%OffChHab$$

This value is expressed as a percent of the total wetted area contained in the active channel. The value can exceed 100%.

Chapter 4.4 describes the basis for specific life stage Key Habitat rules for bull trout.

3.3.3. Estimating Food Availability

Food is a special case Level 3 Survival Factor because it modifies both life stage productivity and life stage capacity as determined from the quantity of Key Habitat. Hence it affects both density-independent and density-dependent survival. It is an essential element of both habitat quality and quantity.

The importance of food to population performance is a truism so evident that it is often ignored in analyzing salmonid population response to environmental change. The nascent understanding of the role of salmon carcasses in affecting basic stream productivity and food abundance for juvenile salmonids (Cederholm and others 2001; Stockner 2003) has emphasized the need to include food when modeling salmonid response to habitat change.

3.3.3.1. Food effects on life stage capacity limits

The effects of food in EDT are based in large measure on work by Ptolemy (1993). He developed equations for estimating maximum salmonid densities in fluvial habitats based on fish size and nutrient indicators in British Columbia streams considered to be at or near full seeding and with little or no environmental disturbance. Further studies since his original publication continue to validate the equations (Ron Ptolemy, personal communications).

Ptolemy's work is built on Allen's (1969) observations that the maximum density of a life stage of stream-dwelling salmonids within in an area of stream is a function of fish size. Allen's concept was further developed by Grant and Kramer (1990) who concluded that fish size explained 87 percent of the variation in territory size. For a given size of fish, the density that can be supported in an area of habitat would be limited by the amount of aquatic food available. Mason and Chapman (1965) and Chapman (1966) hypothesized that the spatial requirements of fish limit their density below ceilings *set by the food supply*. Mason (1976) found proof of such food limitation for juvenile coho in a field study where he supplemented the natural food abundance in a stream. Subsequent work in British Columbia with nutrient enrichment of streams has produced strong evidence for food limitations (Stockner 2003).

While the concept relating food in streams to maximum fish density is well established, a quantitative relationship linking food and density is not available. To get around this, we assume that there is a relationship between stream alkalinity and food available for salmonids within a stream. Alkalinity is broadly correlated with the productive capacity of streams, with respect to both primary production and fish production (McFadden and Cooper 1962; Ptolemy 1993; Bisson and Bilby 1998). Hard waters tend to be more productive, though reasons for this have not been clearly established (Hynes 1970; Allan 1995); it is generally assumed that it is due to food production (Ptolemy 1993).

We then apply the relationship between alkalinity and fish density developed by Ptolomy (1993) to calculate maximum fish density for different life stages. The key concept in our use of Ptolomy's equation is that while he related stream alkalinity to fish density, we assume the correlation is a surrogate for the effect of food availability, as suggested by Ptolemy himself. However, the abundance of organisms in streams used as food by salmonids is not simply a function of alkalinity. Food abundance is also affected by the health of the benthic invertebrate population, the quantity of salmon carcasses, and the amount of allochthanous inputs from the riparian zone. Because of this, we develop a term for use in Ptolomy's equation that incorporates a broad definition of food, and we assume that this food term affects fish density in the same manner portrayed by Ptolomy for alkalinity alone in the largely pristine streams he studied. Ptolemy's equation for the relationship between fish density for a life stage and alkalinity is:

$$Fish\_Density = 3300 \times ALKA^{0.5} \times SIZE^{-3}$$

where *Fish_Density* is measured in fish per m^2 of habitat, *ALKA* is alkalinity and *SIZE* is fork length in cm.[13] In EDT, an index of food based on Level 2 Attributes is converted to an alkalinity term (*ALKA*) and used in Ptolomy's equation to estimate maximum fish density for a life stage. The EDT index of alkalinity based on food attributes for use in Ptolomy's equation is created in two steps: first, development of a food index based on Level 2 Attributes, and second, creating a relationship between this food index and the stream alkalinity term in Ptolomy's equation.

The index of food availability in EDT incorporates four or five Level 2 Environmental Attributes depending on life stage:

- Alkalinity—use of this attribute is based on observations that alkalinity is broadly correlated with primary and secondary productivity of streams;
- Benthic Community Richness—this attribute describes benthic diversity and is a measure of how land use affects food availability, measured by the B-IBI;
- Riparian Function—this attribute reflects potential contributions of terrestrial insects to fish food availability;
- Salmon Carcasses—this attribute defines the relative quantity of salmonid carcasses within the area; and
- Fish Community Richness—this attribute reflects how fish prey become an important source of food for Age-2 and older bull trout.

[13] / The equation differs slightly for coho for reasons given in Ptolemy (1993).

EDT incorporates these four or five (depending on life stage) Attributes to derive a FOOD index for each stream as:

$$FOOD = 4 - \left[\sum_j (a_j \bullet ATT_j^{\,b_j}) \right]$$

where *a* and *b* are rule parameters for the Level 2 Attributes of alkalinity, benthos, riparian function, salmon carcasses, and fish community richness (ATT_j). This results in an index for Food that is scaled from 0-4 with a 0 indicating a lack of food and a 4 indicating a super abundance of food (note that this is opposite of the categorical ratings for most attributes). We then associate our scale of 0-4 for food ratings with the range of alkalinity seen across the Pacific Northwest (Figure 12). This relationship results in a value of "alkalinity" for use in Ptolomy's equation that incorporates a broader measure of food controls applicable to streams with more constraints on food production than just alkalinity. Using Ptolomy's equation with this food term, we calculate a maximum fish density for a given environmental condition.

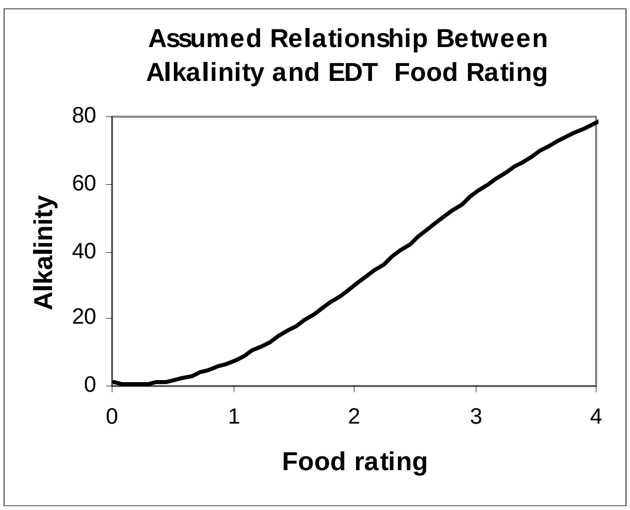

Figure 12. Assumed relationship between food rating and total alkalinity, based on the range of alkalinity values applied by Ptolemy (1993). Alkalinity here is used as a surrogate of total food availability in a stream to juvenile salmonids.

The last step in calculating the fish density is to use the density derived above, which accounts for the food availability in the stream, to adjust the Benchmark densities. To do this, we compute a scalar between 0 and 1 that reflects the adjustment described above to the Ptolomy estimate of density as a result of food abundance in the stream:

$$Food\_Scalar = Fish\_Density / Max\_Density$$

where, *Fish_Density* is the fish density adjusted for food conditions in the stream that comes from the Ptolomy equation, and *Max_Density* is the fish density from the Ptolomy equation when all the food attributes are set to their maximum (best) value. Finally, *Food_Scalar* times the Benchmark density in Appendix B gives the adjusted fish density that is used to compute capacity in the stream.

3.3.3.2. Food effects on life stage productivity

To this point in the food discussion, the results are applied in a manner that affects how food abundance directly affects Capacity. We also apply the food rating to adjust life stage Productivity, consistent with evidence that suggests that food characteristics affect survival at very low population densities, i.e., in the absence of density effects. Ward and others (2003) and Wilson and others (2003) found that enrichment of food resources in oligotrophic rivers of British Columbia using fertilizers containing marine derived nutrients significantly increased survival even when populations were extremely depressed. This suggests that the quality of food resources can be enhanced in such a manner that it can affect survival even when competition for food is minor.

To estimate the effect on productivity, we apply the attribute ratings in the **Synergistic Form** of the productivity equation presented earlier. The resulting survival factor F_i is allocated equally across the number of deemed relevant life stages for the species. For bull trout, we compute a food factor value for life stages younger than Age-2 and for Age-2 and older separately. For Age-2 and older life stages, we incorporate Fish Community Richness in recognition that bull trout begin switching to fish prey at this age (Shepard and others 1984b).

Although much research is now being focused on improving understanding about what affects food abundance in streams and how it is utilized by fish, there remains considerable uncertainty (Stockner 2003). Results of EDT incorporating effects on both capacity and productivity, however, produce results that compare favorably with how coho and steelhead populations have been found to respond to stream enrichment studies in streams in British Columbia (Ward and others 2003; Wilson and others 2003).

Chapter 4
Highlighted Survival Factors and Examples of Rules

This section describes rules for survival factors selected to illustrate how the rules operate. They address many of the issues generally regarded as the most important ones facing bull trout within the coastal and interior regions. Although this is only a subset of the entire bull trout rule set, it provides a wide range of examples of the different types of rules and how they were formulated. The logic, approach, and key studies applied are given. The range of rules described here illustrate how the rules have different levels of confidence or "proof" depending on how much is known from documented empirical relationships or quantitative studies. Some rules are based on well-documented relationships, while others apply inferences using a weight of evidence approach.

Rules can differ between populations with life history forms that mature as large bodied spawners (i.e., fluvial, adfluvial, and anadromous) versus the form that matures as small-bodied spawners (i.e., resident). The effects of some survival factors, such as channel stability, are expected to differ for very different sized fish or their progeny.

The survival factors and their rules described here:

- Channel stability
- Fine sediment
- Temperature
- Key habitat
- Inter-specific competition (includes hybridization)

4.1. Channel Stability

Issue: Bed scour and channel stability can affect survival of incubating and young bull trout. The effect of bed scour on incubating bull trout redds can be significant (Shellberg 2002).

Life stages highlighted below: Egg incubation (to the point of fry emergence)

Life stage: Egg incubation

<u>Approach to rule formulation:</u> These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2.4.1. They apply the synergistic form of the rules.

Elements of the underlying hypothesis for these rules are:

- Expected egg survival at spawning sites within a reach is related to the average depth of scour that could be measured at habitat types used for spawning (based on Schuette-Hames and Adams 2003); and
- For reaches with comparable mean scour depths, average egg survival is greater in reaches with pockets of stable spawning sites associated with LWD, secondary channels, and the stream margin because spawners will tend to select the more stable sites if available (based on Shellberg 2002).

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following:

Level 2 Attribute	Role	Rationale
Bed scour	Primary	Streambed scour during high flow events can dislodge some or all incubating eggs or alevins at spawning sites resulting in mortality. Major bed scouring events can result in very high loss.
Riparian function	Modifier	Loss of riparian function can result in loss of side channels (somewhat protected from high flows), often used by spawning bull trout if available, increasing susceptibility of eggs to scour events.
Wood	Modifier	Loss of wood, particularly large wood lodged along a stream, can cause a loss in relatively protected sites for egg deposition, increasing overall susceptibility in a reach to bed scour events.
Icing	Modifier	Icing events, particularly severe ones in areas with little wood and impaired riparian function, can alter stream features along the stream margin, creating less suitable sites for egg incubation.
Habitat type - side channel factor	Modifier	Bull trout tend to use low energy side channels compared to the main channel if available.
Habitat type - side channel type	Modifier	Bull trout tend to use low energy side channels compared to the main channel if available.

Char egg burial depth ranges from 2-25 cm, depending on spawner size and gravel size (DeVries 1997). Large females usually bury their eggs deeper than smaller ones. Although burial depth can vary significantly, it is believed to typically be in the range 10-15 cm. We infer from these conclusions the relationship in Figure 13 between egg mortalitiy (shown as sensitivity) and EDT bed scour ratings (see Appendix D for definitions). We assume that mortality rate would differ for different sizes of spawners. Eggs of small-bodied bull trout (i.e., stream resident life history form, maximum spawner length < 275 mm) are shown as more sensitive to bed scour than large bodied bull trout.

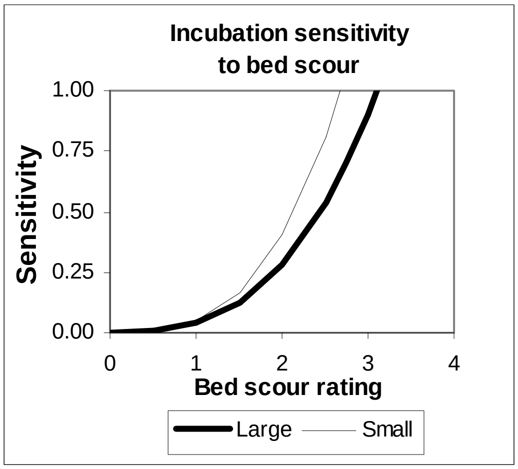

Figure 13. Assumed relationships between EDT bed scour ratings and mortality of incubating bull trout eggs. Different relationships are shown for eggs of small-bodied females (i.e., stream residents, maximum spawner size < 275 mm) and those of large bodied females.

Using the synergistic form of the rules, we formulated assumptions about the amount of increase in mortality that would occur as ratings for the modifying attributes would change from pristine to severely altered conditions. Each of the modifying attributes is assumed to make survival conditions worse as it moves from a rating 0 to a 4. Our conclusions regarding the combined effects of the attributes are not based on empirical studies; they are inferred from the qualitative conclusions of Shellberg (2002).

The rules do not change with stream size or the hydrologic regime of the stream.

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: Incubation (synergistic rule form)					
Attribute (rating to right)	Example				
	A	B	C	D	E
Bed scour	0	1	2	3	2
Riparian function	0	0	0	0	0
Wood	0	0	0	0	3
Icing	0	0	0	0	3
Habitat type - side channel factor	0	0	0	0	2
Habitat type - side channel type	0	0	0	0	0
Large bodied bull trout					
Relative productivity	1.00	0.96	0.72	0.10	0.79
Benchmark survival	0.65	0.65	0.65	0.65	0.65
Absolute survival	0.65	0.62	0.47	0.07	0.52
Small bodied bull trout					
Relative productivity	1	0.95	0.59	0	0.69
Benchmark survival	0.65	0.65	0.65	0.65	0.65
Absolute survival	0.65	0.62	0.39	0	0.45

4.2. Fine Sediment

Issue: Fine sediment entrained or passing through a stream reach can have significant, adverse effects on the survival of incubating eggs and alevins, rearing juveniles, and older life stages of bull trout.

Life stages highlighted below: Egg incubation, 0-age resident rearing, 0-age inactive (overwintering)

Life stage: Egg incubation

Approach to rule formulation: Based on information contained in Chapter 2.4.2 of this report, we formulated two sets of rules to define the effect of fine sediment on incubating eggs and alevins. The first set defines mortality when the dominant particle size for fine sediment within the substrate is sand sized (i.e., 1-6 mm). The second set targets conditions with fine sediment dominated by "fines" (i.e., <1 mm). These different rule formulations are consistent with Kondolf's (2000) recommendations for assessing effects of fine sediment on survival to fry emergence (STE).

We describe these two groups of rules separately below.

(1) *Effects of sand sized fine sediment effects:*

These rules are based on the empirical relationship given in Weaver and Fraley (1991) with modifying effects using a weight of evidence approach. They apply the synergistic form of the rules.

Elements of the underlying hypothesis for these rules are:

- STE of bull trout eggs is affected by the amount of sand-sized particles in and on the substrate, as seen in Figure 3, due primarily to the effects of entombment and secondarily to reduced oxygenation;
- Shallow bed scour that can occur late in the incubation period reduces the potential for entombment by removing sand-laden overlying strata above incubating alevins (based on discussions in the Missoula workshop on November 21, 2002[14]);
- Groundwater entering a spawning reach, even in relatively small quantities, can ameliorate effects of fine sediment on STE; abundant groundwater reduces effects of fine sediment dramatically due to upwelling because of less risk of entombment in addition to improving oxygenation (Weaver and Fraley 1991; Waters 1995; Garrett and others 1998);
- Adverse effects of fine sediment on STE are greater for eggs of small bodied than large bodied bull trout; small bodied female salmonids have smaller eggs than large bodied females, producing smaller fry; smaller fry have more difficulty emerging through sand sized particles than larger fry, thereby experiencing greater mortality (Phillips and others 1975; Tappel and Bjornn 1983); additionally, smaller eggs experience higher mortality than larger eggs under reduced dissolved oxygen conditions (Einum and others 2002).[15]

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following:

Level 2 Attribute	Role	Rationale
Bed scour	Modifier	Bed scour above incubating alevins can remove sand-laden gravel that can potentially block fry emergence from the spawning bed.
Groundwater inputs	Modifier	Groundwater inputs into a reach can lessen the effects of fine sediment; groundwater can provide upwelling in spawning beds and improved conditions for incubation and emergence.
Fine sediment - >1 and <6 mm particles	Primary	Moderate to high concentrations of intragravel fine sediment can cause significant stress and mortality to incubating eggs and alevins through entombment or reduced oxygenation.

[14]/ The role of bed scour on ameliorating sediment effects on STE were discussed at the bull trout biological rules workshop held in Missoula, MT on November 21, 2002. In attendance were Brad Shepard, Tom Weaver, Clint Muhlfeld, Chris Frissell, Craig Barfoot, and Larry Lestelle.

[15]/ It has often been suggested that larger salmonid eggs consume a greater amount of dissolved oxygen than smaller eggs, and therefore, they should experience higher mortality under conditions of reduced oxygenation (Einum and others 2002). This assumption has only recently been tested. Einum and others (2002) reported that the bigger is worse hypothesis is wrong. They found that smaller salmonid eggs experience significantly lower survival than larger eggs under reduced oxygen levels, possibly due to less ability of smaller eggs to cope with stress of low oxygen.

We employed the linear relationship (Figure 3) of Weaver and Fraley (1991) as the basis for estimating the effects of sand sized particles on STE of eggs of large-bodied bull trout. We increased sensitivity to sediment of the eggs of small bodied bull trout, based on the observations of Phillips and others (1975) and Tappel and Bjornn (1983); we assumed a relatively modest increase in sensitivity although the graphs of Tapel and Bjornn suggest that the effect may be greater. We converted Figure 3 into sensitivity (as 1 minus survival) and plotted the values against the appropriate Level 2 rating values on the x-axis (Figure 14). As noted, we formulated a second relationship in Figure 14 for eggs of small bodied female spawners.

Using the synergistic form of the rules, we formulated assumptions about how mortality would change as ratings for the modifying attributes vary. When the bed scour attribute ratings increase to ratings higher than 0 (essentially no scour), the effect of sand-sized sediment is decreased. Our assumption about the amount of effect is based on discussions held at the Missoula workshop on November 21, 2002 (see footnote 12). The second modifying attribute, Groundwater inputs, also operates to ameliorate fine sediment effects. As the groundwater rating decreases from a rating of 4 (no groundwater present), indicating that groundwater input increases, then the effect of fine sediment is assumed to decrease. We had no empirical data to apply here, only qualitative observations summarized in Bjornn and Reiser (1991) and Waters (1995). We assumed, based on those observations, that survival would be dramatically improved when the dominant flow source is well oxygenated groundwater, even when fine sediment quantity is high.

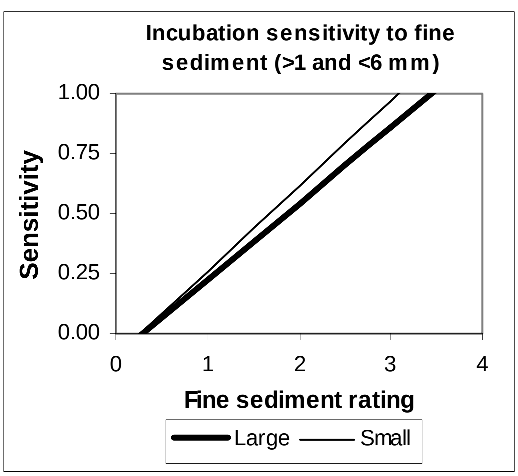

Figure 14. Relationships between EDT fine sediment (>1 and <6 mm) ratings and mortality of incubating bull trout eggs. Different relationships are shown for eggs of small bodied females (i.e., stream residents, maximum spawner size < 275 mm) and those of large bodied females. This relationship represents the total effect of fine sediment when there is no groundwater input occurring into the reach and there is no bed scour.

The rules do not change with stream size or the hydrologic regime of the stream.

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: Incubation (synergistic rule form)					
Attribute (rating to right)	**Example**				
	A	**B**	**C**	**D**	**E**
Fine sediment - >1 and < 6 mm	0	1	3	3	3
Bed scour	0	0	0	2	0
Groundwater inputs	4	4	4	4	0
Large bodied bull trout					
Relative productivity	1.00	0.78	0.14	0.26	0.61
Benchmark survival	0.65	0.65	0.65	0.65	0.65
Absolute survival	0.65	0.51	0.09	0.17	0.40
Small bodied bull trout					
Relative productivity	1	0.74	0.03	0.16	0.50
Benchmark survival	0.65	0.65	0.65	0.65	0.65
Absolute survival	0.65	0.48	0.02	0.10	0.33

(2) Effects of fine sediment < 1 mm diameter:

The effects of fine sediment < 1 mm in diameter on incubating eggs are believed caused primarily to reduced oxygenation corresponding to loss of substrate permeability as fines increase, particularly when redds are located in sites of downwelling (see Chapter 2.4.2). In contrast to the linear relationship between survival and sand-sized sediment, the effects due to smaller particle sizes appear to be manifested through a curvilinear relationship (Figure 4). We are not aware of an empirical relationship established for bull trout for the effects of sediment < 1 mm in size. Therefore we employed the relationship established for coho salmon from Tagart (1984). We apply the synergistic form of the rules.

Elements of the underlying hypothesis for these rules are:

- Survival to emergence (STE) of bull trout eggs is affected by the amount of fine sediment particles < 1 mm in size (when this size fraction is the dominant size of fine sediment) within the substrate because sediment affects oxygenation to eggs and alevins;
- Groundwater entering a spawning reach, even in relatively small quantities, can ameliorate effects of small fine sediment on STE by increasing oxygen supply to eggs (Weaver and Fraley 1991); abundant groundwater reduces effects of fine sediment dramatically due to upwelling, which can significantly improve oxygenation even in heavily sedimented spawning beds (Waters 1995, Garrett and others 1998);

- Adverse effects of fine sediment < 1mm on STE are greater for eggs of small bodied than large bodied bull trout; small bodied female salmonids have smaller eggs than large bodied females, producing smaller fry; smaller eggs experience higher mortality than larger eggs under reduced dissolved oxygen conditions (Einum and others 2002)(see footnote 13 in this document).

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following:

Level 2 Attribute	Role	Rationale
Fine sediment - <1 mm particles	Primary	Moderate to high concentrations of intragravel fine sediment < 1 mm can cause significant stress and mortality to incubating eggs and alevins through reduced oxygenation.
Groundwater inputs	Modifier	Groundwater inputs into a reach can lessen the effects of fine sediment; groundwater can provide upwelling in spawning beds and improved conditions for incubation and emergence.

We employed the curvilinear relationship (Figure 4) of Tagart (1984) as the basis for estimating the effects of < 1 mm particles on STE of eggs of large-bodied bull trout. We increased sensitivity to sediment of the eggs of small bodied bull trout, based on the findings of Einum and others (2002). We assumed a relatively modest increase in sensitivity for the eggs of small-bodied females although the study of Einum and others suggests that the effect of egg size may be greater than what we have applied. We converted Figure 4 into sensitivity (as 1 minus survival) and plotted the values (Figure 15). We formulated a second relationship in Figure 15 for eggs of small bodied female spawners.

Using the synergistic form of the rules, we formulated assumptions about how mortality would change as ratings for the modifying attribute varies. The modifying attribute, Groundwater inputs, operates to ameliorate fine sediment effects. As the groundwater rating decreases from a rating of 4 (no groundwater present), indicating that groundwater input increases, then the effect of fine sediment is assumed to decrease. We had no empirical data to apply here, only qualitative observations summarized in Bjornn and Reiser (1991) and Waters (1995). We assumed, based on those observations, that survival would be dramatically improved when the dominant flow source is groundwater, even when fine sediment quantity is high.

The rules do not change with stream size or the hydrologic regime of the stream.

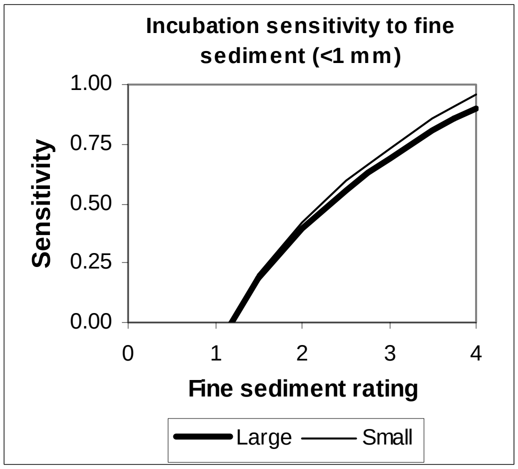

Figure 15. Relationships between EDT fine sediment (<1 mm) ratings and mortality of incubating bull trout eggs. Different relationships are shown for eggs of small bodied females (i.e., stream residents, maximum spawner size < 275 mm) and those of large bodied females. This relationship represents the total effect of fine sediment when there is no groundwater input occurring into the reach.

<u>**Examples of effect**</u>

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: Incubation (synergistic rule form)					
Attribute (rating to right)	Example				
	A	B	C	D	E
Fine sediment - <1 mm	1	2	2	3	3
Groundwater inputs	0	4	0	4	0
Large bodied bull trout					
Relative productivity	1.00	0.61	0.87	0.31	0.71
Benchmark survival	0.65	0.65	0.65	0.65	0.65
Absolute survival	0.65	0.39	0.57	0.20	0.46
Small bodied bull trout					
Relative productivity	1.00	0.58	0.84	0.27	0.65
Benchmark survival	0.65	0.65	0.65	0.65	0.65
Absolute survival	0.65	0.38	0.54	0.17	0.42

<u>**Life stage:**</u> 0-age resident rearing

<u>**Approach to rule formulation:**</u> This group of rules addresses the effects of fine sediment on the 0-age resident rearing stage of bull trout. It includes the effects of two aspects of fine sediment load in a stream, <u>suspended sediment (including turbidity) in the water column and fine sediment that embeds the intersticial spaces of the upper stratum of the substrate (embeddedness).</u> These rules are based on a empirically derived index for sensitivity to suspended sediment in conjunction with a weight of evidence approach that considers

synergistic effects of embeddedness. They apply the synergistic form of the rules.

The rules utilize a scale of severity effect of suspended sediment derived from Newcombe and Jensen (1996), in addition to the general conclusions of the effects of embeddedness on rearing salmonids discussed by Chapman and McLeod (1987).

Elements of the underlying hypothesis for these rules are:

- High amounts of suspended sediment can affect the performance of rearing bull trout by influencing fish behavior and physiology, resulting in stress and reduced survival;
- The severity of effect of suspended sediment increases as a function of both sediment concentration and exposure time, or dose (Newcombe and Jensen 1996; Bash and others 2001);
- Higher water temperatures act through synergism to increase the effect of suspended sediment, probably due to temperature-related patterns of oxygen saturation, respiration rate, and metabolic rate (Newcombe and Jensen 1996);
- Embedded substrates are expected to increase adverse effects of fine sediment on bull trout performance because rearing juveniles utilize cobbles for hiding cover; embedded cobbles reduce the quality of the substrate as resting cover (Bjornn and Reiser 1991); bull trout would be less active when unembedded cobbles are available by providing resting cover, reducing respiration and effects of suspended sediment.

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following:

Level 2 Attribute	Role	Rationale
Turbidity (or suspended sediment)	Primary	High suspended sediment can cause significant stress and mortality to juvenile salmonids due to impairme nt of respiration and feeding efficiency.
Temperature (max)	Modifier	Tolerance to turbidity is decreased as water temperatures increase above preferred temperatures and can increase effect of sediment.
Embeddedness	Modifier	Embeddedness of the substrate surface reduces interstitial spacing between cobbles, reducing the effectiveness of substrate as hiding or refuge cover.

The rules formulated for this life stage are very similar to those applied to the juvenile inactive (or overwintering) life stages. For the 0-age rearing stage, we used suspended sediment as the primary attribute to define the contribution of the sediment factor with embeddedness as a modifier, whereas we reversed the role of these two attributes for the inactive life stage. We assumed that bull trout would be more closely associated with the substrate during winter temperatures than during summer, although their association with substrate during summer is still strong. Also, salmonids in general appear to be less sensitive to suspended sediment during winter (Noggle 1978), apparently because of reduced respiratory and metabolic requirements. We assume these characteristics exist for bull trout as for other salmonids, though it may be less the case for bull trout because of their preference for colder water.

The severity of effect of suspended sediment increases as a function of both sediment concentration and exposure time, or dose (Newcombe and Jensen 1996, Bash and others 2001). Newcombe and Jensen (1996) performed a meta-analysis of data contained in 80 published and documented reports to assess the effects of dose on fish responses, including numerous studies involving salmonids. The analysis yielded empirical equations that relate biological response to duration of exposure and suspended sediment, including two that specifically address salmonids. Equation 1 presented in that paper, applicable to all life stages, is used here to derive their scale of severity (SEV) for estimating effects on salmonid life stages (adapted in Table 5). We then aligned our rating system of 0-4 to their scale, consistent with our intent to span the general range of effects across our rating scale as described earlier (Table 6; also shown as boundaries in Table 5).

We interpret Table 5 as seen in Figure 16 – giving a relationship between life stage survival and SEV (based on discussion in Newcombe and Jensen, we assume these results apply to actively rearing fish, as well as adult prespawners). Figure 16 is then easily converted to a relationship between our rating scale of 0-4 and life stage sensitivity (Figure 17).

Table 5. Scale of Severity (SEV) Index for suspended sediment, adapted from Newcombe and Jensen (1996). Boundaries shown encompass corresponding Level 2 index values, e.g., index value 0 corresponds to SEV values ≤4.5, index value 1 corresponds to SEV values >4.5 and ≤7.5, etc.

Duration (hrs)	Suspended sediment concentration (mg/l)														
	1	2	4	6	8	10	25	50	150	300	1,000	5,000	10,000	15,000	20,000
1	0.6	1.6	2.1	2.4	2.6	2.8	3.4	4.0	4.8	5.3	6.2	7.4	7.9	8.2	8.4
24	2.5	3.5	4.0	4.3	4.5	4.7	5.4	5.9	6.7	7.2	8.1	9.3	9.8	10.1	10.3
48	2.9	3.9	4.4	4.7	4.9	5.1	5.8	6.3	7.1	7.6	8.5	9.7	10.2	10.5	10.7
72	3.1	4.2	4.7	5.0	5.2	5.4	6.0	6.5	7.4	7.9	8.8	9.9	10.5	10.8	11.0
96	3.3	4.3	4.9	5.2	5.4	5.5	6.2	6.7	7.5	8.0	8.9	10.1	10.6	10.9	11.1
120	3.5	4.5	5.0	5.3	5.5	5.7	6.3	6.9	7.7	8.2	9.1	10.3	10.8	11.1	11.3
144	3.6	4.6	5.1	5.4	5.6	5.8	6.5	7.0	7.8	8.3	9.2	10.4	10.9	11.2	11.4
168	3.7	4.7	5.2	5.5	5.7	5.9	6.6	7.1	7.9	8.4	9.3	10.5	11.0	11.3	11.5
336	4.1	5.1	5.6	5.9	6.1	6.3	7.0	7.5	8.3	8.8	9.7	10.9	11.4	11.7	11.9
504	4.3	5.4	5.9	6.2	6.4	6.5	7.2	7.7	8.5	9.1	9.9	11.1	11.6	11.9	12.2
672	4.5	5.5	6.0	6.3	6.6	6.7	7.4	7.9	8.7	9.2	10.1	11.3	11.8	12.1	12.3
840	4.6	5.7	6.2	6.5	6.7	6.9	7.5	8.0	8.8	9.4	10.3	11.4	12.0	12.3	12.5
1,008	4.7	5.8	6.3	6.6	6.8	7.0	7.6	8.1	9.0	9.5	10.4	11.5	12.1	12.4	12.6
1,176	4.8	5.9	6.4	6.7	6.9	7.1	7.7	8.2	9.1	9.6	10.5	11.6	12.2	12.5	12.7
1,344	4.9	5.9	6.5	6.8	7.0	7.1	7.8	8.3	9.1	9.6	10.5	11.7	12.2	12.5	12.7
1,512	5.0	6.0	6.5	6.8	7.0	7.2	7.9	8.4	9.2	9.7	10.6	11.8	12.3	12.6	12.8
1,680	5.1	6.1	6.6	6.9	7.1	7.3	7.9	8.5	9.3	9.8	10.7	11.9	12.4	12.7	12.9
1,848	5.1	6.1	6.7	7.0	7.2	7.3	8.0	8.5	9.3	9.8	10.7	11.9	12.4	12.7	12.9
2,016	5.2	6.2	6.7	7.0	7.2	7.4	8.1	8.6	9.4	9.9	10.8	12.0	12.5	12.8	13.0
2,184	5.2	6.2	6.8	7.1	7.3	7.4	8.1	8.6	9.4	9.9	10.8	12.0	12.5	12.8	13.0
2,352	5.3	6.3	6.8	7.1	7.3	7.5	8.2	8.7	9.5	10.0	10.9	12.1	12.6	12.9	13.1
2,520	5.3	6.3	6.8	7.1	7.4	7.5	8.2	8.7	9.5	10.0	10.9	12.1	12.6	12.9	13.1

Table 6. Scale of severity (SEV) index of ill effects associated with excess suspended sediment adapted from Newcombe and Jensen 1996) and corresponding Level 2 Suspended Sediment ratings used in rule formulation.

SEV	Description of effect	Level 2 SS rating
Nil effect		
0	No behavioral effects	
Behavioral effects		
1	Alarm reaction	
2	Abandonment of cover	0
3	Avoidance response	
Sublethal effects		
4	Short-term reduction in feeding rates; short term reduction in feeding success	
5	Minor physiological stress; increase in rate of coughing;	
6	Moderate physiological stress	1
7	Impaired homing	
8	Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition	
Lethal and paralethal effects		2
9	Reduced growth rate; reduced fish density	
10	0-20% mortality; increased predation	
11	>20 – 40% mortality	3
12	>40 – 60% mortality	
13	>60 – 80% mortality	4
14	>80 – 100% mortality	

The SEV index is easily computed by expressing suspended sediment in mg/l (which can be estimated from turbidity NTUs) and making a reasoned assumption about the percent of time during the worst case month (on average) when that concentration is attained. Details on how SEV is computed this Attribute rated can be found in Lestelle (2004).

Although it is readily accepted that higher temperatures act through synergism to increase the effect of suspended sediment, the extent of the effect has not yet been quantified in a manner to be included directly in the SEV index (Newcombe and Jensen 1996). The authors of the SEV state that the effect probably has to do with temperature-related patterns of oxygen saturation, respiration rate, and metabolic rate of fishes. From our review, we conclude that a noticeable effect of synergy between suspended sediment and temperature is needed in the rule to recognize this effect. We therefore assumed what is likely a conservative synergistic effect, setting the sensitivity to temperature (maximum) in the rule to add approximately 20-25% greater effect with intermediate temperature ratings when they occur with intermediate suspended sediment ratings.

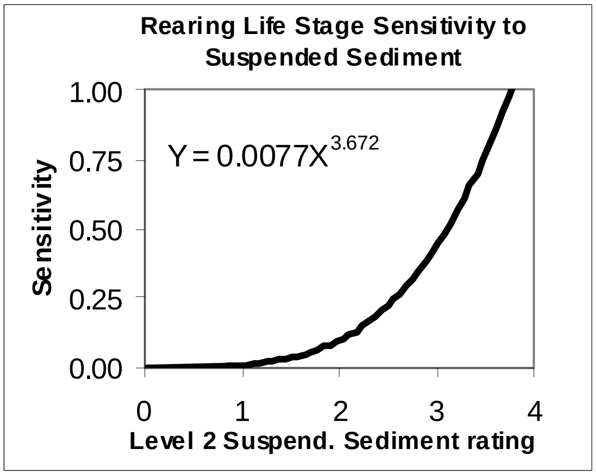

Figure 16. Relationship between scale of severity (SEV) index for suspended sediment (SS) and percent survival in rearing and prespawning life stages for salmonids - interpreted from Newcombe and Jensen (1996).

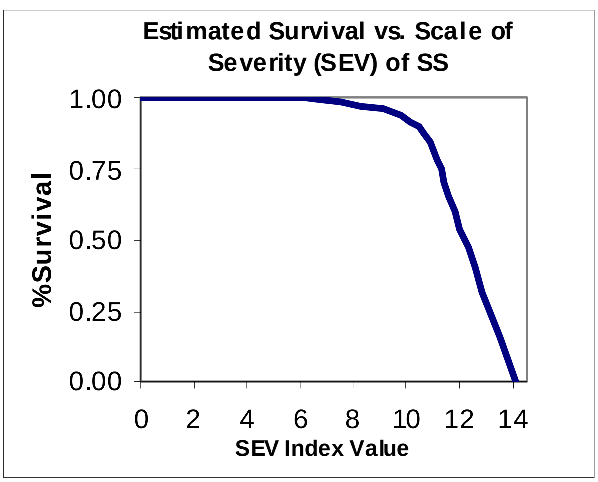

Figure 17. Relationship between ratings for Level 2 Suspended Sediment (SS) and sensitivity of salmonids during active rearing stages, derived by converting the relationship in Figure 16.

An added effect of fine sediment on 0-age resident rearing is expected when the substrate is embedded. Juvenile bull trout remain in close association with the substrate, using cobbles as hiding cover. Embeddedness describes the extent that interstitial spaces between cobble and gravel on the substrate surface is filled with fine particles. It is well documented that the capability of the substrate to hold juvenile salmonids during winter diminishes as the substrate becomes more embedded (Bjornn and Reiser 1991), implying that overall habitat quality during this life stage declines with sedimentation. Because of the close association with cobbles during summer by juvenile bull trout, especially subyearlings, we infer that high embeddedness can increase mortality in this life stage. We therefore use embeddedness as a synergistic modifier to the primary Attribute used in this group of rules, increasing the overall effect of sediment as embeddedness increases. We apply a relatively modest synergistic effect due to embeddedness based on inference from Goetz (1997a) that high embeddedness during summer was not having large effect on survival.

The rules do not change with stream size or the hydrologic regime of the stream.

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: 0-age resident rearing (synergistic rule form)					
Attribute (rating to right)	**Example**				
	A	**B**	**C**	**D**	**E**
Suspended sediment	1	2	2	2	2
Temperature (max)	0	0	2	2	2
Embeddedness	0	0	0	2	3
Relative productivity	0.99	0.90	0.84	0.66	0.46
Benchmark survival	0.60	0.60	0.60	0.60	0.60
Absolute survival	0.60	0.54	0.50	0.40	0.27

Life stage: 0-age inactive (overwintering)

Approach to rule formulation: This group of rules is very similar to the fine sediment rules described above for 0-age resident rearing. It addresses the effects of fine sediment load in a stream on the inactive life stage (or overwintering). It includes effects of both embeddedness and suspended sediment. It applies a weight of evidence approach. The rules are structured using the synergistic form.

Elements of the underlying hypothesis for these rules are:

- The quality of the cobble substrate as refuge cover during overwintering for juvenile bull trout is reduced by embeddedness;

- A high suspended sediment load is expected to contribute to an adverse effect of fine sediment on bull trout performance by influencing fish behavior and physiology, resulting in stress and reduced survival;
- The severity of effect of suspended sediment increases as a function of both sediment concentration and exposure time, or dose (Newcombe and Jensen 1996; Bash and others 2001).

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following:

Level 2 Attribute	Role	Rationale
Embeddedness	Modifier	Embeddedness of the substrate surface reduces interstitial spacing between cobbles, reducing the effectiveness of substrate as hiding or refuge cover.
Turbidity (or suspended sediment)	Primary	High suspended sediment can cause significant stress and mortality to juvenile salmonids due to impairme nt of respiration and feeding efficiency.

Embeddedness describes the extent that interstitial spaces between cobble and gravel on the substrate surface is filled with fine particles. Some species of salmonids, including bull trout, use the voids between cobbles as hiding cover during the inactive (overwintering) life stage. It is well documented that the capability of the substrate to hold juvenile salmonids during winter diminishes as the substrate becomes more embedded (Bjornn and Reiser 1991) implying that overall habitat quality during this life stage declines with sedimentation. Further, the overall sensitivity to fine sediment during this stage can include effects of suspended sediment, as described above for the active rearing stages. Here, however, fish in the inactive stage are much less sensitive to suspended sediment (Noggle 1978), apparently because of reduced respiratory and metabolic requirements. We therefore allowed for some added effect of suspended sediment and assumed that it would operate to increase sensitivity identified with embeddedness in this case.

Efforts to quantify effects of embeddedness on overwintering salmonids in general are based in large part on studies by Bjornn and others (1977) and Hillman and others (1987). Both studies reported that juvenile salmonid densities were reduced by more than half when cobble substrate became highly embedded. We are not aware of any studies in which mortality was specifically assessed in relation to embeddedness, though it is believed to increase under such conditions (Waters 1995).

Lacking a quantitative relationship to apply, we drew on Chapman and McLeod's (1987) interpretation of the Bjornn and others (1977) and Hillman and others (1987) studies. They concluded that a reduction in winter habitat must occur at embeddedness levels somewhere between 0% and 66% and at that level or higher that such areas would be made unusable by overwintering fish. They also stated: "We have no doubt that functional relationships exist between embeddedness and winter holding capacity of the substrate for salmonids, and that those relationships differ by fish size and perhaps by species."

We conclude from the foregoing that it is reasonable to hypothesize a functional relationship between the survival of fish that attempt to overwinter in embedded stream reaches and the degree of embeddeness. We hypothesize that the relationship between survival and embeddedness would show little effect up to about 66% embeddedness, and then exhibit a very rapid decrease in survival above that level (Figure 18). We recast the relationship in Figure 18 in terms of sensitivity corresponding to the Level 2 embeddedness ratings (Figure 19). We assumed that the sensitivities of bull trout are the same as those we have previously applied to Chinook and steelhead during this life stage.

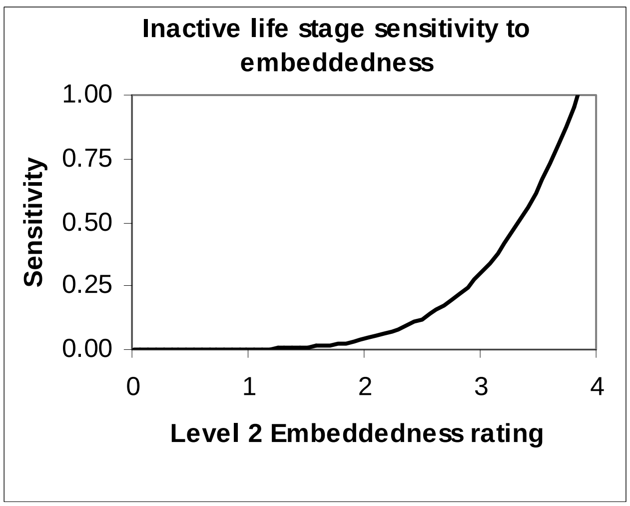

Figure 18. Relationship between survival and embeddedness for juvenile bull trout during the inactive (overwintering) life stage. The relationship is hypothesized based on general conclusions in Chapman and McLeod (1987).

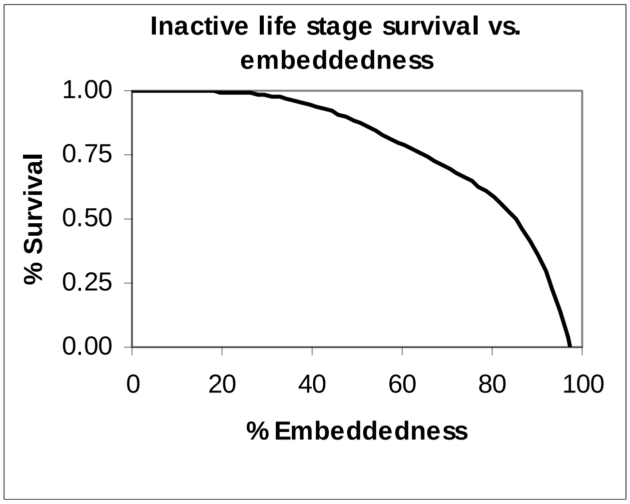

Figure 19. Relationship between ratings for Level 2 Embeddedness and sensitivity for juvenile bull trout during the inactive (overwintering) life stage—based on Figure 18.

Additional mortality due to sedimentation could also occur if pulses of suspended sediment are sufficiently high. The tolerance of juvenile salmonids to suspended sediment during winter is known to be much higher than during periods of active rearing, likely due to a reduced state of activity. Still, some added effect associated with high SS doses is expected. We treat this potential effect as operating in a synergistic manner with embeddedness. If embeddedness is low, then the effect that might be ascribed to high suspended sediment doses should be much lower than if embeddedness is high, when fish should be more exposed to suspended sediment. We consider exposure here in the sense that fish would be more likely to enter the water column when embeddedness is high, instead of remaining in a resting state within the substrate when embeddeness is low. Hence a higher state of activity should make them more vulnerable to suspended sediment.

The rules do not change with stream size or the hydrologic regime of the stream.

<u>**Examples of effect**</u>

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: 0-age inactive (synergistic rule form)					
Attribute (rating to right)	Example				
	A	B	C	D	E
Embeddedness	2	2	3	3	3.8
Suspended sediment	0	2	0	2	0
Relative productivity	0.96	0.86	0.70	0.44	0.05
Benchmark survival	0.70	0.70	0.70	0.70	0.70
Absolute survival	0.67	0.61	0.49	0.31	0.04

4.3. Temperature

Issue: Water temperature is considered the most important factor affecting bull trout abundance and distribution within much of its geographic range. The species is among the most thermally sensitive salmonids in western North America. Consequently, bull trout are believed to be highly vulnerable to increases in water temperature that can occur with land use practices.

Life stages highlighted below: 0-age resident rearing, 0-age inactive, pre-spawning adult migrant

Life stage: 0-age resident rearing

Approach to rule formulation: These rules are based on a weight of evidence approach. Inferences about responses to temperature are drawn from the empirical studies and modeling predictions described in Chapter 2.4.5 (particularly Gamett 2002 and Dunham and others 2003), as well as expert conclusions provided in the Missoula workshop of November 21, 2002, cited earlier (footnote 12). The rules apply the synergistic form.

Elements of the underlying hypothesis for these rules are:

- During warm temperature months, juvenile bull trout are highly sensitive to water temperatures greater than their preferred thermal range, which is among the lowest for salmonids; elevated temperatures can affect behavior and growth rates, indirectly influencing mortality, or mortality rates directly;
- Adverse effects on performance from temperatures near the physiological limits within a stream reach are ameliorated where thermal refugia exist due to spring sources and groundwater upwelling.

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following for the 0-age rearing life stage:

Level 2 Attribute	Role	Rationale
Temperature – maximum daily	Primary	Water temperatures higher than levels preferred by bull trout can cause significant stress or death. Elevated temperatures affect growth and behavior and can cause shock.
Temperature – spatial variation	Modifier	Lack of spatial variation in water temperature can increase overall effect of water temperature in a stream reach. Spatial variation provides relief or refugia from high temperatures.

We formulated the rules for maximum daily temperature and survival of bull trout juveniles based on conclusions provided to us by the technical team who participated in the Missoula workshop, as well as inferences drawn from

Figure 7. The attribute that we use to characterize high temperature considers the number of days in a 30-day period when maximum daily temperature exceeds 16 °C, in addition to numbers of days when the maximum temperature exceeds other levels treated as thresholds. Gamett (2002) found a high correspondence between bull trout presence and density and the maximum daily temperature during summer. A high correspondence was also found between these response variables and the number of days when maximum temperature exceeded 15 °C. Both conditions are used in our rules, though we apply 16 °C instead of 15 °C.

Figure 20 compares the primary relationship used in the rules for bull trout to the relationship that we have previously developed for rainbow-steelhead trout.

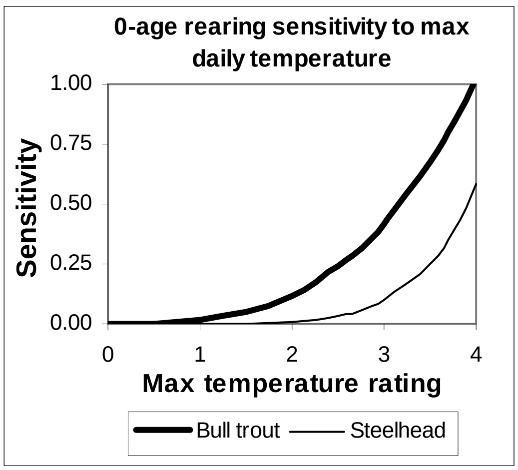

Figure 20. Relationships between EDT maximum daily temperature ratings and mortality of 0-age resident rearing juvenile bull trout and age-0 resident rearing rainbow-steelhead trout.

Applying the rules, combined with corresponding ones for the next two age groups, produces survival through age-2 that closely matches the predicted probability of occurrence seen in Figure 7.[16]

Selong and others (2001) reported that age-0 bull trout had slightly greater temperature tolerance than yearlings.

Using the synergistic form of the rules, we formulated assumptions about how mortality would change as the rating for the modifying attribute, Temperature Spatial Variation, varies. The modifying attribute operates to ameliorate temperature effects. We had no empirical data to apply here. We assumed that when spatial variation is high, i.e., a rating of 0, that there would still be a very

[16]/ We assumed a rating of 2 (midpoint of rating range) for the attribute Temperature spatial variation in the computations because of the likelihood that many streams in the data set analyzed by Dunham and others (2003) had some amount of thermal refugia.

substantial temperature consequence when the maximum temperature measured in a reach is high. When no spatial variation exists at high maximum temperatures, the effect would be to essentially eliminate bull trout from a reach. We believe these conclusions are consistent with the findings of Dunham and others (2003).

The rules do not change with stream size or the hydrologic regime of the stream.

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: 0-age resident rearing (synergistic rule form)					
Attribute (rating to right)	Example				
	A	B	C	D	E
Temperature – maximum daily	2	2	3	3	3
Temperature – spatial variation	0	2	2	3	4
Relative productivity	0.88	0.82	0.46	0.35	0.21
Benchmark survival	0.60	0.60	0.60	0.60	0.60
Absolute survival	0.53	0.49	0.27	0.21	0.13

Life stage: 0-age inactive (overwintering)

Approach to rule formulation: These rules are based on a weak application of a weight of evidence approach. We are unaware of any useful, direct observations about the effects of prolonged cold temperature on bull trout.[17] We formulate our hypothesis based on limited knowledge of the effects of cold temperature on rainbow trout and differences in temperature tolerances in general between the species. The rules apply the synergistic form.

Elements of the underlying hypothesis for these rules are:

- During winter, water temperatures at or near freezing for prolonged periods can increase mortality rate due to reduced metabolism and inadequate energy reserves to sustain vital functions (Bjornn and Reiser 1991);
- Effects of cold water on bull trout are expected to be significantly less than those on other native salmonids of the Pacific Northwest due to their known preferences for colder water;
- Adverse effects on performance from temperatures near the physiological limits within a stream reach are ameliorated where thermal refugia exist due to spring sources and groundwater upwelling (Stanford and Ward 1992).

17/ Selong and others (2001) tested bull trout performance under laboratory conditions to cold water but concluded that the results were inaccurate. We have elected not to use their results.

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following for the 0-age inactive (overwintering) life stage:

Level 2 Attribute	Role	Rationale
Temperature – daily minimum	Primary	Extremely cold water temperatures during winter can cause stress, poor growth, and death.
Temperature – spatial variation	Modifier	Lack of spatial variation in water temperature can increase overall effect of water temperature in a stream reach. Spatial variation provides relief or refugia from cold temperatures.

We formulated the rules for minimum daily temperature and survival of bull trout overwinter based on inferences from Smith and Griffith (1994) about the effects of cold temperature on 0-age rainbow trout, then by extrapolation to bull trout based on an assumed difference in temperature tolerances between the species. Smith and Griffith (1994) presented data on overwintering survival of 0-age rainbow trout under different thermal regimes at sites in the Henry's Fork, Idaho. At the coldest site, where the mean water temperature was 0.8 °C (roughly equivalent to our Level 2 Attribute rating of 4), groups of fish <100 mm in size had no survival. Larger fish exhibited some survival. Fish at warmer sites had dramatically higher survival. We have inferred from these data the relationship shown in Figure 21 for rainbow trout; the relationship shown assumes some thermal refugia exist.

Based on the fact that bull trout are known to thrive in much colder water than rainbow trout, we assume that they should have much higher tolerance for extreme cold water. We apply the relationship shown in Figure 21 in our rules, allowing that there should still be an effect at extreme temperatures. The relationship shown in Figure 21 assumes that pockets of thermal refugia exist within the stream reach.

Using the synergistic form of the rules, we formulated assumptions about how mortality would change as the rating for the modifying attribute, Temperature Spatial Variation, varies. The modifying attribute operates to ameliorate temperature effects. We had no empirical data to apply here. We assumed that when spatial variation is high, i.e., a rating of 0, that there would only be a modest temperature consequence when the minimum temperature for the reach in general is extremely cold.

The rules do not change with stream size or the hydrologic regime of the stream.

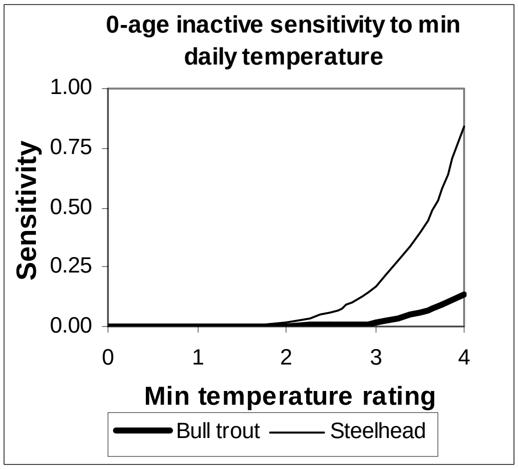

Figure 21. Relationships between EDT minimum daily temperature ratings and mortality of 0-age inactive (overwintering) juvenile bull trout and 0-age resident rearing rainbow-steelhead trout.

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: 0-age inactive (synergistic rule form)					
Attribute (rating to right)	Example				
	A	B	C	D	E
Temperature – minimum daily	2	3	3	4	4
Temperature – spatial variation	0	0	4	0	4
Relative productivity	1.00	0.98	0.93	0.86	0.72
Benchmark survival	0.70	0.70	0.70	0.70	0.70
Absolute survival	0.70	0.69	0.65	0.60	0.50

Life stage: Adult prespawning migrant

Approach to rule formulation: These rules are based on a weight of evidence approach. Inferences about responses to temperature are drawn from the material described in Chapter 2.4.5. The rules apply the synergistic form.

Elements of the underlying hypothesis for these rules are:

- During warm temperature months, adult bull trout are sensitive to water temperatures higher than their preferred thermal range, which is among the lowest for salmonids; elevated temperatures can affect behavior, indirectly influencing mortality, or mortality rates directly;
- Adults of healthy populations of fluvial and anadromous bull trout migrate through mainstem rivers that are known to have temperatures maximum daily temperatures that frequently exceed 20 °C, inferring that adults have higher temperature tolerances than juveniles;

- Adverse effects on performance from temperatures near the physiological limits within a stream reach are ameliorated where thermal refugia exist due to spring sources and groundwater upwelling.

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following for the adult prespawning migrant life stages:

Level 2 Attribute	Role	Rationale
Temperature – daily maximum	Primary	Water temperatures higher than levels preferred by bull trout can cause significant stress or death. Elevated temperatures affect growth and behavior and can cause shock.
Temperature – spatial variation	Modifier	Lack of spatial variation in water temperature can increase overall effect of water temperature in a stream reach. Spatial variation provides relief or refugia from high temperatures.

We formulated the rules for maximum daily temperature and survival of adult prespawning bull trout by assuming a moderate increase in sensitivity compared to rainbow-steelhead trout (Figure 22). Our rainbow-steelhead trout rules are based on data summarized in McCullough (1999).

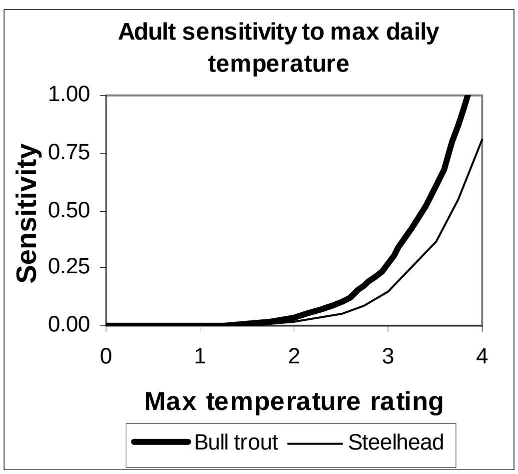

Figure 22. Relationships between EDT maximum daily temperature ratings and mortality of prespawning adult bull trout and rainbow-steelhead trout.

Using the synergistic form of the rules, we formulated assumptions about how mortality would change as the rating for the modifying attribute, Temperature Spatial Variation, varies. The modifying attribute operates to ameliorate temperature effects. We had no empirical data to apply here. We assumed that when spatial variation is high, i.e., a rating of 0, that there would still substantial temperature consequence, given the need for this life stage to migrate through the reach.

The rules do not change with stream size or the hydrologic regime of the stream.

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: Prespawning migrant (synergistic rule form)					
Attribute (rating to right)	**Example**				
	A	**B**	**C**	**D**	**E**
Temperature – maximum daily	1	2	2	3	3
Temperature – spatial variation	0	0	3	3	4
Relative productivity	1.00	0.97	0.89	0.49	0.33
Benchmark survival	0.95	0.95	0.95	0.95	0.95
Absolute survival	0.95	0.92	0.84	0.46	0.31

4.4. Key Habitat

Issue: Bull trout, like other salmonids, demonstrate preferences for specific types of habitat types (i.e., pools vs. riffles) in different life stages. Key habitat is defined as the primary habitat type(s) utilized by the species during a specific life stage. The composition of habitat types in a stream reach can have a significant effect on its capability to hold and produce bull trout.

This section addresses all highlighted life stages together in order to more clearly describe how the key habitat rules are structured.

Life stage: incubation, 1-age resident rearing, prespawning holding

Approach to rule formulation: Rules for habitat type use are given as utilization coefficients (weights), representing preferences during a life stage for each habitat type. The coefficients are based on inferences about observed utilization patterns in different life stages as described in Chapter 2.4.4.

Elements of the underlying hypothesis for these rules are:

- Habitat types selected for spawning and egg incubation are consistent with the patterns seen for most other salmonids;
- Juveniles will use all types of habitat but they are found most often in slow-water habitats; coefficients are assumed to be identical during summer and winter juvenile use;
- Adults primarily select pools for holding habitat.

All of the habitat types delineated in EDT are applied in the rules; their contributions to Key Habitat are simply determined from the coefficients (weights), as shown in Table 7. We conclude that utilization preferences are the same in summer and winter for juvenile bull trout based on the findings of Muhlfeld and others (2003).

Table 7. Utilization coefficients (weights) applied to bull trout incubation, 1-age juvenile rearing, and pre-spawning holding adult life stages. Coefficients are identical for the 1-age resident rearing and 1-age inactive life stages.

Attribute	Weight by life stage			
	Incubation	1-age res rearing	1-age inactive	Pre-spawn holding
Hab type - primary pools	0	1	1	1
Hab type - pool tailouts	0.8	0.43	0.43	0.25
Hab type - glides	0.4	0.5	0.5	0.25
Hab type - backwater pools	0	0.2	0.2	0
Hab type - beaver ponds	0	0.2	0.2	0
Hab type - large cobble/boulder riffles	0	0.43	0.43	0.1
Hab type - small cobble/gravel riffles	0.6	0.43	0.43	0
Hab type - off-channel factor	0	0	0	0
Hab type - side channel factor	1.5	1.5	1.5	1.5

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Incubation life stage

Attribute	Example 1			Example 2			Example 3		
	Percent of reach	Weight	Weighted percent	Percent of reach	Weight	Weighted percent	Percent of reach	Weight	Weighted percent
Hab type - primary pools	50	0	0	10	0	0	15	0	0
Hab type - pool tailouts	20	0.8	16	5	0.8	4	5	0.8	4
Hab type - glides	20	0.4	8	15	0.4	6	10	0.4	4
Hab type - backwater pools	0	0	0	0	0	0	5	0	0
Hab type - beaver ponds	0	0	0	0	0	0	10	0	0
Hab type - large cobble/boulder riffles	0	0	0	30	0	0	30	0	0
Hab type - small cobble/gravel riffles	10	0.6	6	40	0.6	24	25	0.6	15
Hab type - off-channel factor	0	0	0	0	0	0	0	0	0
Hab type - side channel factor	0	1.5	0	25	1.5	12.75	0	1.5	0
Sum	100		30	100		46.75	100		23

1-age resident rearing life stage (identical to 1-age inactive life stage)

Attribute	Example 1			Example 2			Example 3		
	Percent of reach	Weight	Weighted percent	Percent of reach	Weight	Weighted percent	Percent of reach	Weight	Weighted percent
Hab type - primary pools	50	1	50	10	1	10	15	1	15
Hab type - pool tailouts	20	0.43	8.6	5	0.43	2.15	5	0.43	2.15
Hab type - glides	20	0.5	10	15	0.5	7.5	10	0.5	5
Hab type - backwater pools	0	0.2	0	0	0.2	0	5	0.2	1
Hab type - beaver ponds	0	0.2	0	0	0.2	0	10	0.2	2
Hab type - large cobble/boulder riffles	0	0.43	0	30	0.43	12.9	30	0.43	12.9
Hab type - small cobble/gravel riffles	10	0.43	4.3	40	0.43	17.2	25	0.43	10.75
Hab type - off-channel factor	0	0	0	0	0	0	0	0	0
Hab type - side channel factor	0	1.5	0	25	1.5	12.75	0	1.5	0
Sum	100		72.9	100		62.5	100		48.8

Prespawning holding adult

Attribute	Example 1			Example 2			Example 3		
	Percent of reach	Weight	Weighted percent	Percent of reach	Weight	Weighted percent	Percent of reach	Weight	Weighted percent
Hab type - primary pools	50	1	50	10	1	10	15	1	15
Hab type - pool tailouts	20	0.25	5	5	0.25	1.25	5	0.25	1.25
Hab type - glides	20	0.25	5	15	0.25	3.75	10	0.25	2.5
Hab type - backwater pools	0	0	0	0	0	0	5	0	0
Hab type - beaver ponds	0	0	0	0	0	0	10	0	0
Hab type - large cobble/boulder riffles	0	0.1	0	30	0.1	3	30	0.1	3
Hab type - small cobble/gravel riffles	10	0	0	40	0	0	25	0	0
Hab type - off-channel factor	0	0	0	0	0	0	0	0	0
Hab type - side channel factor	0	1.5	0	25	1.5	18.66	0	1.5	0
Sum	100		60	100		36.66	100		21.75

4.5. Inter-Specific Competition

Issue: Other salmonids, particularly non-native species, compete with bull trout for food and living space. Competitive interactions between bull trout and other native species is low due to resource partitioning. Interactions with non-native species, such as brook trout, can be high. In addition to competition for food and space, hybridization can occur between bull trout and other species, particularly with brook trout. We treat hybridization here as a form of inter-specific competition, occurring in the spawning life stage.

Life stages highlighted below: Spawning and 0-age resident rearing

Life stage: Spawning

Approach to rule formulation: This rule is based on a weight of evidence approach drawn from material discussed in Chapter 2.3.3. It involves only one Level 2 Attribute – the population status of naturally reproducing brook trout in the geographic area.

Elements of the underlying hypothesis for these rules are:

- Bull trout and brook trout are known to readily hybridize, which can act to significantly reduce the performance of the bull trout population – most bull trout-brook trout hybrids are males and are likely sterile; and
- Hybridization is likely a larger issue with populations of small bull trout, i.e., with resident residual populations; migratory bull trout may have a reproductive advantage over resident brook trout due to their larger size;
- The overall effect of hybridization will be related to the abundance of brook trout in the geographic area.

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following:

Level 2 Attribute	Role	Rationale
Brook trout population status	Primary	The extent of hybridization will be a function of the size of the brook trout population—larger numbers of brook trout will increase the likelihood of hybridization between the species.

Hybridization between bull trout and brook trout will decrease the productivity of the bull trout population because hybrids act as a drain on reproductive potential of the bull trout population. In effect, hybridization acts as a source of mortality on the spawning population. We are unaware of any empirical quantitative relationships between brook trout abundance and effects on the production of bull trout progeny. We infer the relationships shown in Figure 23 based on conclusions presented in Reiman and McIntyre (1991) and McPhail and Baxter (1996) that loss to bull trout population performance could be substantial.

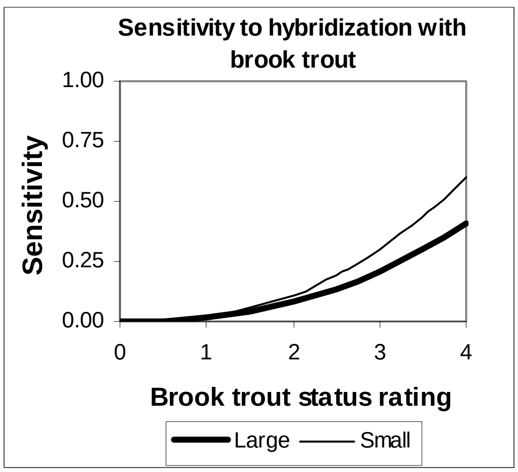

Figure 23. Assumed relationships between EDT brook trout status ratings and sensitivity to hybridization by bull trout. Different relationships are shown for small and large bodied spawners.

At a population status level of 4 for brook trout (a very abundant population number), we assume that there would be a loss in reproductive potential between 40-60%, depending on whether the bull trout population is comprised of small bodied or large bodied individuals. McPhail and Baxter (1996) surmised that the effect of hybridization would be greater on a population of resident residual fish than for fluvial or adfluvial bull trout. Large bodied bull trout spawners appear to have a reproductive advantage over resident brook trout. We assumed that sensitivity to hybridization would be approximately 50% greater for small bodied populations than for large bodied ones.

The rules do not change with stream size or the hydrologic regime of the stream.

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: Spawning (one attribute form)					
Attribute (rating to right)	Example				
	A	B	C	D	E
Brook trout status	0	1	2	3	4
Large bodied bull trout					
Relative productivity	1.00	0.98	0.92	0.79	0.59
Benchmark survival	1.0	1.0	1.0	1.0	1.0
Absolute survival	1.00	0.98	0.92	0.79	0.59
Small bodied bull trout					
Relative productivity	1.00	0.98	0.89	0.70	0.40
Benchmark survival	1.0	1.0	1.0	1.0	1.0
Absolute survival	1.00	0.98	0.89	0.70	0.40

Life stage: 0-age resident rearing

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2.3.1. It involves six Level 2 Attributes, the naturally reproducing population status levels of brook trout, brown trout, cutthroat trout, rainbow-steelhead trout, Chinook salmon, and coho salmon. The effect of competitive interactions with hatchery produced individuals of the same species is address through a separate survival factor, competition with hatchery fish, and is not incorporated directly into these rules. These rules utilize the rule structure of the independent form, the effect of each species can be viewed in isolation of the effects of other species.

Elements of the underlying hypothesis for these rules are:

- Competition for food and living space between bull trout juveniles and other salmonid species occurs and can adversely effect bull trout population performance;
- The potential for adverse interactions is greatest with brook trout, followed by other non-native species, including brown and rainbow trout, then by native species that were present under historical conditions;
- The level of effect of interactions between bull trout and another species will be related to the population status, or relative abundance, of the competing species.

The Level 2 Environmental Attributes, their role in the rules, and the rationale for including them are shown in the following:

Level 2 Attribute	Role	Rationale
Brook trout population status	Independent (primary)	Competitive interactions with this species will be a function of the size of the competing population.
Brown trout population status	Independent (primary)	Competitive interactions with this species will be a function of the size of the competing population.
Rainbow-steelhead trout population status	Independent (primary)	Competitive interactions with this species will be a function of the size of the competing population.
Cutthroat trout population status	Independent (primary)	Competitive interactions with this species will be a function of the size of the competing population.
Chinook salmon population status	Independent (primary)	Competitive interactions with this species will be a function of the size of the competing population.
Coho salmon population status	Independent (primary)	Competitive interactions with this species will be a function of the size of the competing population.

Competition with other salmonid species for food and space will adversely affect the population performance of bull trout. Quantitative relationships between the abundance of other species and growth and survival of bull trout juveniles do not exist but they can be generally inferred from various studies and conclusions that have been described in the scientific literature, as presented in this document. We formulated sensitivity rules for each of the six species of interest as shown in Figure 24.

Examples of effect

Examples of results obtained by applying the rules are shown below. See Appendix D for rating definitions.

Life stage: 0-age resident rearing (independent rule form)					
	Example				
Attribute (rating to right)	A	B	C	D	E
Brook trout status	2	3	4	0	2
Brown trout status	0	0	0	3	2
Cutthroat trout status	0	0	0	0	0
Rainbow trout status	0	0	0	0	2
Chinook salmon status	0	0	0	0	0
Coho salmon status	0	0	0	0	0
Relative productivity	0.92	0.79	0.59	0.91	0.88
Benchmark survival	0.60	0.60	0.60	0.60	0.60
Absolute survival	0.55	0.48	0.35	0.55	0.53

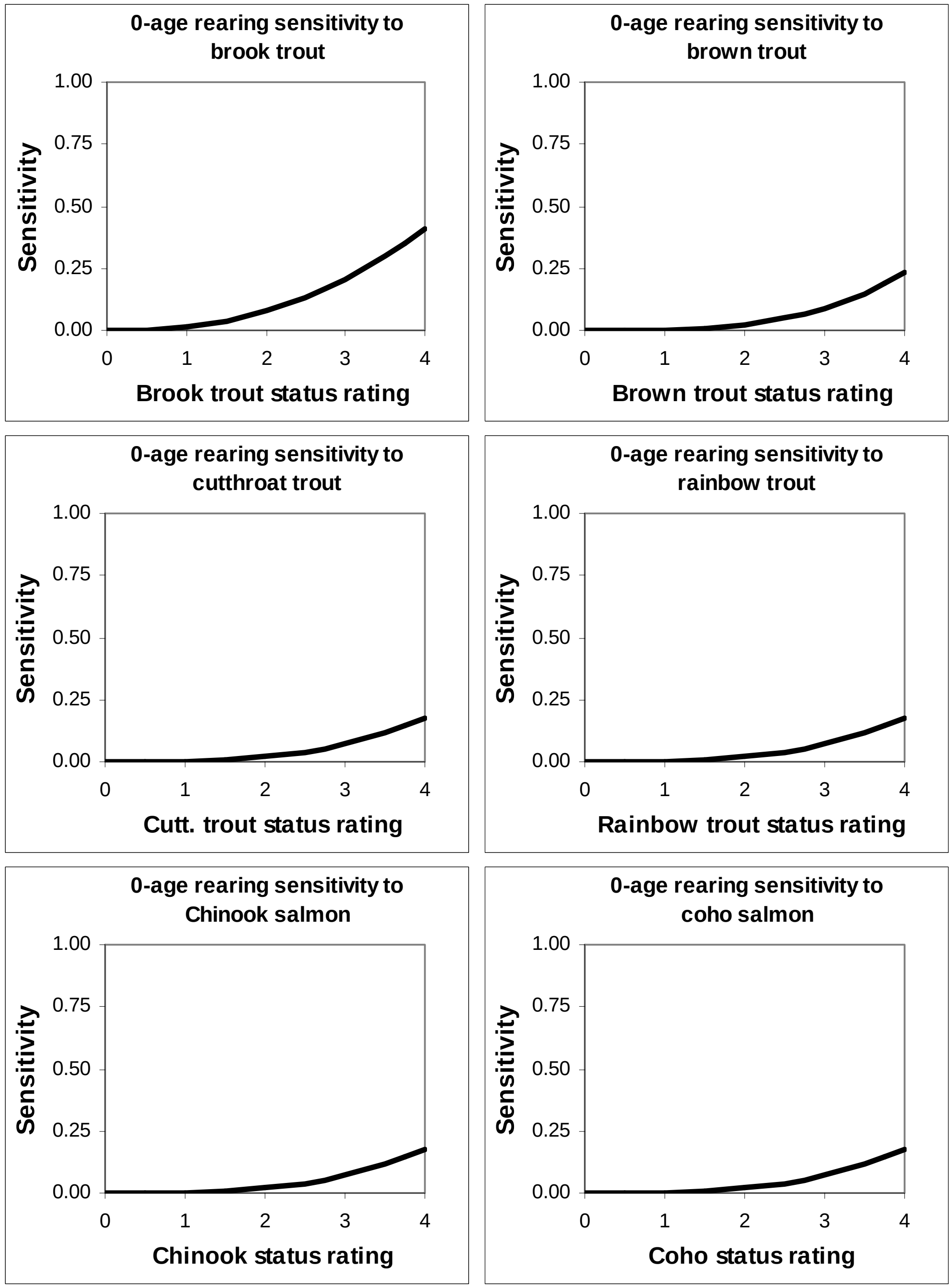

Figure 24. Assumed relationships between EDT species status ratings and sensitivity to competitive interactions by bull trout in the 0-age resident rearing life stage. A rating of 0 indicates the species is not present. A rating of 4 indicates an unusually high average abundance.

Chapter 5
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Appendices

Appendix A: Bull Trout Life Stages

Appendix Table A-1. Bull trout life stages within the freshwater environment.

Life stage	Description
Spawning	Period of active spawning, beginning when fish move on to spawning beds and initiate redd digging and ending when gametes are released. Note: For computational purposes, the reproductive potential associated with a spawning female is incorporated at the beginning of this stage; this potential includes sex ratio (average females per total spawners) and average fecundity per female.
Egg incubation	Egg incubation and alevin development; stage begins at the moment of the release of gametes by spawners and ends at fry emergence (losses to egg viability that occur in the instant prior to fertilization are included here).
Fry colonization	Fry emergence and initial dispersal; time period is typically very short, beginning at fry emergence and ending when fry begin active feeding associated with a key habitat.
0-age resident rearing	Rearing by age 0 fish that is largely associated with a small "home range"; these fish are generally territorial. Note: the seasons associated with this life stage should not be construed to mean that active feeding does not occur during winter.
0-age transient rearing	Rearing by age 0 fish accompanied by directional movement (i.e., these fish do not have home ranges); these fish are non-territorial, though agonistic behavior may still be exhibited. This life stage is probably rare for bull trout.
0-age migrant	Directional migration by age 0 fish that tends to be rapid and not strongly associated with feeding/rearing. This type of movement typically occurs when fish redistribute within the stream system prior to, or during, winter.
0-age inactive	Period when activity by 0 and 1 age fish is reduced, typically associated with overwintering; fish may need to be partly sustained by lipid reserves during this period. Note: 0-age is the age at the start of the life stage.
1-age resident rearing	Feeding/rearing by age 1 fish that is associated with a home range; these fish are often territorial. Note: the seasons associated with this life stage should not be construed to mean that active feeding does not occur during winter.
1-age transient rearing	Feeding/rearing by age 1 fish accompanied by directional movement (i.e., these fish do not have home ranges); these fish are non-territorial, though agonistic behavior may still be exhibited. This life stage is probably rare for bull trout.
1-age migrant	Directional migration by age 1 fish that tends to be rapid and not strongly associated with feeding/rearing.
1-age inactive	Period when activity by 1 age fish is reduced, typically associated with overwintering; fish may need to be partly sustained by lipid reserves during this period. Note: 1-age is the age at the start of the life stage.
2+-age resident rearing	Feeding/rearing by sub-adult (age 2 and older) fish that is associated with a home range; these fish are often territorial. Note: the seasons associated with this life stage should not be construed to mean that active feeding does not occur during winter.
2+-age transient rearing	Feeding/rearing by sub-adult (age 2 and older) fish accompanied by directional movement (i.e., these fish do not have home ranges); these fish are non-territorial, though agonistic behavior may still be exhibited. This life stage may describe movements by sub-adult bull trout moving into tributaries or upper mainstem to avoid warm temperatures (e.g., Swanberg 1996).
2+-age migrant	Directional migration by sub-adult (age 2 and older) fish that may be rapid and not strongly associated with feeding/rearing.
2+-age inactive	Period when activity by 2 age fish is reduced, typically associated with overwintering; fish may need to be partly sustained by lipid reserves during this period. Note: 2-age is the age at

Appendix Table A-1. Bull trout life stages within the freshwater environment.

Life stage	Description
	the start of the life stage.
Transient/migrant prespawner	Directional upstream migration by sexually mature fish migrating to their spawning grounds; may be rapid and not strongly associated with feeding/rearing.
Holding prespawner	Sexually mature fish that are largely stationary and holding, while en route to their spawning grounds; distance to the spawning grounds from holding sites may be short or long.
Post spawner holding/migrant	Post spawner fish; life stage describes stationary/holding behavior immediately following spawning and rapid downstream migration.
5+-age resident rearing	Feeding/rearing by adult (age 5 and older) fish that is associated with a home range; these fish are often territorial. Note: the seasons associated with this life stage should not be construed to mean that active feeding does not occur during winter.
5+-age transient rearing	Feeding/rearing by adult (age 5 and older) fish accompanied by directional movement (i.e., these fish do not have home ranges); these fish are non-territorial, though agonistic behavior may still be exhibited. This life stage may describe movements by adult bull trout moving into tributaries or upper mainstem to avoid warm temperatures (e.g., Swanberg 1996).
5+-age migrant	Directional migration by age 5 and older adult fish that may be rapid and not strongly associated with feeding/rearing. This life stage may describe movements by adult bull trout moving into tributaries or upper mainstem to avoid warm temperatures (e.g., Swanberg 1996).
5+-age inactive	Period when activity by age 5 and older fish is reduced, typically associated with overwintering; fish may need to be partly sustained by lipid reserves during this period. Note: 5-age is the age at the start of the life stage.

Appendix B: Benchmark Values for Bull Trout

The EDT method associates survival with habitat. The productivity and capacity values derived in the EDT process are characteristics of the environment by time and location as interpreted "though the eyes of salmon" by species and life stage (Mobrand et al. 1997). The procedure for deriving these productivity and capacity values involves what we refer to as a shaping of survival conditions over time and space, as salmonids might experience them in completing their life cycle. The shaping of survival conditions is done with reference to a defined set of "benchmark" conditions.

From literature we can identify, or hypothesize where data are limited, habitat requirements by life stage for the species. We can take it a step further and describe optimal conditions and the expected survival and density limits by life stage. We refer to the survival and density values associated with optimal conditions as reference benchmarks. Thus benchmarks provide us with a set of descriptions for optimal conditions expressed as productivity survival, maximum densities, and habitat characteristics for each life stage. These conditions constitute what can be thought of "as good as it gets" for survival of the species in nature. We have employed a set of benchmark values derived from reviewing relevant sources of information, including discussions with scientists having expertise in survival of bull trout by life stage under various conditions. For bull trout, we derived benchmark productivities (survival) for most life stages from inferences from other salmonid species for which we have previously estimated benchmarks. The benchmark productivity of the incubation life stage is based on discussions that occurred at the Missoula Workshop on bull trout rules in November of 2002. Stereotypical life stage durations for bull trout were defined in consultation with Chris Frissell. Benchmark densities for all juvenile life stages are based principally on two sources: 1) use of Ptolemy's equation relating rearing density to alkalinity and salmonid fish size (Ptolemy 1993) and 2) maximum rearing densities reported in Montana streams by Read and others (1982) and Weaver and others (1983). We also reviewed rearing densities reported in Martin (1992) and Goetz (1997).

The systematic shaping of survival conditions using the habitat rating procedures is intended to assure that productivity and capacity values for each life history segment along a trajectory are: a) bounded by the biological limits of the species, b) scaled consistently across time, space, and life stage, and c) scaled consistently with the benchmark values.

It is important to keep in mind that benchmark or optimal conditions are different from template (pre-development) conditions. Template conditions were not always optimal for salmon survival. The benchmark descriptions serve as a point of reference for both the patient and template and for all watersheds.

Appendix Table B-1. Benchmark assumptions for bull trout.

Life stage	Stereotypical duration (weeks)	Productivity	Density (fish/m2	
			Migratory	Resident
Spawning	1	1.00	0.50	4.00
Egg incubation	27	0.60	200	150
Fry colonization	2	0.75	17	37
0-age resident rearing	27	0.60	3.0	11.5
0-age transient rearing	27	0.50	3.0	11.5
0-age migrant	2	0.90	30	30
0-age inactive	18	0.70	2.30	9.50
1-age resident rearing	34	0.75	0.30	1.00
1-age transient rearing	34	0.60	0.30	1.00
1-age migrant	2	0.95	30	30
1-age inactive	18	0.75	0.23	0.83
2+-age resident rearing	34	0.90	0.09	0.57
2+-age transient rearing	6	0.95	0.90	0.57
2+-age migrant	2	0.98	30	30
2+-age inactive	18	0.90	0.09	0.41
Transient/migrant prespawner	6	0.95	2	4
Holding prespawner	10	0.95	1	2
Post spawner holding/migrant	2	0.70	1	2
5+-age resident rearing	34	0.95	0.005	0.010
5+-age transient rearing	6	0.95	0.005	0.010
5+-age migrant	2	1.00	2	4
5+-age inactive	18	0.95	0.005	0.010

Appendix C: Level 2 Environmental Attribute Definitions

Appendix Table C-1. Level 2 Environmental Attributes (or ecological attributes).

Code	Attribute	Definition
Alka	Alkalinity	Alkalinity, or acid neutralizing capacity (ANC), measured as milliequivalents per liter or mg/l of either HCO3 or CaCO3.
BdScour	Bed scour	Average depth of bed scour in salmonid spawning areas (i.e., in pool-tailouts and small cobble-gravel riffles) during the annual peak flow event over approximately a 10-year period. The range of annual scour depth over the period could vary substantially. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter).
BenComRch	Benthos diversity and production	Measure of the diversity and production of the benthic macroinvertebrate community. Three types of measures are given (choose one): a simple EPT count, Benthic Index of Biological Integrity (B-IBI)—a multimetric approach (Karr and Chu 1999), or a multivariate approach using the BORIS (Benthic evaluation of Oregon RIverS) model (Canale 1999). B-IBI rating definitions from Morley (2000) as modified from Karr et al. (1986). BORIS score definitions based on ODEQ protocols, after Barbour et al. (1994).
ChLngth	Channel length	Length of the primary channel contained with the stream reach -- Note: this attribute will not be given by a categories but rather will be a point estimate. Length of channel is given for the main channel only--multiple channels do not add length.
WidthMx	Channel width - month maximum width (ft)	Average width of the wetted channel during peak flow month (average monthly conditions). If the stream is braided or contains multiple channels, then the width would represent the sum of the wetted widths along a transect that extends across all channels. Note: Categories are not to be used for calculation of wetted surface area; categories here are used to designate relative stream size.
WidthMn	Channel width - month minimum width (ft)	Average width of the wetted channel. If the stream is braided or contains multiple channels, then the width would represent the sum of the wetted widths along a transect that extends across all channels. Note: Categories are not to be used for calculation of wetted surface area; categories here are used to designate relative stream size.
ConfineHdro	Confinement - Hydromodifications	The extent that man-made structures within or adjacent to the stream channel constrict flow (as at bridges) or restrict flow access to the stream's floodplain (due to streamside roads, revetments, diking or levees) or the extent that the channel has been ditched or channelized, or has undergone significant streambed degradation due to channel incision/entrenchment (associated with the process called "headcutting"). Flow access to the floodplain can be partially or wholly cutoff due to channel incision. Note: Setback levees are to be treated differently than narrow-channel or riverfront levees--consider the extent of the setback and its effect on flow and bed dynamics and micro-habitat features along the stream margin in reach to arrive at rating conclusion. Reference condition for this attribute is the natural, undeveloped state.
Confine	Confinement - natural	The extent that the valley floodplain of the reach is confined by natural features. It is determined as the ratio between the width of the valley floodplain and the bankful channel width. Note: this attribute addresses the natural (pristine) state of valley confinement only.

Appendix Table C-1. Level 2 Environmental Attributes (or ecological attributes).

Code	Attribute	Definition
DisOxy	Dissolved oxygen	Average dissolved oxygen within the water column for the specified time interval.
Emb	Embeddedness	The extent that larger cobbles or gravel are surrounded by or covered by fine sediment, such as sands, silts, and clays. Embeddedness is determined by examining the extent (as an average %) that cobble and gravel particles on the substrate surface are buried by fine sediments. This attribute only applies to riffle and tailout habitat units and only where cobble or gravel substrates occur.
FnSediSm	Fine sediment - <1 mm particles	Percentage of fine sediment particles smaller than 1 mm in size within salmonid spawning substrates, located in pool-tailouts, glides, and small cobble-gravel riffles.
FnSediLg	Fine sediment - <6 mm particles	Percentage of fine sediment particles smaller than 6 mm in size (sand sized) within salmonid spawning substrates, located in pool-tailouts, glides, and small cobble-gravel riffles.
FshComComp	Fish community composition	Indicator of the presence or absence of various fish species within the drainage (species of relevance in the rules).
FshComRch	Fish community richness	Measure of the richness of the fish community (no. of fish taxa, i.e., species).
FshSpStatus	Fish species status	Status of various naturally reproducing fish species within the drainage (species of relevance in the rules).
FshPath	Fish pathogens	The presence of pathogenic organisms (relative abundance and species present) having potential for affecting survival of stream fishes.
FSpIntro	Fish species introductions	Extent of introductions of exotic fish species in the vicinity of the stream reaches under consideration.
FlwHigh	Flow - change in average annual peak flow	The extent of relative change in average peak annual discharge compared to an undisturbed watershed of comparable size, geology, orientation, topography, and geography (or as would have existed in the pristine state). Evidence of change in peak flow can be empirical where sufficiently long data series exists, can be based on indicator metrics (such as T_{Qmean}, see Konrad [2000]), or inferred from patterns corresponding to watershed development. Relative change in peak annual discharge here is based on changes in the peak annual flow expected on average once every two years (Q_{2yr}).
FlwLow	Flow - change in average annual low flow	The extent of relative change in average daily flow during the normal low flow period compared to an undisturbed watershed of comparable size, geology, and flow regime (or as would have existed in the pristine state). Evidence of change in low flow can be empirically-based where sufficiently long data series exists, or known through flow regulation practices, or inferred from patterns corresponding to watershed development. Note: low flows are not systematically reduced in relation to watershed development, even in urban streams (Konrad 2000). Factors affecting low flow are often not obvious in many watersheds, except in clear cases of flow diversion and regulation.
FlwDielVar	Flow - Intra daily (diel) variation	Average diel variation in flow level during a season or month. This attribute is informative for rivers with hydroelectric projects or in heavily urbanized drainages where storm runoff causes rapid changes in flow.

Appendix Table C-1. Level 2 Environmental Attributes (or ecological attributes).

Code	Attribute	Definition
FlwIntraAnn	Flow - intra-annual flow pattern	The average extent of intra-annual flow variation during the wet season -- a measure of a stream's "flashiness" during storm runoff. Flashiness is correlated with % total impervious area and road density, but is attenuated as drainage area increases. Evidence for change can be empirically derived using flow data (e.g., using the metric T_{Qmean}, see Konrad [2000]), or inferred from patterns corresponding to watershed development.
Grad	Gradient	Average gradient of the main channel of the reach over its entire length. Note: Categorical levels are shown here but values are required to be input as point estimates for each reach.
HbBckPls	Habitat type - backwater pools	Percentage of the wetted channel surface area comprising backwater pools.
HbBvrPnds	Habitat type - beaver ponds	Percentage of the wetted channel surface area comprising beaver ponds. Note: these are pools located in the main or side channels, not part of off-channel habitat.
HbGlide	Habitat type - glide	Percentage of the wetted channel surface area comprising glides. Note: There is a general lack of consensus regarding the definition of glides (Hawkins et al. 1993), despite a commonly held view that it remains important to recognize a habitat type that is intermediate between pool and riffle. The definition applied here is from the ODFW habitat survey manual (Moore et al. 1997): an area with generally uniform depth and flow with no surface turbulence, generally in reaches of <1% gradient. Glides may have some small scour areas but are distinguished from pools by their overall homogeneity and lack of structure. They are generally deeper than riffles with few major flow obstructions and low habitat complexity.
HbLrgCbl	Habitat type - large cobble/boulder riffles	Percentage of the wetted channel surface area comprising large cobble/boulder riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter).
HbOfChFctr	Habitat type - off-channel habitat factor	A multiplier used to estimate the amount of off-channel habitat based on the wetted surface area of the all combined in-channel habitat.
HbPlTails	Habitat type - pool tailouts.	Percentage of the wetted channel surface area comprising pool tailouts.
HbPls	Habitat type - primary pools	Percentage of the wetted channel surface area comprising pools, excluding beaver ponds
HbSmlCbl	Habitat type - small cobble/gravel riffles	Percentage of the wetted channel surface area comprising small cobble/gravel riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter).
HbSdChFctr	Habitat type – side channel factor	The percentage of the active channel's wetted surface area comprised of side channels.
HbSdChType	Habitat type – side channel type	The average type of side channels within the reach, where type refers to a relative scale of water velocity flowing the side channels.
Harass	Harassment	The relative extent of poaching and/or harassment of fish within the stream reach.

Appendix Table C-1. Level 2 Environmental Attributes (or ecological attributes).

Code	Attribute	Definition
HatFOutp	Hatchery fish outplants - general	The magnitude of hatchery fish outplants made into the drainage over the past 10 years – all species combined here.
HatFOutpSp	Hatchery fish outplants – species specific	The magnitude of hatchery fish outplants for particular species made into the drainage over the past 10 years. This attribute addresses specific salmonid species.
FlwGrndw	Hydrologic regime - groundwater rating	The relative amount of groundwater being contributed to the surface flow within the reach.
HydroRegimeNatural	Hydrologic regime - natural	The natural flow regime within the reach of interest. Flow regime typically refers to the seasonal pattern of flow over a year; here it is inferred by identification of flow sources. This applies to an unregulated river or to the pre-regulation state of a regulated river.
HydroRegimeReg	Hydrologic regime - regulated	The change in the natural hydrograph caused by the operation of flow regulation facilities (e.g., hydroelectric, flood storage, domestic water supply, recreation, or irrigation supply) in a watershed. Definition does not take into account daily flow fluctuations (See Flow-Intra-daily variation attribute).
Icing	Icing	Average extent (magnitude and frequency) of icing events over a 10-year period. Icing events can have severe effects on the biota and the physical structure of the stream in the short-term. It is recognized that icing events can under some conditions have long-term beneficial effects to habitat structure.
MetWatCol	Metals - in water column	The extent of dissolved heavy metals within the water column.
MetSedSls	Metals/Pollutants - in sediments/soils	The extent of heavy metals and miscellaneous toxic pollutants within the stream sediments and/or soils adjacent to the stream channel.
MscToxWat	Miscellaneous toxic pollutants - water column	The extent of miscellaneous toxic pollutants (other than heavy metals) within the water column.
NutEnrch	Nutrient enrichment	The extent of nutrient enrichment (most often by either nitrogen or phosphorous or both) from anthropogenic activities. Nitrogen and phosphorous are the primary macro-nutrients that enrich streams and cause build ups of algae. These conditions, in addition to leading to other adverse conditions, such as low DO can be indicative of conditions that are unhealthy for salmonids. Note: care needs to be applied when considering periphyton composition since relatively large mats of green filamentous algae can occur in Pacific Northwest streams with no nutrient enrichment when exposed to sunlight.
Obstr	Obstructions to fish migration	Obstructions to fish passage by physical barriers (not dewatered channels or hindrances to migration caused by pollutants or lack of oxygen).
PredRisk	Predation risk	Level of predation risk on fish species due to presence of top level carnivores or unusual concentrations of other fish eating species. This is a classification of per-capita predation risk, in terms of the likelihood, magnitude and frequency of exposure to potential predators (assuming other habitat factors are constant). NOTE: This attribute is being updated to distinguish risk posed to small bodied fish (<10 in) from that to large bodied fish (>10 in).

Appendix Table C-1. Level 2 Environmental Attributes (or ecological attributes).

Code	Attribute	Definition
RipFunc	Riparian function	A measure of riparian function that has been altered within the reach.
SalmCarcass	Salmon Carcasses	Relative abundance of anadromous salmonid carcasses within watershed that can serve as nutrient sources for juvenile salmonid production and other organisms. Relative abundance is expressed here as the density of salmon carcasses within subdrainages (or areas) of the watershed, such as the lower mainstem vs the upper mainstem, or in mainstem areas vs major tributary drainages.
TmpMonMx	Temperature - daily maximum (by month)	Maximum water temperatures within the stream reach during a month.
TmpMonMn	Temperature - daily minimum (by month)	Minimum water temperatures within the stream reach during a month.
TmpSptVar	Temperature - spatial variation	The extent of water temperature variation (cool or warm water depending upon season) within the reach as influenced by inputs of groundwater or tributary streams, or the presence of thermally stratified deep pools.
Turb	Turbidity	The severity of suspended sediment (SS) episodes within the stream reach. (Note: this attribute, which was originally called turbidity and still retains that name for continuity, is more correctly thought of as SS, which affects turbidity.) SS is sometimes characterized using turbidity but is more accurately described through suspended solids, hence the latter is to be used in rating this attribute. Turbidity is an optical property of water where suspended, including very fine particles such as clays and colloids, and some dissolved materials cause light to be scattered; it is expressed typically in nephelometric turbidity units (NTU). Suspended solids represents the actual measure of mineral and organic particles transported in the water column, either expressed as total suspended solids (TSS) or suspended sediment concentration (SSC)—both as mg/l. Technically, turbidity is not SS but the two are usually well correlated. If only NTUs are available, an approximation of SS can be obtained through relationships that correlate the two. The metric applied here is the Scale of Severity (SEV) Index taken from Newcombe and Jensen (1996), derived from: $SEV = a + b(\ln X) + c(\ln Y)$, where, X = duration in hours, Y = mg/l, a = 1.0642 , b = 0.6068, and c = 0.7384. Duration is the number of hours out of month (with highest SS typically) when that concentration or higher normally occurs. Concentration would be represented by grab samples reported by USGS. See rating guidelines.
Wdrwl	Water withdrawals	The number and relative size of water withdrawals in the stream reach.
WdDeb	Wood	The amount of wood (large woody debris or LWD) within the reach. Dimensions of what constitutes LWD are defined here as pieces >0.1 m diameter and >2 m in length. Numbers and volumes of LWD corresponding to index levels are based on Peterson et al. (1992), May et al. (1997), Hyatt and Naiman (2001), and Collins et al. (2002). Note: channel widths here refer to average wetted width during the high flow month (< bank full), consistent with the metric used to define high flow channel width. Ranges for index values are based on LWD pieces/CW and presence of jams (on larger channels). Reference to "large" pieces in index values uses the standard TFW definition as those > 50 cm diameter at midpoint.

Appendix D: Definitions of Level 2 Environmental Attribute Index Values

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Alka	Alkalinity	Alkalinity, or acid neutralizing capacity (ANC), measured as milliequivalents per liter or mg/l of either HCO3 or CaCO3.	Very low (average value typically would be 0-5 mg/l)	Moderately low (average value typically would be 5-10 mg/l)	Moderately high (average value typically would be 10-40 mg/l)	High (average value typically would be 40-100 mg/l)	Very high (average value typically would be 100-300 mg/l)
BdScour	Bed scour	Average depth of bed scour in salmonid spawning areas (i.e., in pool-tailouts and small cobble-gravel riffles) during the annual peak flow event over approximately a 10-year period. The range of annual scour depth over the period could vary substantially. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter).	Average depth of scour >0 cm and <2 cm	Average depth of scour >2 cm and <10 cm	Average depth of scour >10 cm and <18 cm	Average depth of scour >18 cm and <24 cm	Average depth of scour >24 cm and <40 cm

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
1	Benthos diversity and production	Measure of the diversity and production of the benthic macroinvertebrate community. Three types of measures are given (choose one): a simple EPT count, Benthic Index of Biological Integrity (B-IBI)—a multimetric approach (Karr and Chu 1999), or a multivariate approach using the BORIS (Benthic evaluation of Oregon RIverS) model (Canale 1999). B-IBI rating definitions from Morley (2000) as modified from Karr et al. (1986). BORIS score definitions based on ODEQ protocols, after Barbour et al. (1994).	(1) Simple EPT index -- Macroinvertebrates abundant; multiple species of families Emphemeroptera, Plecoptera, and Trichoptera are present. OR (2) B-IBI (10 metrics) -- >=45Comparable to least disturbed reference condition; overall high taxa diversity, particularly of mayflies, stoneflies, caddisflies, long-lived clinger, and intolerant taxa. Relative abundance of predators high. OR (3) BORIS score -- Minimal impairment in benthic community — <1 standard deviation from the reference mean AND considered "ideal or good watershed and stream condition for reference condition."	(1) Simple EPT index -- Intermediate OR (2) B-IBI (10 metrics) -- >=37 and <45.Slightly divergent from least disturbed condition; absence of some long-lived and intolerant taxa; slight decline in richness of mayflies, stoneflies, and caddisflies; proportion of tolerant taxa increases. OR (3) BORIS score -- Minimal impairment in benthic community — <1 standard deviation from the reference mean AND considered "marginal watershed and stream condition for reference condition."	(1) Simple EPT index -- Macroinvertebrates common or abundant but 1-2 families among Emphemeroptera, Plecoptera, and Trichoptera are not present. OR (2) B-IBI (10 metrics) -- >=27 and <37.Total taxa reduced—particularly intolerant, long-lived, stonefly, and clinger taxa. Relative abundance of predator declines; proportion of tolerant taxa continues to increase. OR (3) BORIS score -- Moderate impairment in benthic community — >1 and <2 standard deviations from the reference mean.	(1) Simple EPT index -- Intermediate. OR (2) B-IBI (10 metrics) -- >=17 and <27.Overall taxa diversity depressed; proportion of predators greatly reduced as is long-lived taxa richness; few stoneflies or intolerant taxa present; dominance by three most abundant taxa often very high. OR (3) BORIS score -- Severe impairment in benthic community —>2 and <2.5 standard deviations from the reference mean.	(1) Simple EPT index -- Macroinvertebrates are present only at extremely low densities and/or biomass. OR (2) B-IBI (10 metrics) -- <17.Overall taxa diversity very low and dominated by a few highly tolerant taxa; mayfly, stonefly, caddisfly, clinger, long-lived and intolerant taxa largely absent. Relative abundance of predators very low. OR (3) BORIS score -- Extremely severe impairment in benthic community—>2.5 standard deviations from the reference mean.
ChLngth	Channel length	Length of the primary channel contained with the stream reach -- Note: this attribute will not be given by a categories but rather will be a point estimate. Length of channel is given for the main channel only--multiple channels do not add length.					

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
WidthMx	Channel width - month maximum width (ft)	Average width of the wetted channel during peak flow month (average monthly conditions). If the stream is braided or contains multiple channels, then the width would represent the sum of the wetted widths along a transect that extends across all channels. Note: Categories are not to be used for calculation of wetted surface area; categories here are used to designate relative stream size.	< 15 ft	> 15 ft and < 60 ft	> 60 ft and < 100 ft	> 100 ft and 360 ft	> 360 ft
WidthMn	Channel width - month minimum width (ft)	Average width of the wetted channel. If the stream is braided or contains multiple channels, then the width would represent the sum of the wetted widths along a transect that extends across all channels. Note: Categories are not to be used for calculation of wetted surface area; categories here are used to designate relative stream size.	< 15 ft	> 15 ft and < 60 ft	> 60 ft and < 100 ft	> 100 ft and 360 ft	> 360 ft

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
ConfineHdro	Confinement – Hydromodifi ca-tions	The extent that man-made structures within or adjacent to the stream channel constrict flow (as at bridges) or restrict flow access to the stream's floodplain (due to streamside roads, revetments, diking or levees) or the extent that the channel has been ditched or channelized, or has undergone significant streambed degradation due to channel incision/entrenchment (associated with the process called "headcutting"). Flow access to the floodplain can be partially or wholly cutoff due to channel incision. Note: Setback levees are to be treated differently than narrow-channel or riverfront levees--consider the extent of the setback and its effect on flow and bed dynamics and micro-habitat features along the stream margin in reach to arrive at rating conclusion. Reference condition for this attribute is the natural, undeveloped state.	The stream channel within the reach is essentially fully connected to its floodplain. Very minor structures may exist in the reach that do not result in flow constriction or restriction. Note: this describes both a natural condition within a naturally unconfined channel as well as the natural condition within a canyon.	Some portion of the stream channel, though less than 10% (of the sum of lengths of both banks), is disconnected from its floodplain along one or both banks due to man-made structures or ditching.	More than 10% and less than 40% of the entire length of the stream channel (sum of lengths of both banks) within the reach is disconnected from its floodplain along one or both banks due to man-made structures or ditching.	More than 40% and less than 80% of the entire length of the stream channel (sum of lengths of both banks) within the reach is disconnected from its floodplain along one or both banks due to man-made structures or ditching.	Greater than 80% of the entire length of the stream channel (sum of lengths of both banks) within the reach is disconnected from its floodplain along one or both banks due to man-made structures or ditching.
Confine	Confinement - natural	The extent that the valley floodplain of the reach is confined by natural features. It is determined as the ratio between the width of the valley floodplain and the bankful channel width. Note: this attribute addresses the natural (pristine) state of valley confinement only.	Reach mostly unconfined by natural features -- Average valley width > 4 channel widths.	Reach comprised approximately equally of unconfined and moderately confined sections.	Reach mostly moderately confined by natural features -- Average valley width 2 - 4 channel widths.	Reach comprised approximately equally of moderately confined and confined sections.	Reach mostly confined by natural features -- Average valley width < 2 channel widths.

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
DisOxy	Dissolved oxygen	Average dissolved oxygen within the water column for the specified time interval.	> 8 mg/L (allows for all biological functions for salmonids without impairment at temperatures ranging from 0-25 C)	> 6 mg/L and < 8 mg/L (causes initial stress symptoms for some salmonids at temperatures ranging from 0-25 C)	> 4 and < 6 mg/L (stress increased, biological function impaired)	> 3 and < 4 mg/L (growth, food conversion efficiency, swimming performance adversely affected)	< 3 mg/L
Emb	Embeddedness	The extent that larger cobbles or gravel are surrounded by or covered by fine sediment, such as sands, silts, and clays. Embeddedness is determined by examining the extent (as an average %) that cobble and gravel particles on the substrate surface are buried by fine sediments. This attribute only applies to riffle and tailout habitat units and only where cobble or gravel substrates occur.	< 10% of surface covered by fine sediment	> 10 and < 25 % covered by fine sediment	> 25 and < 50 % covered by fine sediment	> 50 and < 90 % covered by fine sediment	> 90% covered by fine sediment
FnSediSm	Fine sediment - <1 mm particles	Percentage of fine sediment particles smaller than 1 mm in size within salmonid spawning substrates, located in pool-tailouts, glides, and small cobble-gravel riffles.	Particle sizes <1 mm: < 6%	Particle sizes <1 mm: > 6% and < 11%	Particle sizes <1 mm: > 11% and < 18%	Particle sizes <1 mm: > 18% and < 30%	Particle sizes <1 mm: > 30% fines
FnSediLg	Fine sediment - <6 mm particles	Percentage of fine sediment particles smaller than 6 mm in size (sand sized) within salmonid spawning substrates, located in pool-tailouts, glides, and small cobble-gravel riffles.	Particle sizes <6 mm: <10%	Particle sizes <6 mm: >10% and <25%	Particle sizes <6 mm: >25% and <40%	Particle sizes <6 mm: >40% and <60%	Particle sizes <6 mm: >60%
FshComComp	Fish community composition	Indicator of the presence or absence of various fish species within the drainage (species of relevance in the rules).	This attribute identifies presence or absence of various species – no rating given.				
FshComRch	Fish community richness	Measure of the richness of the fish community (no. of fish taxa, i.e., species).	2 or fewer fish taxa	3-7 fish taxa	8-17 fish taxa	18-25 fish taxa	> 25 fish taxa

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
FshSpStatus	Fish species status	Status of various naturally reproducing fish species within the drainage (species of relevance in the rules).	Species of interest not present.	Species of interest at very low density, reflecting a population of marginal sustainability.	Species of interest stable, though depressed compared to a healthy, robust population due to reduced environmental quality, moderate to severe harvest pressure, or strong competitive interactions with other species.	Species of interest considered, though abundance reduced from maximum potential capacity due to one or more of the following: harvest, bottlenecks on habitat capacity at younger age classes, or competition with one or more competing species. Note: this is the status that is assumed if the species were naturally occurring within a diverse assemblage of species.	Species of interest very robust and abundant. This status level corresponds to an especially high abundance due to factors that favor this species in the drainage due to one or more of the following: low harvest impact, favorable habitat conditions, or low competition interactions with other potentially competing species.
FshPath	Fish pathogens	The presence of pathogenic organisms (relative abundance and species present) having potential for affecting survival of stream fishes.	No historic or recent fish stocking in drainage and no known incidences of whirling disease, C. shasta, IHN, or IPN	Historic fish stocking, but no fish stocking records within the past decade, or sockeye population currently existing in drainage, or known incidents of viruses among kokanee populations within the watershed.	On-going periodic, frequent, or annual fish stocking in drainage or known viral incidents within sockeye, Chinook, or steelhead populations in the watershed.	Operating hatchery within the reach or in the reach immediately downstream or upstream	Known presence of whirling disease or C. shasta within the watershed.
FSpIntro	Fish species introductions	Extent of introductions of exotic fish species in the vicinity of the stream reaches under consideration.	No non-native species reported or known to be in the sub-drainage of interest.	1-2 non-native species reported or known to be in the sub-drainage of interest.	3-7 non-native species reported or known to be in the sub-drainage of interest.	8-14 non-native species reported or known to be in the sub-drainage of interest.	15 or more non-native species reported or known to be in the sub-drainage of interest.

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
FlwHigh	Flow - change in average annual peak flow	The extent of relative change in average peak annual discharge compared to an undisturbed watershed of comparable size, geology, orientation, topography, and geography (or as would have existed in the pristine state). Evidence of change in peak flow can be empirical where sufficiently long data series exists, can be based on indicator metrics (such as T_{Qmean}, see Konrad [2000]), or inferred from patterns corresponding to watershed development. Relative change in peak annual discharge here is based on changes in the peak annual flow expected on average once every two years (Q_{2yr}).	Peak annual flows expected to be strongly reduced relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >40% and <100% decrease in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known by regulated flow levels. This condition is associated with flow regulation or water diversion projects.	Peak annual flows expected to be moderately reduced relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >20% and <40% decrease in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known by regulated flow levels. This condition is associated with flow regulation or water diversion projects.	Peak annual flows expected to be comparable to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR <20% change in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state); OR <5% reduction in average T_{Qmean} compared to the undeveloped watershed state.	Peak annual flows expected to be mod-erately increased relative to an un-disturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of int-erest); OR >20% and <40% increase in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs per-taining to a water-shed devel-opment state); OR >5% and <15% reduction in average T_{Qmean} compared to the undeveloped watershed state. This condition exemp-lified in some for-ested watersheds with high road density that exper-ience signify-cant rain on snow events, as the North Fork Stillaguamish River (Pess et al. *in review*). Note: many managed forested watersheds in the Pacific North-west exhibit slight, if any, increases in peak annual flows since logging com-menced (see Ziemer and Lisle 1998).	Peak annual flows expected to be strongly increased relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >40% and <110%+ increase in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state); OR >15% and <45% reduction in average T_{Qmean} compared to the undeveloped watershed state. This condition exemplified in watersheds with significant urbanization (e.g., >20%).

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
FlwLow	Flow - change in average annual low flow	The extent of relative change in average daily flow during the normal low flow period compared to an undisturbed watershed of comparable size, geology, and flow regime (or as would have existed in the pristine state). Evidence of change in low flow can be empirically-based where sufficiently long data series exists, or known through flow regulation practices, or inferred from patterns corresponding to watershed development. Note: low flows are not systematically reduced in relation to watershed development, even in urban streams (Konrad 2000). Factors affecting low flow are often not obvious in many watersheds, except in clear cases of flow diversion and regulation.	Average daily low flows expected to be strongly increased compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >75% increase in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be moderately increased compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >20% and <75% increase in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be comparable to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR <20% change in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state).	Average daily low flows expected to be moderately reduced compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >20% and <50% reduction in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be severely reduced compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >50% and <=100% reduction in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
FlwDielVar	Flow - Intra daily (diel) variation	Average diel variation in flow level during a season or month. This attribute is informative for rivers with hydroelectric projects or in heavily urbanized drainages where storm runoff causes rapid changes in flow.	Essentially no variation in discharge during an average 24-hr period during season or month. This characterizes conditions not influenced by flow ramping or accelerated storm runoff. This rating also would apply to small suburban-urbanized drainages with impervious surfaces of <10% in high rainfall climates (e.g., Puget Lowlands) and with little or no flow detention systems in place.	Slight to low variation in flow stage during an average 24-hr period during season or month. This pattern typical of routine (everyday) slight to low ramping condition associated with flow regulation, averaging <2 inches change in stage per hour. This condition has both slight to low rates of change in flow and high frequency with which it occurs. This rating also would apply to small suburban-urbanized drainages with impervious surfaces of ~10-25% in high rainfall climates (e.g., Puget Lowlands) and with little or no flow detention systems in place.	Low to moderate variation in flow stage during an average 24-hr period during season or month. This pattern typical of routine (everyday) low to moderate ramping condition associated with flow regulation, averaging >2 inches and <6 inches change in stage per hour. This condition has both moderate to high rates of change in flow and high frequency with which it occurs. This rating also would apply to small suburban- urbanized drainages with impervious surfaces of ~25-40% in high rainfall climates (e.g., Puget Lowlands) and with little or no flow detention systems in place.	Moderate to high variation in flow stage during an average 24-hr period during season or month. This pattern typical of routine (everyday) moderate to high ramping condition associated with flow regulation, averaging between 6 inches to 12 inches change in stage per hour. This condition has both moderate to high rates of change in flow and high frequency with which it occurs. This rating also would apply to small suburban to urbanized drainages with impervious surfaces of ~40-50% in high rainfall climates (e.g., Puget Lowlands) and with little or no flow detention systems in place.	Extreme variation in flow stage during an average 24-hr period during season or month. This pattern typical of routine (everyday) extreme ramping condition associated with flow regulation, averaging between 12 inches to 24 inches change in stage per hour. This condition is both extreme in the rate of change in flow and the frequency with which it occurs. This rating would apply to small, heavily urbanized drainages with impervious surfaces of 50-80% in high rainfall climates (e.g., Puget Lowlands) and with little or no flow detention systems in place.

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
FlwIntraAnn	Flow - intra-annual flow pattern	The average extent of intra-annual flow variation during the wet season -- a measure of a stream's "flashiness" during storm runoff. Flashiness is correlated with % total impervious area and road density, but is attenuated as drainage area increases. Evidence for change can be empirically derived using flow data (e.g., using the metric T_{Qmean}, see Konrad [2000]), or inferred from patterns corresponding to watershed development.	Storm runoff response (rates of change in flow) expected to be slowed greatly relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >15% increase in average T_{Qmean} compared to the undeveloped watershed state or as known by regulated flow levels. This condition is associated with flow regulation.	Storm runoff response (rates of change in flow) expected to be moderately slower relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >5% and <15% increase in average T_{Qmean} compared to the undeveloped watershed state or as known by regulated flow levels. This condition is associated with flow regulation.	Storm runoff response (rates of change in flow) comparable to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR <5% reduction in average T_{Qmean} compared to the undeveloped watershed state.	Storm runoff response (rates of change in flow) expected to be moderately increased relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >5% and <15% reduction in average T_{Qmean} compared to the undeveloped watershed state. This condition exemplified in some managed forested watersheds with high road density, likely most evident in small drainages.	Storm runoff response (rates of change in flow) expected to be strongly increased relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >15% and <45% reduction in average T_{Qmean} compared to the undeveloped watershed state. This condition exemplified in watersheds with significant urbanization.
Grad	Gradient	Average gradient of the main channel of the reach over its entire length. Note: Categorical levels are shown here but values are required to be input as point estimates for each reach.	0 - 0.1%	>0.10% and <0.5%	>0.5% and <1%	>1% and <2%	>2% and <4%
HbBckPls	Habitat type - backwater pools	Percentage of the wetted channel surface area comprising backwater pools.	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
HbBvrPnds	Habitat type - beaver ponds	Percentage of the wetted channel surface area comprising beaver ponds. Note: these are pools located in the main or side channels, not part of off-channel habitat.	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
HbGlide	Habitat type - glide	Percentage of the wetted channel surface area comprising glides. Note: There is a general lack of consensus regarding the definition of glides (Hawkins et al. 1993), despite a commonly held view that it remains important to recognize a habitat type that is intermediate between pool and riffle. The definition applied here is from the ODFW habitat survey manual (Moore et al. 1997): an area with generally uniform depth and flow with no surface turbulence, generally in reaches of <1% gradient. Glides may have some small scour areas but are distinguished from pools by their overall homogeneity and lack of structure. They are generally deeper than riffles with few major flow obstructions and low habitat complexity.	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
HbLrgCbl	Habitat type - large cobble/boulder riffles	Percentage of the wetted channel surface area comprising large cobble/boulder riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter).	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
HbOfChFctr	Habitat type - off-channel habitat factor	A multiplier used to estimate the amount of off-channel habitat based on the wetted surface area of the all combined in-channel habitat.	No off-channel habitat present	>0 X and < 0.05 X	>0.05 X and < 0.25 X	>0.25 X and < 0.5 X	>0.5 X
HbPlTails	Habitat type - pool tailouts.	Percentage of the wetted channel surface area comprising pool tailouts.	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
HbPls	Habitat type - primary pools	Percentage of the wetted channel surface area comprising pools, excluding beaver ponds	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
HbSmlCbl	Habitat type - small cobble/grave l riffles	Percentage of the wetted channel surface area comprising small cobble/gravel riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter).	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
HbSdChFctr	Habitat type – side channel factor	The percentage of the active channel's wetted surface area comprised of side channels.	0 - <0.25% of wetted surface area encompasses side channels	>0.25% and <5% of wetted surface area encompasses side channels	>5% and <25% of wetted surface area encompasses side channels	>25% and <50% of wetted surface area encompasses side channels	>50% of wetted surface area encompasses this encompasses side channels

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Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
HbSdChType	Habitat type – side channel type	The average type of side channels within the reach, where type refers to a relative scale of water velocity flowing the side channels.	Water velocity through side channels is very slow, suitable for holding newly emerged salmonid fry without displacement by velocity.	Water velocity through side channels tends to be slow, though a small percentage of areas (relatively few in number) contain moderate velocity flows. Small juveniles would be able to hold within the lower velocity areas but might have difficulty holding in areas with the faster moving water.	Water velocity through side channels is diverse, ranging from areas of very low velocity to areas with relatively high velocities. Small juveniles would be able to hold within the lower velocity areas but would have difficulty holding in the highest velocity areas.	Water velocity through side channels tends to be high, though some areas (relatively few in number) contain very low velocity flows. Small juveniles would be able to hold within the lower velocity areas but would have difficulty holding in the highest velocity areas.	Water velocity through side channels is very high, representative of a very high enery condition, typically associated with very high gradient and/or high water volume contained within channels with low width to depth ratio of wetted channel. Small juvenile salmonids would be unable to hold themselves within the channel without sufficient refugia from high velocities.
Harass	Harassment	The relative extent of poaching and/or harassment of fish within the stream reach.	Reach is distant from human population centers, no road access or no local concentration of human activity.	Reach is distant from human population centers, but with partial road access or little local concentration of human activity.	Reach is near human population center, but has limited public access (through roads or boat launching sites).	Extensive road and/or boat access to the reach with localized concentrations of human activity.	Reach is near human population center or has extensive recreational activities, and has extensive road access and/or opportunities for boat access.
HatFOutp	Hatchery fish outplants - general	The magnitude of hatchery fish outplants made into the drainage over the past 10 years – all species combined here.	No hatchery fish releases in the past decade.	No more than two instances of fish releases in the past decade in the drainage.	Fish releases made into the drainage every 1-3 years at isolated locations within the drainage.	Fish releases made at multiple sites in the drainage, but only in 1-3 years during the past decade. When the species released is the same as focus species, chance for some superimposition can occur here.	Fish releases made every 1-3 years and at multiple sites in the drainage. When the species released is the same as focus species, superimposition can occur here.

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
HatFOutpSp	Hatchery fish outplants – species specific	The magnitude of hatchery fish outplants for particular species made into the drainage over the past 10 years. This attribute addresses specific salmonid species.	No hatchery fish releases of this species in the past decade.	The number of hatchery fish of this species usually is < 5% of the number of naturally produced juveniles (at approximately the same size class) in the drainage. An estimate of the number of naturally produced fish present will normally be based on a crude approximation.	The number of hatchery fish of this species usually is > 5% and < 25% of the number of naturally produced juveniles (at approximately the same size class) in the drainage. An estimate of the number of naturally produced fish present will normally be based on a crude approximation.	The number of hatchery fish of this species usually is > 25% and < 50% of the number of naturally produced juveniles (at approximately the same size class) in the drainage. An estimate of the number of naturally produced fish present will normally be based on a crude approximation.	The number of hatchery fish of this species usually exceeds 50% of the number of naturally produced juveniles (at approximately the same size class) in the drainage. An estimate of the number of naturally produced fish present will normally be based on a crude approximation.
FlwGrndw	Hydrologic regime - groundwater rating	The relative amount of groundwater being contributed to the surface flow within the reach.	Groundwater discharge into surface waters is the major source of flow in reach.	Abundant sites of groundwater discharge into surface waters.	Intermittent sites of groundwater discharge into surface waters and total quantity of groundwater discharge not a major source of flow in reach.	Infrequent sites of groundwater discharge into surface waters and total quantity of groundwater discharge not a major source of flow in reach.	No evidence of concentrated groundwater inputs.
HydroRegimeNatural	Hydrologic regime - natural	The natural flow regime within the reach of interest. Flow regime typically refers to the seasonal pattern of flow over a year; here it is inferred by identification of flow sources. This applies to an unregulated river or to the pre-regulation state of a regulated river.	Groundwater-source-dominated; strongly buffered peak flows (as in a springbrook or in river like the Metolius in central Oregon)	Spring snowmelt dominated, non-glacial; temporally consistent and moderate peak and low flows	Rain-on-snow transitional; consistent spring peak and low flows with inconsistent and flashy winter or early spring rain-on-snow peaks	Rainfall-dominated; flashy winter and early spring peaks, consistently low summer flows and variable spring and fall flows.	Glacial runoff system; high, turbid low flows, generally buffered peak flows except with occasional outburst floods and infrequent rain-on-snow events

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
HydroRegimeReg	Hydrologic regime - regulated	The change in the natural hydrograph caused by the operation of flow regulation facilities (e.g., hydroelectric, flood storage, domestic water supply, recreation, or irrigation supply) in a watershed. Definition does not take into account daily flow fluctuations (See Flow-Intra-daily variation attribute).	No artificial flow regulation occurs upstream to affect hydrograph.	Project operations have not changed median flows between months or season as the project is operated as a run-of-river facility, or project storage is < 15 days of the annual mean daily flow of the river.	Project operations have not changed median flows between months or season as the project is operated as a run-of-river facility, or project storage is > 15 and < 30-days of the annual mean daily flow of the river.	Project operations have resulted in a measurable shift in median flows between months or seasons. The project provides limited flood control during periods of high run-off (winter or spring). The project's reservoir is operated each year to store more than 30 but less than 60-days of the annual mean daily flow of the river.	Project operations have resulted in a major shift in median flows between months or seasons. The project is operated to provide significant flood control during high run-off periods (winter or spring). The project's reservoir is operated each year to store more than 60-days of the annual mean daily flow of the river.
Icing	Icing	Average extent (magnitude and frequency) of icing events over a 10-year period. Icing events can have severe effects on the biota and the physical structure of the stream in the short-term. It is recognized that icing events can under some conditions have long-term beneficial effects to habitat structure.	Anchor ice and icing events do not occur.	Some anchor ice may occur infrequently, having little or no impact to physical structure of stream, in-stream structure, and stream banks/bed.	Likelihood for some anchor ice and/or icing events is moderate to high each year and effects on stream, in-stream structure, and stream banks/beds is considered low to moderate.	Likelihood for anchor ice and/or icing events is high each year, having effects on stream, in-stream structure, and stream banks/beds that differ widely within the reach--from low to high across the reach.	Likelihood of severe anchor ice or overbank ice jams is high each year, having major and extensive effects on stream, in-stream structure, and stream banks across the reach.
MetWatCol	Metals - in water column	The extent of dissolved heavy metals within the water column.	No toxicity expected due to dissolved heavy metals to salmonids under prolonged exposure (1 month exposure assumed).	May exert some low level chronic toxicity to salmonids (1 month exposure assumed).	Consistently chronic toxicity expected to salmonids(1 month exposure assumed).	Usually acutely toxic to salmonids (1 month exposure assumed).	Always acutely toxic to salmonids (1 month exposure assumed).

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
MetSedSls	Metals/Pollutants - in sediments/soils	The extent of heavy metals and miscellaneous toxic pollutants within the stream sediments and/or soils adjacent to the stream channel.	Metals/pollutants at natural (background) levels with no or negligible effects on benthic dwelling organisms or riparian vegetation (under continual exposure).	Deposition of metals/pollutants in low concentrations such that some stress symptoms occur to benthic dwelling organisms or riparian vegetation root/shoot growth is impaired (under continual exposure).	Stress symptoms increased or biological functions moderately impaired to benthic dwelling organisms; or few areas within the riparian zone present where no vegetation exists (slickens); ecotonal to these areas occupied only by tolerant species; horizons containing metals/pollutant concentrations influencing root growth and composition are common within the riparian corridor.	Growth, food conversion, reproduction, or mobility of benthic organisms severely affected; or large areas of the riparian zone devoid of vegetation; ecotonal areas occupied only by metals/pollutant-tolerant species; few areas in the riparian zones which are unaffected.	Metals/pollutant concentrations in sediments/soils are lethal to large numbers of the benthic species and/or riparian zone is practically devoid of vegetation.
MscToxWat	Miscellaneous toxic pollutants - water column	The extent of miscellaneous toxic pollantants (other than heavy metals) within the water column.	No substances present that may periodically be at or near chronic toxicity levels to salmonids.	One substance present that may only periodically rise to near chronic toxicity levels (may exert some chronic toxicity) to salmonids.	More than one substance present that may periodically rise to near chronic toxicity levels or one substance present > chronic threshold and < acute threshold (consistently chronic toxicity) to salmonids.	One or more substances present > acute toxicity threshold but < 3X acute toxicity threshold (usually acutely toxic) to salmonids.	One or more substances present with > 3X acute toxicity (always acutely toxic) to salmonids.

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NutEnrch	Nutrient enrichment	The extent of nutrient enrichment (most often by either nitrogen or phosporous or both) from anthropogenic activities. Nitrogen and phosphorous are the primary macro-nutrients that enrich streams and cause build ups of algae. These conditions, in addition to leading to other adverse conditions, such as low DO can be indicative of conditions that are unhealthy for salmonids. Note: care needs to be applied when considering periphyton composition since relatively large mats of green filamentous algae can occur in Pacific Northwest streams with no nutrient enrichment when exposed to sunlight.	Unenriched streams (corresponding to benthic chlorophyll *a* values 0.5-3 mg/m2). Nutrient levels typical of oligotrophic conditions (small supply of nutrients, low production of organic matter, low rates of decomposition, and high DO). No enrichment is occurring nor is suspected. Green filamentous algae may be present at certain times of year, particularly in unshaded areas.	Very small amount of enrichment suspected to be occurring through land use activities (corresponding to benthic chlorophyll *a* values 3-20 mg/m2). Green filamentous algae present in summer months in unshaded reaches.	Nutrient levels typical of oligotrophic conditions (small supply of nutrients, low production of organic matter, low rates of decomposition, and high DO). Some enrichment known to be occurring (corresponding to benthic chlorophyll *a* values 20-60 mg/m2), often associated with failing skeptics tanks or runoff from areas of heavy fertilizer usage. Dense mats of green or brown filamentous algae present in summer months.	Euthrophic (abundant nutrients associated with high level of primary production, frequently resulting in oxygen depletion).Very obvious enrichment of reach is occurring from point sources or numerous non-point sources (corresponding to benthic chlorophyll *a* values 60-600 mg/m2). Large, dense mats of green or brown filamentous algae will be present during summer months.	Super enrichment of reach is strongly evident. Known, major point sources of organic waste inputs, such as runoff from large feedlot operation, wash water from farm products processing, or significant sewage facilities with inadequate treatment (corresponding to benthic chlorophyll *a* values 600-1200 mg/m2). In most severe cases, filamentous bacteria abundant, associated with low D.O. and hydrogen sulfide. In less severe cases, large dense mats of green or brown filamentous algae generally cover the substrate.

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Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Obstr	Obstructions to fish migration	Obstructions to fish passage by physical barriers (not dewatered channels or hindrances to migration caused by pollutants or lack of oxygen). Note: Rating here is used as a flag in the database. The nature of the obstruction is required to be defined more carefully in a follow-up form.	None documented or inferred.	One or barriers to juvenile migrants at certain flow levels.	One or barriers to juvenile migrants at all flow levels.	One or barriers to juvenile migrants at all flow levels and barrier(s) to adult migration at certain flow levels.	One or more barriers to all fish migration at all flow levels.
PredRisk	Predation risk	Level of predation risk on fish species due to presence of top level carnivores or unusual concentrations of other fish eating species. This is a classification of per-capita predation risk, in terms of the likelihood, magnitude and frequency of exposure to potential predators (assuming other habitat factors are constant). NOTE: This attribute is being updated to distinguish risk posed to small bodied fish (<10 in) from that to large bodied fish (>10 in).	Many or most native predators are depressed or rare, none are greatly increased over natural levels, and there is expected a significant numerical survival advantage to fish as a result compared to historical predator abundance.	Some native predators are moderately depressed, none are greatly increased over natural levels, and there is expected some small to moderate numerical survival advantage to fish as a result compared to historical predator abundance.	Diversity and per-capita abundance of predators exists so that predation risk is at near-natural level and distribution.	Moderate increase in population density or moderately concentrated population of predator species exists due to artifacts of human alteration of the environment (e.g., top-down food web effects, habitat manipulations) compared to historical condition.	Excessive population density or concentrated population of predator species exists due to artifacts of human alteration of the environment (e.g., top-down food web effects, habitat manipulations) compared to historic condition.

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RipFunc	Riparian function	A measure of riparian function that has been altered within the reach.	Strong linkages with no anthropogenic influences.	>75-90% of functional attributes present (overbank flows, vegetated streambanks, groundwater interactions typically present).	50-75% functional attribute rating- significant loss of riparian functioning- minor channel incision, diminished riparian vegetation structure and inputs etc.	25-50% similarity to natural conditions in functional attributes- many linkages between the stream and its floodplain are severed.	< 25% functional attribute rating: complete severing of floodplain-stream linkages
SalmCarcass	Salmon Carcasses	Relative abundance of anadromous salmonid carcasses within watershed that can serve as nutrient sources for juvenile salmonid production and other organisms. Relative abundance is expressed here as the density of salmon carcasses within subdrainages (or areas) of the watershed, such as the lower mainstem vs the upper mainstem, or in mainstem areas vs major tributary drainages.	Super abundant -- average number of carcasses per mile of main channel habitat (within an appropriately designated area) >800.	Very abundant -- average number of carcasses per mile of main channel habitat (within an appropriately designated area) >400 and < 800.	Moderately abundant -- average number of carcasses per mile of main channel habitat (within an appropriately designated area) >200 and < 400.	Not abundant -- average number of carcasses per mile of main channel habitat (within an appropriately designated area) >25 and <200.	Very few or none -- average number of carcasses per mile of main channel habitat (within an appropriately designated area) <25.
TmpMonMx	Temperature - daily maximum (by month)	Maximum water temperatures within the stream reach during a month.	Warmest day < 10 C	Warmest day>10 C and <16 C	> 1 d with warmest day 22-25 C or 1-12 d with >16 C	> 1 d with warmest day 25-27.5 C or > 4 d (non-consecutive) with warmest day 22-25 C or >12 d with >16 C	> 1 d with warmest day 27.5 C or 3 d (consecutive) >25 C or >24 d with >21 C

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
TmpMonMn	Temperature - daily minimum (by month)	Minimum water temperatures within the stream reach during a month.	Coldest day >4 C	< 7 d with <4 C and minimum >1 C	1 to 7 d < 1 C	8 to 15 days < 1 C	> 15 winter days < 1 C
TmpSptVar	Temperature - spatial variation	The extent of water temperature variation (cool or warm water depending upon season) within the reach as influenced by inputs of groundwater or tributary streams, or the presence of thermally stratified deep pools.	Super abundant sites of groundwater discharge into surface waters (primary source of stream flow), tributaries entering reach, or deep pools that provide abundant temperature variation in reach.	Abundant sites of groundwater discharge into surface waters, tributaries entering reach, or deep pools that provide abundant temperature variation in reach.	Occasional sites of groundwater discharge into surface waters, tributaries entering reach or deep pools that provide intermittent temperature variation in reach.	Infrequent sites of groundwater discharge into surface waters, tributaries entering reach or deep pools that provide infrequent temperature variation in reach.	No evidence of temperature variation in reach.

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Turb	Turbidity	The severity of suspended sediment (SS) episodes within the stream reach. (Note: this attribute, which was originally called turbidity and still retains that name for continuity, is more correctly thought of as SS, which affects turbidity.) SS is sometimes characterized using turbidity but is more accurately described through suspended solids, hence the latter is to be used in rating this attribute. Turbidity is an optical property of water where suspended, including very fine particles such as clays and colloids, and some dissolved materials cause light to be scattered; it is expressed typically in nephelometric turbidity units (NTU). Suspended solids represents the actual measure of mineral and organic particles transported in the water column, either expressed as total suspended solids (TSS) or suspended sediment concentration (SSC)—both as mg/l. Technically, turbidity is not SS but the two are usually well correlated. If only NTUs are available, an approximation of SS can be obtained through relationships that correlate the two. The metric applied here is the Scale of Severity (SEV) Index taken from Newcombe and Jensen (1996), derived from: SEV = a + b(lnX) + c(lnY) , where, X = duration in hours, Y = mg/l, a = 1.0642 , b = 0.6068, and c = 0.7384. Duration is the number of hours out of month (with highest SS typically) when that concentration or higher normally occurs. Concentration would be represented by grab samples reported by USGS. See rating guidelines.	SEV Index <= 4.5 Clear with infrequent (short duration-- several days per year) concentrations of low concentrations (< 50 mg/l) of suspended sediment. No adverse effects on biota of these low doses.	SEV Index >4.5 and <= 7.5 Occasional episodes (days) of low to moderate concentrations (<500 mg/L), though very short duration episodes (hours) may occur with of higher concentrations (500 to 1000). These concentrations are always sublethal to juvenile and adult salmonids- though some behavioral modification may occur.	SEV Index >7.5 and <= 10.5 Occasional episodes of moderate to relatively high concentrations (>500 and <1000 mg/L), though shorter duration episodes (<1 week) may occur with higher concentrations (1000-5000 mg/L). The higher concentrations stated can be expected to result in major behavioral modification, severe stress, severely reduced forage success and direct mortality.	SEV Index >10.5 and <= 12.5 On-going or occasional episodes (periodic events annually lasting weeks at a time) of high concentrations of suspended sediment (>5000 and <10000 mg/L), or shorter duration episodes lasting hours or days of higher concentrations. These conditions result in direct, high mortality rates.	SEV Index >12.5 Extended periods (month) of very high concentrations (>10000 mg/L). These represent the most extreme severe conditions encountered and result in very high mortality of fish species.

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Wdrwl	Water withdrawals	The number and relative size of water withdrawals in the stream reach.	No withdrawals.	Very minor water withdrawals with or without screening (entrainment probability considered very low).	Several of significant water withdrawals along reach though all sites known or believed to be screened with effective screening devices. (Note: one site that withdraws substantial portion of flow without screening falls into this category.)	Several sites of significant water withdrawals along reach without screening or screening believed to be ineffective. (Note: one site that withdraws substantial portion of flow without screening falls into this category.)	Frequent sites of significant water withdrawals along reach without screening or screening believed to be ineffective.

Appendix Table D-1. Level 2 Environmental Attributes and associated rating definitions.

Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
WdDeb	Wood	The amount of wood (large woody debris or LWD) within the reach. Dimensions of what constitutes LWD are defined here as pieces >0.1 m diameter and >2 m in length. Numbers and volumes of LWD corresponding to index levels are based on Peterson et al. (1992), May et al. (1997), Hyatt and Naiman (2001), and Collins et al. (2002). Note: channel widths here refer to average wetted width during the high flow month (< bank full), consistent with the metric used to define high flow channel width. Ranges for index values are based on LWD pieces/CW and presence of jams (on larger channels). Reference to "large" pieces in index values uses the standard TFW definition as those > 50 cm diameter at midpoint.	A complex mixture of single large pieces and accumulations consisting of all sizes, decay classes, and species origins; cross-channel jams are present where appropriate vegetation and channel conditions facilitate their existence; large wood pieces are a dominant influence on channel diversity (e.g., pools, gravel bars, and mid-channel islands) where channel gradient and flow allow such influences. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- 3-10 pieces/CW, 25-50 ft -- 3-10 pieces/CW, 50-150 ft -- 7-30 pieces/CW, 150-400 ft -- 20-50 pieces/CW in conjunction with large jams in areas where accumulations might occur, >400 ft -- 15-37 pieces/CW in conjunction with large jams in areas where accumulations might occur.	Complex array of large wood pieces but fewer cross channel bars and fewer pieces of sound large wood due to less recruitment than index level 1; influences of large wood and jams are a prevalent influence on channel morphology where channel gradient and flow allow such influences. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- 2-3 pieces/CW, 25-50 ft -- 2-4 pieces/CW, 50-150 ft -- 3-7 pieces/CW , 150-400 ft -- 10-20 pieces/CW (excluding large jams) in conjunction with large jams in areas where accumulations might occur, >400 ft -- 8-15 pieces/CW (excluding large jams) in conjunction with large jams in areas where accumulations might occur.	Few pieces of large wood and their lengths are reduced and decay classes older due to less recruitment than in index level 1; small debris jams poorly anchored in place; large wood habitat and channel features of large wood origin are uncommon where channel gradient and flow allow such influences. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- 1-2 pieces/CW, 25-50 ft -- 1-2 pieces/CW, 50-150 ft -- 1-3 pieces/CW , 150-400 ft -- 10-20 pieces/CW without large jams in areas where accumulations might occur, >400 ft -- 8-15 pieces/CW without large jams in areas where accumulations might occur.	Large pieces of wood rare and the natural function of wood pieces limited due to diminished quantities, sizes, decay classes and the capacity of the riparian streambank vegetation to retain pieces where channel gradient and flow allow such influences. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- 0.33-1 pieces/CW, 25-50 ft -- 0.33-1 pieces/CW, 50-150 ft -- 0.33-1 pieces/CW , 150-400 ft -- 3-10 pieces/CW without large jams in areas where accumulations might occur, >400 ft -- 2-8 pieces/CW without large jams in areas where accumulations might occur.	Pieces of LWD rare. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- <0.33 pieces/CW, 25-50 ft -- <0.33 pieces/CW, 50-150 ft -- <0.33 pieces/CW , 150-400 ft -- <3 pieces/CW with accumulations where they might occur, >400 ft -- <2 pieces/CW with no accumulations where they might occur.

Appendix E: Level 3 Survival Factors

Appendix Table E-1. Level 3 Survival Factors.

Factor	Definition
Channel stability	The effect of stream channel stability (within reach) on the relative survival or performance of the focus species; the extent of channel stability is with respect to its streambed, banks, and its channel shape and location.
Chemicals	The effect of toxic substances or toxic conditions on the relative survival or performance of the focus species. Substances include chemicals and heavy metals. Toxic conditions include low pH.
Competition (with hatchery fish)	The effect of competition with hatchery produced animals on the relative survival or performance of the focus species; competition might be for food or space within the stream reach.
Competition (with other species)	The effect of competition with other species on the relative survival or performance of the focus species; competition might be for food or space.
Flow	The effect of the amount of stream flow, or the pattern and extent of flow fluctuations, within the stream reach on the relative survival or performance of the focus species. Effects of flow reductions or dewatering due to water withdrawals are to be included as part of this attribute.
Food	The effect of the amount, diversity, and availability of food that can support the focus species on its relative survival or performance.
Habitat diversity	The effect of the extent of habitat complexity within a stream reach on the relative survival or performance of the focus species.
Harassment	The effect of harassment, poaching, or non-directed harvest (i.e., as can occur through hook and release) on the relative survival or performance of the focus species.
Key habitat	The relative quantity of the primary habitat type(s) utilized by the focus species during a life stage; quantity is expressed as percent of wetted surface area of the stream channel.
Obstructions	The effect of physical structures impeding movement of the focus species on its relative survival or performance within a stream reach; structures include dams and waterfalls.
Oxygen	The effect of the concentration of dissolved oxygen within the stream reach on the relative survival or performance of the focus species.
Pathogens	The effect of pathogens within the stream reach on the relative survival or performance of the focus species. The life stage when infection occurs is when this effect is accounted for.
Predation	The effect of the relative abundance of predator species on the relative survival or performance of the focus species.
Sediment load	The effect of the amount of the amount of fine sediment present in, or passing through, the stream reach on the relative survival or performance of the focus species.
Temperature	The effect of water temperature with the stream reach on the relative survival or performance of the focus species.
Withdrawals (or entrainment)	The effect of entrainment (or injury by screens) at water withdrawal structures within the stream reach on the relative survival or performance of the focus species. This effect does not include dewatering due to water withdrawals, which is covered by the flow attribute.

Appendix F: Associations Used in Translating Level 2 Environmental Attribute Values to Level 3 Survival Factor Values

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
Spawning	Channel stability	No effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	Hatchery fish outplants – species specific (brook trout)						
	Competition (with other species)	Fish species status (brook trout)						
	Flow	Flow - Intra daily (diel) variation						
	Food	No effects						
	Habitat diversity	Gradient	Confinement - natural	Confinement - Hydromodifications	Riparian function	Wood		
	Harassment	Harassment	Habitat type - primary pools	Riparian function	Turbidity (susp. sed.)	Wood		
	KeyHabitat	Habitat type- small cobble/gravel riffles	Habitat type- pool tailouts	Habitat type-glides	Habitat type – side channel factor	Habitat type – side channel type		
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk						
	Sediment load	Turbidity (susp. sed.)	Temperature - daily maximum (by month)					

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
Incubation	Channel stability	Bed scour	Icing	Riparian function	Wood	Habitat type - side channel factor	Habitat type - side channel type	
	Chemicals	Miscellaneous toxic pollutants - water column	Metals/Pollutants - in sediments/soils	Metals - in water column				
	Competition (with hatchery fish)	Hatchery fish outplants – species specific (brook trout)	Hatchery fish outplants – species specific (brown trout)					
	Competition (with other species)	Fish species status (brook trout)	Fish species status (brown trout)					
	Flow	Flow - Intra daily (diel) variation						
	Food	no effects						
	Habitat diversity	No effect						
	Harassment	Harassment						
	KeyHabitat	Habitat type- small cobble/gravel riffles	Habitat type- glides	Habitat types- pool tailouts				
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	No effect						

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Sediment load	Fine sediment - <1 mm OR Fine sediment - <6 mm	Hydrologic regime - groundwater rating	Bed scour (only with Fine sediment < 6 mm)				
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
Fry colonization	Channel stability	Bed scour	Icing	Riparian function	Wood	Habitat type - side channel factor	Habitat type - side channel type	
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	No effect						
	Competition (with other species)	Fish species status (brook trout)	Fish species status (brown trout)					
	Flow	Flow - change in interannual variability in high flows Flow - Intra daily (diel) variation	Confinement - natural	Confinement - Hydromodifications	Gradient	Flow - intra-annual flow pattern	Riparian function	Wood
	Food	Alkalinity	Benthos diversity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient	Confinement - Hydromodifications	Riparian function	Wood	Icing	Habitat type - side channel factor	Habitat type - side channel type
	Harassment	no effects						
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Hatchery fish outplants		
	Sediment load	Turbidity (susp. sed.)	Embeddedness					
	Temperature	Temperature - daily maximum (by month)	Temperature - daily minimum (by month)	Temperature - spatial variation				
	Withdrawals	Water withdrawals						
0-age resident and transient rearing	Channel stability	Bed scour	Icing	Riparian function	Wood	Habitat type - side channel factor	Habitat type - side channel type	
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	Hatchery fish outplants – species specific (brook trout)	Hatchery fish outplants – species specific (brown trout)	Hatchery fish outplants – species specific (rainbow-steelhead trout)	Hatchery fish outplants – species specific (cutthroat trout)	Hatchery fish outplants – species specific (Chinook salmon)	Hatchery fish outplants – species specific (coho salmon)	
	Competition (with other species)	Fish species status (brook trout)	Fish species status (brown trout)	Fish species status (rainbow-steelhead trout)	Fish species status (cutthroat trout)	Fish species status (Chinook salmon)	Fish species status (coho salmon)	
	Flow	Flow - changes in interannual variability in low flows Riparian function	Embeddedness Wood	Habitat type-backwater pools Flow - Intra daily (diel) variation	Habitat type-beaver ponds	Habitat type-primary pools	Confinement - Hydromodifications	Confinement - natural
	Food	Alkalinity	Benthos Diversity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient	Confinement - natural	Confinement - Hydromodifications	Riparian function	Wood		
	Harassment	Harassment	Habitat type - primary pools	Riparian function	Turbidity (susp. sed.)	Wood		

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	KeyHabitat	Habitat type- backwater pools Habitat type- side channel factor	Habitat type- beaver ponds	Habitat type- glides	Habitat type-large cobble/boulder riffles	Habitat type- pool tailouts	Habitat type- primary pools	Habitat type- small cobble/gravel riffles
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily max. (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Hatchery fish outplants		
	Sediment load	Turbidity (susp. sed.)	Temperature - daily max. (by month)	Embeddedness				
	Temperature	Temperature - daily max. (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
0-age migrant	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	No effect						
	Competition (with other species)	No effect						
	Flow	No effect						
	Food	no effects						
	Habitat diversity	Riparian function	Confinement - natural	Confinement - Hydromodifications	Wood			
	Harassment	No effect						

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Key Habitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Hatchery fish outplants		
	Sediment load	Turbidity (susp. sed.)	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
0-age Inactive	Channel stability	Bed scour	Icing	Riparian function	Wood	Habitat type - side channel factor	Habitat type - side channel type	
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	Hatchery fish outplants – species specific (brook trout)	Hatchery fish outplants – species specific (brown trout)	Hatchery fish outplants – species specific (rainbow-steelhead trout)	Hatchery fish outplants – species specific (cutthroat trout)			
	Competition (with other species)	Fish species status (brook trout)	Fish species status (brown trout)	Fish species status (rainbow-steelhead trout)	Fish species status (cutthroat trout)	Fish species status (Chinook salmon)	Fish species status (coho salmon)	

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Flow	Flow - change in interannual vari-ability in high flows Flow - Intra daily (diel) variation	Confinement - natural	Confinement - Hydromodifications	Gradient	Flow-intra-annual flow pattern	Riparian function	Wood
	Food	Benthos diversity and production	Alkalinity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient Habitat type - side channel type	Confinement - natural	Confinement - Hydromodifications	Riparian function	Wood	Icing	Habitat type - side channel factor
	Harassment	Harassment						
	KeyHabitat	Habitat type- backwater pools Habitat type- side channel factor	Habitat type- beaver ponds	Habitat type- glides	Habitat type-large cobble/boulder riffles	Habitat type- pool tailouts	Habitat type- primary pools	Habitat type- small cobble/gravel riffles
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily max. (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature-daily min. (by month)	Hatchery fish outplants		
	Sediment load	Embeddedness	Turbidity (susp. sed.)					
	Temperature	Temperature - daily min. (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
1-age resident and transient rearing	Channel stability	Bed scour	Icing	Riparian function	Wood	Habitat type - side channel factor	Habitat type - side channel type	
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	Hatchery fish outplants – species specific (brook trout)	Hatchery fish outplants – species specific (brown trout)	Hatchery fish outplants – species specific (rainbow-steelhead trout)	Hatchery fish outplants – species specific (cutthroat trout)			

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Competition (with other species)	Fish species status (brook trout)	Fish species status (brown trout)	Fish species status (rainbow-steelhead trout)	Fish species status (cutthroat trout)			
	Flow	Flow - changes in interannual vari-ability in low flows Riparian function	Embeddedness Wood	Habitat type- backwater pools Flow - Intra daily (diel) variation	Habitat type- beaver ponds	Habitat type- primary pools	Confinement - Hydromodification s	Confinement - natural
	Food	Alkalinity	Benthos diversity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient	Confinement - natural	Confinement - Hydromodifications	Riparian function	Wood		
	Harassment	Harassment	Habitat type - primary pools	Riparian function	Turbidity (susp. sed.)	Wood		
	KeyHabitat	Habitat type- backwater pools Habitat type- side channel factor	Habitat type- beaver ponds	Habitat type- glides	Habitat type-large cobble/boulder riffles	Habitat type- pool tailouts	Habitat type- primary pools	Habitat type- small cobble/gravel riffles
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature-daily max. (by month)	Hatchery fish outplants		
	Sediment load	Turbidity (susp. sed.)	Temperature - daily max. (by month)					
	Temperature	Temperature - daily min. (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
1-age migrant	Channel stability	No effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Competition (with hatchery fish)	No effects						
	Competition (with other species)	No effects						
	Flow	No effects						
	Food	No effects						
	Habitat diversity	Gradient	Confinement - natural	Confinement - Hydromodifications	Riparian function	Wood		
	Harassment	Harassment						
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Hatchery fish outplants		
	Sediment load	Turbidity (susp. sed.)	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily minimum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
1-age	Channel stability	Bed Scour	Icing	Riparian Function	Wood			

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
inactive	Chemicals	Misc toxic pollutants- water column	Metals/Pollutants- in sediments/soils	Metals- in water column				
	Competition (with hatchery fish)	No effect						
	Competition (with other species)	No effect						
	Flow	Flow- change in interannual variability in high flows	Confinement- Hydromodifications	Confinement- natural	Gradient	Flow- intra-annual flow pattern	Riparian function	Wood
	Food	Alkalinity	Salmon Carcasses	Benthos diversity	Riparian function			
	Habitat diversity	Gradient	Confinement- Hydromodifications	Confinement- natural	Riparian Function	Wood		
	Harassment	No effect						
	KeyHabitat	Habitat type- backwater pools Habitat type- side channel factor	Habitat type- beaver ponds	Habitat type- glides	Habitat type-large cobble/boulder riffles	Habitat type- pool tailouts	Habitat type- primary pools	Habitat type- small cobble/gravel riffles
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved Oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature- daily Max (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature- daily Min (by month)	Hatchery fish outplants		
	Sediment load	Embeddedness	Turbidity					
	Temperature	Temperature- daily Min (by month)	Temperature- spatial variation					
	Withdrawals	Water withdrawals						

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
2+ age resident and transient rearing	Channel stability	Bed scour	Icing	Riparian function	Wood	Habitat type - side channel factor	Habitat type - side channel type	
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	Hatchery fish outplants – species specific (brook trout)	Hatchery fish outplants – species specific (brown trout)	Hatchery fish outplants – species specific (rainbow-steelhead trout)	Hatchery fish outplants – species specific (cutthroat trout)			
	Competition (with other species)	Fish species status (brook trout)	Fish species status (brown trout)	Fish species status (rainbow-steelhead trout)	Fish species status (cutthroat trout)			
	Flow	Flow - changes in interannual vari-ability in low flows Riparian function	Embeddedness Wood	Habitat type-backwater pools Flow - Intra daily (diel) variation	Habitat type-beaver ponds	Habitat type-primary pools	Confinement - Hydromodifications	Confinement - natural
	Food	Alkalinity	Benthos diversity	Riparian function	Salmon Carcasses	Fish community richness		
	Habitat diversity	Gradient	Confinement - natural	Confinement - Hydromodifications	Riparian function	Wood		
	Harassment	Harassment	Habitat type - primary pools	Riparian function	Turbidity (susp. sed.)	Wood		
	KeyHabitat	Habitat type-backwater pools Habitat type- side channel factor	Habitat type-beaver ponds	Habitat type- glides	Habitat type-large cobble/boulder riffles	Habitat type- pool tailouts	Habitat type-primary pools	Habitat type- small cobble/gravel riffles
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily max. (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature-daily ma. (by month)	Hatchery fish outplants		
	Sediment load	Turbidity (susp. sed.)	Temperature - daily max. (by month)					

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Temperature	Temperature - daily min. (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
2+ age migrant	Channel stability	No effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	No effects						
	Competition (with other species)	No effects						
	Flow	No effects						
	Food	No effects						
	Habitat diversity	Gradient	Confinement - natural	Confinement - Hydromodifications	Riparian function	Wood		
	Harassment	Harassment						
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Hatchery fish outplants		
	Sediment load	Turbidity (susp. sed.)	Temperature - daily maximum (by month)					

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Temperature	Temperature - daily minimum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
2+ age inactive	Channel stability	Bed Scour	Icing	Riparian Function	Wood			
	Chemicals	Misc toxic pollutants- water column	Metals/Pollutants- in sediments/soils	Metals- in water column				
	Competition (with hatchery fish)	No effect						
	Competition (with other species)	No effect						
	Flow	Flow- change in interannual variability in high flows	Confinement- Hydromodifications	Confinement- natural	Gradient	Flow- intra-annual flow pattern	Riparian function	Wood
	Food	Alkalinity	Salmon Carcasses	Benthos diversity	Riparian function	Fish community richness		
	Habitat diversity	Gradient	Confinement- Hydromodifications	Confinement- natural	Riparian Function	Wood		
	Harassment	No effect						
	KeyHabitat	Habitat type- backwater pools Habitat type- side channel factor	Habitat type- beaver ponds	Habitat type- glides	Habitat type-large cobble/boulder riffles	Habitat type- pool tailouts	Habitat type- primary pools	Habitat type- small cobble/gravel riffles
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved Oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature- daily Max (by month)	Nutrient enrichment			

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature-daily Min (by month)	Hatchery fish outplants		
	Sediment load	Embeddedness	Turbidity					
	Temperature	Temperature- daily Min (by month)	Temperature-spatial variation					
	Withdrawals	Water withdrawals						
Prespawning migrant - transient	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	No effect						
	Competition (with other species)	No effect						
	Flow	Flow - changes in interannual variability in low flows Riparian function	Embeddedness Wood	Habitat type-backwater pools Flow - Intra daily (diel) variation	Habitat type-beaver ponds	Habitat type-primary pools	Confinement - Hydromodifications	Confinement - natural
	Food	Alkalinity	Benthos diversity	Riparian function	Salmon Carcasses	Fish community richness		
	Habitat diversity	Gradient	Confinement - natural	Confinement - Hydromodifications	Riparian function	Wood		
	Harassment	Harassment	Habitat type - primary pools	Riparian function	Turbidity (susp. sed.)	Wood		
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk						
	Sediment load	Turbidity (susp. sed.)	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	No effects						
Prespawning holding	Channel stability	No effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/Pollutants - in sediments/soils				
	Competition (with hatchery fish)	No effects						
	Competition (with other species)	No effects						
	Flow	Flow - changes in interannual variability in low flows Riparian function	Embeddedness Wood	Habitat type- backwater pools Flow - Intra daily (diel) variation	Habitat type- beaver ponds	Habitat type- primary pools	Confinement - Hydromodifications	Confinement - natural
	Food	Alkalinity	Benthos diversity	Riparian function	Salmon Carcasses	Fish community richness		
	Habitat diversity	Gradient	Confinement - Hydromodifications	Riparian function	Wood			
	Harassment	Harassment	Habitat type - primary pools	Riparian function	Turbidity (susp. sed.)	Wood		
	KeyHabitat	Habitat type- glides	Habitat type-large cobble/boulder riffles	Habitat type- pool tailouts	Habitat type- primary pools	Habitat type – side channel factor		

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for bull trout.

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk						
	Sediment load	Turbidity (susp. sed.)	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	No effect						

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Appendix 2

Qualitative Habitat Assessment (QHA) User's Guide

Qualitative Habitat Assessment (QHA) User's Guide Version 1.1

June 21, 2003

Overview

The Qualitative Habitat Assessment technique (QHA) provides a structured, "qualitative" approach to analyzing the relationship between a given fish species and its habitat. It does this through a systematic assessment of the condition of several aquatic habitat attributes (sediment, water temperature, etc.) that are thought to be key to biological production and sustainability. Attributes are assessed for each of several stream reaches or small watersheds within a larger hydrologic system. Habitat attribute findings are then considered in terms of their influence on a given species and life stage.

QHA relies on the expert knowledge of natural resource professionals with experience in a given local area to describe physical conditions in the target stream and to create an hypothesis about how the habitat would be used by a given fish species. The hypothesis is the "lens" through which physical conditions in the stream are viewed. The hypothesis consists of weights that are assigned to life stages and habitat attributes, as well as a description of how reaches are used by different life stages. These result in a composite weight that is applied to a physical habitat score in each reach. This score is the difference between a rating of physical habitat in a reach under the current condition and a theoretical "reference" condition.

The ultimate result is an indication of the relative restoration and protection value for each reach and habitat attribute. QHA also provides a means to compare restoration and protection ratings to other biological and demographic information of the user's choosing. QHA includes features for documenting the decision process and describing the level of confidence that users have in the various ratings.

QHA should not be viewed as a sophisticated analytical model. QHA simply supplies a framework for reporting information and analyzing the relationships between a species and its environment. It is up to knowledgeable scientists, managers, and planners to interpret results and make actual decisions regarding these relationships and the actions that might be taken to protect or strengthen these relationships.

Applications

The QHA was developed for use in Columbia Basin Fish and Wildlife Program subbasin planning and similar "mid-scale" aquatic habitat assessments. The QHA is intended for use in stream environments at subbasin and provincial scales; it would not be particularly useful for detailed assessments covering only a few stream reaches or small watersheds or, conversely, for coarse-scale region-wide assessments. The minimum number of reaches or small watersheds where QHA results would be meaningful is, perhaps, 20-25. There is no upper limit to the number of reaches or small watersheds but 300-400 would be a reasonable upper limit.

The QHA was developed primarily for resident salmonids, though, with modifications, it may have applicability to other fish species as well.

While it is possible to integrate lake or reservoir assessment findings with QHA, as currently constructed this technique would be of limited use for areas where a lake or reservoir is the dominant fish habitat. QHA could, however, be used to support a lake assessment by characterizing fish/habitat relationships in lake tributaries. (We discuss opportunities for considering lakes and reservoirs in the Q&A section at the end of this user's guide.) It may also be possible to use QHA techniques and data to supplement assessments of aquatic-related terrestrial species using IBIS or other wildlife and ecosystem assessment techniques, but this type of application has not yet been explored in any detail.

An Overview of Qualitative Biological Assessment

Use of professional judgment (or, if you prefer, expert opinion) as an analytical technique is often criticized for being subjective and lacking consistency. On the other hand, it is well recognized that a strictly quantitative approach may not always be possible, or even preferred. For example, using a quantitative approach may not make sense in areas where data are limited, when there is not enough time allotted to conduct a rigorous quantitative assessment, or where appropriate tools or expertise are not available. In these situations a more qualitative approach is indicated. The 2000 *Template for Subbasin Assessment*, for example, referenced the use of "opinions of local fish managers" as a valid analytical tool.

The QHA was designed to capitalize on the strengths of professional judgment while minimizing subjectivity and inconsistency. QHA is what we call a "structured qualitative assessment." In other words, it is a systematic assessment of species habitat relationships that relies principally on existing local professional knowledge and judgment but that "structures" the process by: (1) following a logical and replicable sequence, (2) using the best available quantitative data as the basis for decisions, (3) generating a product that is similar in form to products resulting from other more quantifiable approaches, and (4) documenting the decision process.

Products

QHA produces a series of tables that (1) describe the physical habitat, (2) establish an hypothesis concerning how species interact with the natural environment, and (3) identify where restoration and/or protection activities may be the most productive. Taken as a whole, these tables offer a means to focus the attention of biologists and planners and track the decision process. They do not, however, constitute a complete assessment. That is the purview of local biologists and planners.

Relationship to Other Assessment Techniques

QHA relies on the same conceptual framework as the Ecosystem Diagnosis and Treatment (EDT) technique. There are, however, several important differences. While each of the habitat characteristics used in QHA is also used in EDT, EDT considers many more habitat factors and links these more directly to measurable data. QHA, by contrast, relies on the judgment of knowledgeable professionals to draw these linkages.

EDT relies on a set of objective biological rules derived from the technical literature to establish the relationship between a species and its habitat. Again, QHA relies on professional judgment to make this connection. EDT uses a series of life history trajectories to model the movement of fish through its environment over several life stages and over the entire life history. QHA collapses life history into fewer stages. Importantly, QHA treats each stream reach or small watershed as an independent static unit whereas EDT evaluates the connectivity of reaches and the variation in conditions within a year. Again, QHA relies on the knowledge of experts to think through life history dynamics.

EDT analysis can incorporate information on out-of-subbasin effects, i.e., survival outside of the natal subbasin including ocean survival as well as harvest. QHA does not consider conditions outside the subbasin. (We discuss opportunities for considering out-of-subbasin effects in the Q&A section at the end of this user's guide.)

Lastly, EDT produces a series of numerical products that estimate productivity, abundance, and related factors that give an indication of how well habitat supports fish. As a qualitative technique QHA does not generate these outputs but rather produces an index of habitat condition and a series of products that suggest directions for management.

Getting Started

The QHA package consists of two computer files. The first is the user's manual. You are reading it so presumably you have access to this file. The second is a spreadsheet file containing several tables. Examples of QHA applications in other Columbia Basin subbasins are also available upon request.

The technique makes use of the Microsoft Excel spreadsheet program. Essentially, the user opens Excel and loads the QHA Excel file, changes the name of the file to reflect the name of your subbasin (example: QHA Flathead, or, if more than one species will be considered, QHA Flathead bulltrout), and proceeds to move through a series of sheets (or tabs) shown on the bottom of the computer screen. The first time user will definitely want to move through the tabs in sequence from left to right. The first task is to construct a table that lists all stream reaches or small watersheds that will be subjected to assessment. The majority of the work in inputting information will be in tables accessed through the current, reference, and hypothesis tabs. Interpretation of results occurs in tables accessed through the protection rankings, restoration rankings, and tornado tabs.

These tables are generated using information entered in the current, reference, and hypothesis tables. Note that tables are "protected" so that change is restricted to specific input cells. If you get an error message about protection, that means you are trying to input data in a calculation cell.

Modification and Technical Support

The QHA will have to be customized to each subbasin to, at the least, incorporate a list of reaches or small watersheds and insure that the reach list transfers to other tables and that internal calculations are working properly. (We discuss reaches in more detail later.) Modifications may also be necessary to meet the needs of the individual province or subbasin. Planners will also need to have some training in the use of the product. With this in mind, the Council will make available a limited amount of technical support. Generally this support would take the form of (1) assistance in establishing a list of reaches or small watershed, (2) assistance in adapting the product to the local situation, (3) training in the use of the product, and (4) trouble shooting. For further information please contact Drew_Parkin@msmn.com.

Users who have experience with Excel programming may feel compelled to modify or expand the technique to meet the unique needs of a given province or subbasin. The developers of the product encourage users to think of ways that the QHA might be improved. However, as a courtesy, and as a means to maintain consistency among provinces and subbasins, it is requested that, prior to making significant modifications, you contact the developers of the product to apprise us of what you intend to do. This will allow us to keep abreast of how the product is being used and keep track of potential enhancements to the product. Besides, we may be able to help with the modifications, particularly if they have broad applicability.

Following is a description of each of the most important tabs, working from left to right.

The Setup Tab

This sheet provides a means for subbasin planners to input essential background information on the drainage being assessed, the focal species being considered, and the people contributing to the assessment. It is important to identify a focal species at this point, as this species will be the focus of the assessment. (In the Q&A section of this guide we discuss how QHA might be used with multiple focal species.)

The Reach Tab

Within this tab one will find a table that will house a list of "reaches" or "small watersheds" that collectively make up the subbasin. It is crucial that this table be constructed correctly as it is the basis for all other tables in the QHA system. More precisely, the QHA system is set up such that this table automatically transfers to all other tables. You will note that the table has several columns, one for a sequence number, one for a name, and others for identifying hydrologic units based on the USGS hydrologic unit system. It is also possible to add other columns, for example a column that lists reach or watershed numbers. Only a sequence number and a name are necessary for this application, but it is strongly recommended that some hydrologic units be included so that reaches/watersheds can be sorted into sub-subbasin units. This is particularly important for larger subbasins such as the Salmon, Willamette, John Day, Yakima, and Kootenai.

It is possible to add reaches or small watersheds during the assessment, though this should be done sparingly to ensure that everything transfers correctly. The key thing to remember is that changes to the reach/watershed system should only be made to the table in the reach tab.

Planners need to decide whether to use reaches or small watersheds and how these will be delineated. A reach is a linear stretch of stream with distinct upstream and downstream delineations. By contrast, a small watershed is a polygon that includes several reaches that drain to the same point.

Reaches may be hydrologically defined, as is the case in the USGS/EPA river reach system where a reach is defined as the area between given confluences. The 1:100,000-scale river reach system is an example of a hydrologically defined reach system. (This system is available through www.streamnet.org.) The alternative to a purely hydrological reach definition is a system based on ecological character, whereby subbasin planners manually review the streams in the subbasin and divide them into meaningful ecologically consistent segments.

The alternative to the reach is the small watershed. For the purposes at hand, planners wishing to use small watersheds should consider using the 6th field hydrologic unit code (HUC), available through http://nppc.bpa.gov. This is the finest scale that has been defined in a systematic fashion and that results in a number of units per subbasin that should be manageable (typically 50 to 300, with an average of 100). Note that 7th and 8th field HUCs are used by some national forests but these have not been consistently defined across the Columbia Basin. A systematic Basin-wide layer of 4th field HUCs is also available but in most cases this is too coarse for subbasin planning purposes. No systematic, region-wide 5th field HUC layer exists, though the US Forest Service/Bureau of Land Management ICBEMP project did develop a 5th field HUC system for use in areas east of the Cascade Crest. Planners who wish to use 5th field HUCs should consult www.icbemp.gov. Again, our recommendation is that planners wishing to use a small watershed approach first consider the 6th field HUC.

Regardless of whether planners elect to use reaches or small watersheds, these should be arrayed in the table in hydrologic sequence. In larger subbasins, planners may find it useful to group these into major drainages and assign assessment responsibilities accordingly. For example, a system such as the John Day, Salmon, or Flathead could be divided into four or five distinct units – lower mainstem, north fork, south fork, middle fork, etc. This will prove useful later when planners want to look at habitat characteristics for a specific fish population.

The number of reaches or small watersheds will depend on the level of resolution that is appropriate for this exercise. Planners will use their discretion to "lump" or "split" to arrive at a number of reaches or watersheds that is scientifically defensible and realistic in terms of workload. We assume that each subbasin will have between 50 and 400 reaches or small watersheds, depending on size and complexity of this type. We base this on (1) the scale of typically available data, (2) the amount of time that it will take to fill in the table, and 3) the resolution that is appropriate for a qualitative assessment. Planners may, of course, define reaches or small watersheds at finer levels of resolution if they believe this is necessary. In this case we recommend that reaches be used rather than small watersheds as defining fine-scale watersheds would be extremely time-consuming and subject to error. Planners often express interest in using the finest scale hydrography available. In most cases this is the 1:24,000-scale. Prior to making this decision be aware that the typical Columbia basin subbasin has between 500 and 3,000 1:100,000-scale river reaches.

Setting up the reach table is one area where subbasin planners may wish to seek technical assistance. The Council is prepared to offer such assistance. This assistance would typically consist of working with planners to select an appropriate system and them using reach or watershed delineations supplied by planners to construct the reach table and prepare a final QHA file for use by subbasin planners.

The Current and Reference Conditions Tabs

Introduction. The "current" and "reference" tables are the heart of the assessment. Using these tables subbasin planners characterize the physical condition of the subbasin. This is accomplished by supplying information concerning a range of habitat characteristics, with information arrayed by reach or small watershed.

Definition of Current. In the "current" conditions table planners rate the condition of the aquatic environment as it is today. The one conceivable wrinkle is a situation where significant habitat modification is currently underway or planned that will significantly change habitat quality within a defined short-term timeframe. In these cases planners may decide to characterize current conditions as if these changes were complete. Examples might include situations where an antiquated dam is scheduled for removal, where previously undeveloped lands are being urbanized, or where a major habitat restoration effort is underway. Regardless, any such deviations from the current condition should be clearly documented.

Definition of Reference. In the "reference" conditions table planers describe a "normative" condition for this subbasin that is used to contrast the current condition. This allows us to define "degradation " or "restoration potential." In a subbasin with little cultural modification this reference condition might equate to "historic" conditions, that is, the conditions that were in place at the time of European settlement. By contrast, in a subbasin where "permanent" cultural modification has occurred (through urbanization, damming, channel modification, etc.) a more apt reference may be the "potential" conditions, that is, the best conditions that could hope to be achieved through aggressive action while still maintaining these "permanent" or "long-term" cultural modifications. For example, if we were considering the lower Willamette in Portland, the reference condition might refer to a potential condition where all realistic restoration actions have been taken while still maintaining the urban fabric. Another example is a situation where a major dam exists or where a major highway has modified the river shoreline and where these modifications are expected to remain for the foreseeable future. In these cases the reference condition would be a theoretical state where these modifications remain but realistic actions had been taken to mitigate negative effects.

Planners have latitude in how they define the reference condition as long as it is realistic and defensible. In any case, it is important that planners document the rationale for selecting a given reference condition.

A variation that perhaps goes beyond the scope of subbasin planning would be to conduct the exercise with two reference conditions – a true "historical" characterization and a "potential" characterization that recognizes permanent modifications. Understanding the differences between these two reference conditions would certainly provide additional insights and a context for making decisions on habitat restoration and protection strategies

<u>Habitat Characteristics</u>. In both the reference and current condition tables we look at 11 habitat characteristics. These are:

Riparian condition
Channel structure
Habitat Diversity
Fine sediment
High flow
Low flow
Oxygen
Low winter temperature
High summer temperature
Pollutants
Artificial obstructions

Definitions for all of the above can be found in the "definitions" tab.

These eleven are the habitat characteristics (or attributes) that are generally thought to be the main "drivers" of fish production and sustainability. There may, of course, be unique situations where planners believe that other attributes may be equally or more important. While, for purposes of consistency we encourage planners to retain the existing list of attributes, it is possible to substitute attributes or expand the definition of an attribute to encompass a more expansive concept. If this is the case, planners should clearly identify the change and document why this change was made. Theoretically it would also be possible to add factors. We have elected not to offer this option, as it would have implications for the Excel algorithms. While someone with skills in spreadsheet design could, of course, make any changes that they may desire, for the sake of consistency and comparability, we ask that you refrain from changing or adding habitat characteristics unless absolutely necessary, and then only after contacting product developers.

Physical Habitat Score. The current and reference condition tables consider the relative condition of the physical environment by viewing each of the 11 habitat attributes through the eyes of salmonids species. The cell that forms the intersection between a reach/small watershed and a habitat characteristic is rated according to the following rating scheme:

0 = ≤ 20% of optimum
1 = 20% to 40% of optimum
2 = 40% to 60% of optimum
3 = 60% to 80% of optimum
4 = 80% to 100% of optimum

Optimum is defined as the ideal condition of an attribute for salmonids. Note that historic conditions does not necessarily equate to optimum. For example, it is entirely possible that historic high summer temperature or channel structure limited productivity to a greater or lesser extent.

There is no magic in the above rating scheme. The numerical scores are only included to give planners an idea of relative value. (There is, obviously, little or no difference between, say, 37% of optimum and 43% of optimum.) Our intent here is to have enough categories that knowledgeable professionals can discriminate between conditions but not so many that they would exceed what is considered realistic in a qualitative assessment. Planners have the option of using whole numbers (0 through 4) or decimal places if they wish to discriminate more finely, e.g., 3.50 or 3.75. The only rule is that they be consistent. (The algorithm is set up to handle two decimal places.) Using whole numbers is the simplest approach and may save some time, but we have been around too many fish biologists to not make allowances for finer numerical discrimination!

For the algorithm to work each and every cell must be rated. If you leave a cell blank it will automatically receive a rating of zero, which, as described above, translates to ≤ 20% of optimum. If you absolutely do not know you have two choices. First, you can give a rating based on what you would suspect it to be and give a low confidence rating. (Confidence ratings will be described later.) One way to address areas where you have little information is to extrapolate a rating using another similar watershed where you have a higher level of confidence. As described later in the documentation section, there is a place in the table to note areas where ratings are extrapolated from other locations. Second, you can elect not to rate the reach or small watershed for any attribute. This will effectively drop the reach or small watershed from the assessment. (A flag will be placed in the reach table for this purpose.)

Confidence Levels. Above the list of habitat attributes on both the current and reference conditions tables is a row entitled "attribute confidence." In this row subbasin planners have the option of rating the level of confidence that those filing in the table have in their knowledge of each habitat attribute in this subbasin. The rating scale is as follows:

0 = unknown
1 = speculative
2 = expert opinion
3 = well documented

Similarly, at the right side of the table is a column labeled "reach confidence." This provides planners with the option of identifying the confidence that the planners have in their knowledge of individual reaches or small watersheds. The same rating scale is used. Use of these confidence levels is optional and they do not affect computations.

While confidence ratings do not figure into habitat rating calculations, we strongly advise using the confidence ratings as this will help to document the decision process and, ultimately, in the tornado table, give an indication concerning how confident planners are in the final ratings. While it would be possible to fill in the confidence ratings for only some reaches or some habitat characteristics, we urge you to give confidence ratings for all habitat characteristics and all reaches or small watersheds. This need not be a burdensome task. It may, for example, be possible to fill in confidence ratings for "blocks" of similar reaches at one time. Determining confidence in the knowledge of attributes takes only a few minutes.

By filling in the row and column confidence ratings it is possible to ascribe a confidence level for any given cell in the table. In fact, this is what the spreadsheet does (though you cannot see it.) Essentially, what happens is as follows:

(1) For each cell a rating is given that is the sum of the row and column confidence ratings, i.e., a number between 0 and 6.
(2) This is then divide by 6 to give a number between 0 and 1.
(3) The ratings in each row are added up to give a number between 0 and 10.
(4) The row sum number is then divided by 11 (the number of attributes). The final confidence rating is a number between 0 (no confidence) to 1 (absolute certainty).

The QHA includes hidden tables that contain the information described immediately above. If planners wish to see this we may decide to modify the QHA to make this accessible via a tab. A summary of confidence ratings can be viewed by going to the tornado tab where you will see a "restoration confidence" and a "protection confidence" rating for each reach/small watershed, with numbers derived using the above formula.

Completing Forms. Filling in the current and reference forms is the most time consuming element of the QHA. You will want to carefully consider how best to accomplish this, both for reasons of accuracy and efficiency. We assume that the forms will be completed by a group of local experts, either collectively through a Delphi approach, or individually, with individuals or sub-groups each taking responsibility for a portion of the subbasin. (If done individually allowance should be made for peer review. Even with the full group approach this is still a good idea.)

Should planners start with the reference conditions or the current conditions? Ultimately the choice is up to those who will be completing the tables. Particularly in less altered subbasins, it could be argued that starting with the normative (reference) condition makes sense in that this focuses attention on how the system would operate in its natural condition. Planners could then proceed to complete the current conditions table by asking the question "What has changed?" Planners could then zero in on habitat characteristics that have changed and "adjust" the table rankings accordingly to create the current conditions reference table. On the other hand, planners may be more comfortable with what they know, i.e., the current conditions, and then proceed to the reference conditions. Regardless, time and effort can be saved (and accuracy gained) by using one table as a departure point for the other, as opposed to doing each independent of the other.

Planners will also need to decide whether to look at all characteristics in a given reach/small watershed (rows) or look at multiple reaches/small watersheds for an individual habitat characteristic.

Depending on preference, prior to initiating the assessment tables can be set up with no value or a default value that would serve as a frame of reference for decisions and to simplify data entry. For example, the default value on the reference table could be set to 4, which represents ideal conditions for the species.

<u>Documentation</u>. The current and reference conditions tables offer the opportunity to identify source materials or make comments. (The documentation column is to the extreme right side of the table.) In its most simple form planners click on the word "documentation" to access the documentation table, where all of the bibliographic materials that planners have used to complete the tables may be listed. By including a documentation number planners can also place this number in the appropriate cell in the documentation column, thereby linking the document to one or more specific reaches. (If document #4 provides information that informs the decisions on 20 different reaches or small watersheds the number 4 would be inserted in all twenty cells.) This documentation feature can also be used to insert comments. You will notice that we do not provide an option to provide documentation for an individual cell. We felt this would be excessive for a methodology of this type. While a compromise, we concluded that the row-by-row approach made the most sense.

Documentation does not influence any ratings so there is no absolute requirement that planners avail themselves of this feature. Planners should make their own decisions regarding how to best use the documentation feature. However, we believe that faithful use of the documentation feature will pay significant dividends, both in structuring the decision process and defending the resultant products. At the very least, use of the documentation feature will create a bibliography that can be inserted into subbasin plan documents.

The Hypothesis Tab

Introduction. This tab allows planners to use their knowledge of fish biology and the local subbasin to define a "hypothesis" concerning how the focal species uses the stream habitat. This creates a set of weights that are attached to the score for each Reach/Attribute cell to compute the final score. In other words, the hypothesis is the pair of "glasses" through which we will judge the scores for each reach and attribute. By clicking the "hypothesis" tab you see two tables. The first provides subbasin planners with the opportunity to apply their understanding of biological systems to make decisions regarding (1) the relative importance of each life stage to fish productivity and sustainability and (2) for each life stage, the relative importance of each habitat characteristic. The second table is used to characterize how fish currently use each reach or small watershed and how they would use these areas in a reference condition, be it historical or potential.

Life Stage Weight. First look at the table at the top of the screen. Using this table, the first order of business is to rate what we call "habitat utilization life stages" according to overall importance in the subbasin. Importance in this case really implies biologically limiting. In other words, the habitat utilization life stages are ranked according to their potential for limiting the population's persistence and abundance. This might be because fish spend the longest period in this stage (juvenile rearing, for example) or because the life stage is particularly susceptible to habitat conditions (spawning, for example). Remember that the ranking will result in a weight that is applied to the Physical Habitat Rating in the current and reference conditions tables. Judge "importance" accordingly.

There are three habitat utilization life stages. These are 1) spawning and incubation, 2) growth and feeding, and 3) migration. These warrant some explanation as they often incorporate multiple life stages. (We do this to simplify the completion of forms and the calculations.) Spawning and incubation is self-explanatory. Growth and feeding refers to areas where either juvenile or adult fish reside for major portions of time for either juvenile growth (commonly called rearing) or adult feeding. Migration refers to areas used by juvenile or adult fish as corridors used for moving from one longer-term use are to another.

Planners should rate habitat utilization life stages using a 3, 2.5, 2, 1.5, and 1 scale, with 3 being most important. You may rate all three differently or give two or all three equal weight. Giving two a weight of 1 and the third a weight of 3 would indicate that one is significantly more important than the others. The reason for doing this is to define the life stage that will be used to evaluate the importance of the various habitat characteristics for each reach or small watershed.

The second task is to rate each habitat characteristic for each habitat utilization life stage. The scale is as follows:

0 = no effect
1 = does effect
2= critical effect

By rating both life stages and habitat characteristics you are establishing a simple hypothesis concerning how a given species interacts with its environment in this subbasin. The QHA applies the hypothesis to the information you have developed in the reference and current condition tables to develop a series of products. (We will get to the products later.)

As an example, one typical hypothesis would weight spawning/incubation highest and certain factors (e.g., sediment) as most important for the spawning/incubation life stage. The simplest hypothesis would be to rate all life stages and habitat attributes equally. In other words, there would be no weighting. In other words, all life stages and habitat attributes would have the same effect on productivity. In this case the final score for a given cell is simply the difference between the reference and current conditions.

In practice, it may be useful to consider more than one hypothesis, for example all 1s as described immediately above and one or more hypotheses where you use differential weightings that reflect your conclusions concerning how the biological system operates. You could then generate a set of products using both hypotheses and compare findings. This "multiple hypotheses" concept would be particularly useful in a situation where there is a difference of opinion among participants concerning how life stages and habitat characteristics should be weighted. There is no reason why these multiple hypotheses could not be run given that they are relatively simple to construct and all would make use of the same reference and current condition tables. Ultimately, of course, the objective should be to agree on one hypothesis. If this were not possible the only option would be to report multiple findings and describe why this was necessary.

Distribution. The lower table in the hypothesis tab arrays life stage distribution by reach/small watershed. You will note that two conditions are identified – reference and current. For each there are four categories – range, spawning, growth/feeding, and migration. Range refers to the overall range of the species within the study area, including spawning areas, growth and feeding areas, and migration corridors. The other three are subsets of range. A given reach or small watershed may be (and often is) used for two or more life stages. The idea here is to tag those reaches/small watersheds where the fish are present during any life stage. Planners may proceed in any way that they desire, though, typically they will start by tagging all reaches that constitute the range of the species and then proceed to tagging life stages.

For the current condition biologists will use their knowledge of the subbasin. In some cases (particularly bull trout, salmon, and steelhead) there are GIS data layers available to help with this. See www.streamnet.org or contact the river information system coordinator in your state's fish and wildlife agency. For the reference condition you will obviously need to extrapolate from your understanding of what conditions are required by fish at a given life stage and what conditions would be like if the subbasin were fully restored or, if you prefer, the historical distribution of the species within the study area.

In most cases the current distribution will be the same as – or a subset of – the reference conditions. In a subbasin with little disturbance the reference and current distribution may be close to the same. In more developed areas spawning and rearing may have shifted or contracted. There may also be instances where a natural barrier has been removed, providing access to areas previously inaccessible.

Planners will need to determine what level of evidence is needed to define a reach as being used for any given life stage. This may range from documented observations to an extrapolation based on your knowledge of landform and habitat character. For purposes of QHA a more liberal interpretation is probably the best approach, as long as it can be defended. Obviously, consistency across the subbasin is important. The distribution table provides the opportunity to document the level of confidence that planners have in their determinations.

Note that the distribution table and the life stage/habitat characteristics table interact. That is, in the computations, the ratings given in the life stage/habitat characteristics table are applied to reaches where a given life stage exists. For a hypothesis where all life stages and characteristics received the same weight (e.g., 1), this would have no effect. But if you had weighted one life stage higher than the others, and if a given reach/small watershed had all three life stages present, the life stage with the highest rating would drive the computation. In other words, if more than one life stage exists in a reach/small watershed, the analysis will focus on what you have determined to be the most important.

The Restoration Rankings Tab

This table provides a ranking of the final reach and attributes scores. Note that the scores themselves have no inherent meaning and, for this reason, the focus is on the relative ranking of the scores between reaches and between attributes. The highest rank is given a 1 (and highlighted in red), followed by 2 and so on. The table also identifies which reaches/small watersheds offer the highest restoration opportunity from a multiple habitat characteristic perspective (to the left of each row under the "reach score" column) and which habitat characteristics had the highest overall score (at the bottom of each column on the "attribute score" row). These scores adhere to the same 1, 2, 3 hierarchy.

This table was generated using information provided earlier in the current conditions table, the reference conditions table, and the hypothesis tables. The restoration table summarizes your physical and biological conclusions based on how you described the habitat and your hypothesis about the focal species. Planners should not accept this as absolutely correct or as the total answer. Rather, they should use it as a tool to provoke thought. Assuming planners are comfortable with the table, what does this suggest about limiting factors and potential restoration actions? Later in this guide we identify a list the questions that planners may wish to consider when analyzing this table.

The restoration rankings table is generated using the following algorithm:

$$\text{Restoration Attribute Score}_{ij} = (\text{Reference}_{ij} - \text{Current}_{ij}) * \text{LSWeight}_{ijk}$$

Where the Restoration Attribute Score is for reach *i* for attribute *j*, Reference is the attribute score for the reach and attribute from the Reference tab, and Current is the attribute score for the reach and attribute from the Current tab. LSWeight is the weight you assigned in the hypothesis table to the attribute (j) for the highest ranked life stage (k) using the reach (i). This equation results in a number that provides a relative indication of the effect of restoring conditions beyond the current condition. The reach score is the simple sum of the individual attribute scores.

Protection Rankings Tab

This table is the same as the restoration ranking table except that it identifies relative protection value rather than restoration value. The ranking is generated from an algorithm using information from the current conditions tables and the hypothesis tables. However, there is no explicit degradation reference condition identified and instead, QHA assumes that the degraded reference condition is the lowest rating for each attribute (0). In other words, the protection score is zero minus the current condition.

Planners will want to use this table as a jumping off point to consider areas that warrant protection, starting by asking whether the table is an accurate depiction of the real situation. If so, planners can proceed to identify major implications for management. Later in this guide we identify a list the questions that planners may want to consider when analyzing this table.

The protection rankings table is generated from information in the current conditions tables and the hypothesis tables using the following algorithm:

$$\text{Protection Attribute Score}_{ij}. = (0 - \text{Current}_{ij}) * \text{LSWeight}_{ijk}$$

This results in a negative number that indicates a potential loss to the focal species if conditions were degraded beyond the current condition.

Tornado Tab

Click on the tornado tab and you will see a summary chart that shows, for each reach or small watershed: (1) relative restoration ratings, (2) relative protection ratings, and (3) confidence ratings for each of these. We call this a tornado because it often looks like one. The purpose of this diagram is to allow planners to look at the system from a holistic perspective. The tornado diagram displays the reach scores for protection and restoration. These scores have no inherent meaning but do have relative value to compare protection and restoration values between reaches.

To the left and right of the tornado diagram are a series of numbers between zero and one that summarize the confidence that planners have in these depictions based on the confidence ratings described earlier. This is important in that it suggests the potential level of uncertainty that may be involved in undertaking restoration or protection activities in a given reach or small watershed. Similarly, it may suggest areas where future research is indicated. (As with everything else in the QHA, planners should do a reality check on these confidence ratings.)

The sample tornado diagram suggests that a given reach often has both restoration and protection value. This may seem counter-intuitive but it is surprising how often this is the case. In fact, this may be one of the most important lessons to learn from the assessment, that is, it makes little sense to spend precious resources restoring a given habitat variable if others are allowed to degrade. For example, a reach with a rating of 2 for an attribute lies midway between fully optimal (4) and fully degraded (0) and will have an Protection Score of -2 (0-2) and a Restoration Score of 2 (4-2). If the reach and attribute are ranked high by the hypothesis then it will have both a high protection and restoration value, indicating that current conditions are good enough to have value to the focal species but that there is also room for improvement.

Other Factors Tab

We are considering adding an additional "other factors" tab that would provide a means to add additional information related to include in reaches/small watersheds that planners believe may be important to the decision process. These would be in a table similar to the distribution graph/table but instead of range, spawning, etc. the headings would be one or more of the following:

<u>Biological Significance</u> (i.e., genetics) – Reaches/small watersheds with strains of native fish that meet a specified standard for genetic purity

<u>Exotic Species</u> -- Presence/absence of non-native species that may compete with, prey upon, or inter-breed with the focal species

<u>Disease</u> – Known and suspected presence of diseases that might affect fish

<u>Special Characteristics</u> – To be defined

<u>Research</u> – Reaches/small watersheds where past or ongoing research has established a base of information that would be useful in long-term monitoring

<u>Land Management</u> (private, mixed, public, special protections)

<u>Other</u> (a placeholder for planners to introduce other ideas meaningful to their area and their analysis)

If implemented, these columns of information could be juxtaposed next to the tornado diagram so that these factors could be considered in the context of potential habitat restoration and protection. Please let us know if this feature would be useful and the attributes that you believe should be included. It may be that we elect to include this as a custom feature for those subbasins where planners elect to use it.

Documentation Tab

This table serves as repositories for bibliographic references and comments generated while completing the reference and current conditions tables. Information presented here will aid in generating a bibliography for the assessment portion of the plan document.

Definitions Tab

This tab presents definitions for each of the habitat characteristics used in the QHA. It also presents a table that identifies the types of measurable data that could be useful in determining the condition of each habitat characteristic. This latter table is arranged by life stage. These definitions are similar to the environment-habitat relationships in EDT. Further information on their meaning can be found in EDT documentation.

Analysis: Using the QHA to Make Decisions

Perhaps the single most important thing to remember concerning the QHA is that it does not make assessment decisions. It simply organizes the thoughts of the various local experts and presents information that subbasin planners may find useful in making these decisions. This section identifies some of the questions that could be explored using the information generated through QHA and displayed on the restoration rankings table, the protection rankings table, and the tornado graph.

The first question that should be asked when one looks at the restoration and protection tables is: Does this make sense? In other words, do the tables capture the prevailing expert opinion concerning how this system operates and what actions may be needed to improve its operation? If there is a disconnect between prevailing expert opinion and what the tables seem to indicate, what is the reason for this? Were the reference and current conditions tables completed properly? Are there additional factors that influence the system that were not captured in the reference and current conditions tables? Might prevailing wisdom be in error? If changes in the reference or current conditions are needed planners should do this. But please, do so with caution. The objective here is to use information to make decisions, not tweak the data until preconceived results are achieved!

This is also a good time to consider an alternative hypothesis. Earlier we suggested possibly establishing a “constant” hypothesis where all of the numbers on the hypothesis table are set to 1 in order to compare and contrast results with your more custom hypothesis. Are there differences between, say, a restoration ranking table using hypothesis A and a table based on hypothesis B?

Once planners feel comfortable with the various tables they may wish to use these as a departure point for considering any of a number of questions concerning the relationship of the focal species to its environment.

Perhaps the fundamental question that must be considered is: What are the implications of the tornado diagram for management? The tornado diagram melds both protection and restoration values into one graphic. The greater the length of the bar, the greater the potential value of the action. Each reach or small watershed will typically have values for both restoration and protection. In simplified form, here are the potential relationships:

Restoration: Protection:	High	Medium	Low
High	1	2	3
Medium	4	5	6
Low	7	8	9

Following are some of the implications for the various combinations:

1. A reach or small watershed will never have both high restoration value and high protection value.

7. This is the classic case of a reach or small watershed where the habitat has been significantly degraded and where restoration would result in significant biological benefit. (Cost is not a consideration in QHA and must obviously be taken into account.)

3 and, to some degree, 2. These are areas where the habitat is in good condition and where minor restoration actions could potentially provide significant dividends.

9 and, to a lesser extent, 6 and 8. These areas do not provide major opportunities for additional restoration or protection.

4 and 5. These are mid-range combinations where decisions on whether to take action will likely be determined by a number of factors.

The above is, at best, a cursory indication of the potential implications of the tornado diagram for management. Decisions in a specific subbasin will need to be made by subbasin planners based on a wide array of factors.

Following are some of the additional questions that planners may wish to consider:

- Are there clusters of reaches/small watersheds in close proximity that exhibit similar characteristics and that should be considered as a group?

- Which reaches/small watersheds currently provide the best habitat conditions for this species?

- Which have habitat conditions that are not conducive for this species?

- Are there clusters of adjacent small watersheds/reaches where the same habitat attributes are in poor condition?

- Looking at the entire subbasin (or, for larger subbasins, at all of the reaches/small watersheds for a given fish population), which habitat attributes are typically in a condition that supports this species or population? If there are multiple populations which have the most supportive habitats?

- Again looking at the entire subbasin or at a population unit within the subbasin, which habitat attributes are typically in a condition that is not conducive for this species?

- For the subbasin as a whole (or population units) what appear to be the major limiting factors?

- Which of these limiting factors are the result of natural conditions and which are the result of human modifications?

- Are there assemblages of habitat characteristics in poor condition that are influenced by the same upland land uses?

- Similarly, are there clusters of adjacent small watersheds/reaches where several habitat characteristics are in degraded condition? What does this suggest concerning causes and potential cures?

- Are there combinations of factors that appear to be related and that might be treated collectively?

- Where are there clusters of adjacent small watersheds/reaches where habitat attributes are in good condition?

- Based on habitat quality and population strength, which cluster of small watersheds/reaches should be considered strongholds and could serve as core areas to build from?

- Where have migratory linkages between populations or sub-populations been disrupted? Which areas afford the best opportunities for re-establishing linkages?

- Which clusters of small watersheds/reaches offer the highest benefit from protection of existing habitat conditions? Of these, which are at greatest risk?

- Which clusters of small watersheds/reaches have the highest potential for restoration of habitat conditions?

- Are there isolated small watersheds/reaches in poor condition where restoration might have significant benefit?

- For those areas identified for restoration, which habitat attribute(s) should be the primary focus for restoration?

- Are there areas where both protection and restoration are particularly indicated and what does this suggest in terms of treatment?

- What is the status of the various areas where protection is indicated? Are some of these more vulnerable than others?

- Where do we have the highest confidence in our findings regarding restoration and protection? Where the least? Does this indicate the need for further research and, if so, what and where?

- Are there additional factors not covered in the QHA that should be considered and what are their implications? (See the discussion in the "other factors tab, above.)

There is certainly no requirement that planners consider all of these questions. They are offered here to provoke thought and suggest some of the areas where QHA results may be of use.

Questions and Answers

In this section we try to answer some of the key questions that have been asked of us concerning QHA. There is some unavoidable redundancy with information supplied in other sections of the user's guide, though we tried to keep it to a minimum.

Can the reference and current conditions tables be used for multiple fish species?

The current and reference condition tables consider the condition of several habitat characteristics without regard to a specific fish species (though there is an underlying assumption that the 0 to 4 ratings are made in the context of salmonids). Therefore, the information generated for these tables should be useful for multiple salmonid species. The transferability of existing current and range this to one or more other species must be determined by biologists who are familiar with both the subbasin and the biological needs of the species in question. (This raises the question of whether this is transferable to non-salmonids. Where species are similar in their biological response, biologists may decide that the products are, in fact transferable. Or, they may conclude that the biological response is similar but may need some revision. In this case the prudent (and efficient) approach would be to use the products for one species as a template for creating similar products for another species. A common example would be focus on a specific habitat characteristic, e.g., water temperature, where local biologists believe there may be differences between species.)

The hypothesis tables provide the means to link the current and reference tables to a given species. If planners wish to apply QHA to multiple species the way to do this is, therefore, to develop a new hypothesis that reflects the biological response of the new species. New range information will also be needed.

Essentially, if planners conduct the QHA analysis for two or more species they would end up with two or more Excel files, say – QHA Flathead bull trout and QHA Flathead cutthroat. With a few simple manipulations it would be possible to create an additional file where tornado diagrams for multiple species could be displayed side by side. This could help to determine if there are opportunities for restoration and/or protection actions that might provide mutual benefit.

How might we deal with areas where we have little information?

Information gaps are an issue regardless of assessment technique. A technique based on expert opinion (as is the case with QHA) probably allows more flexibility for dealing with this issue than a purely quantitative approach that relies on measurable field sampling. (This is both an advantage and a disadvantage!) One approach for dealing with this may be to identify similar watersheds where there is a good base of information and assume that the target watershed has similar environmental characteristics and biological responses. If this is done it is important to make note of this in the comment fields. Planners will also want to give a confidence rating that reflects this. If there is no information and no similar watersheds (an unlikely scenario), planners may leave blank those rows in the table where this is the case. If this is the case please leave the entire row blank or the program will attempt to compute a score with only partial information and errors will result. (From an algorithm perspective it is best to give a rating for all cells.)

Can this technique be used with anadromous fish?

Earlier in this user's guide we summarized the differences between QHA and EDT. EDT was originally developed for anadromous fish and this continues to be its primary use. QHA, by contrast, was developed to assess resident salmonids. While there are undoubtedly situations where QHA could be helpful in assessing anadromous fish/habitat relationships, it is important to understand the limitations.

Unlike EDT, QHA does not follow a fish through its entire life history as it moves from its natal watershed to, in the case of anadromous species, the ocean and back. With QHA, following a life cycle trajectory is left up to knowledgeable experts who draw inferences from QHA restoration and protection ranking tables.

There are several scenarios where QHA could arguably be used to support an anadromous fish assessment. One would be to use QHA as an initial inquiry that would set the framework for future quantitative analyses. Another, applicable mainly to large subbasins, would be to use QHA as a means to gain and overview of the entire subbasin while targeting smaller watersheds where more rigorous quantitative assessment may be warranted. The trick here would be to produce qualitative and quantitative products that are compatible so that the subbasin could continue to be viewed from a comprehensive perspective. Yet another scenario would be a subbasin where limitations in both time and resource dictated that an expert opinion approach be employed.

We are currently evaluating whether changes would be needed in the hypothesis table to make the QHA more applicable to anadromous fish. It would be possible, for example, to add additional life stages.

Can QHA be used in subbasins with lakes and reservoirs? How about links to mainstem reaches?

As presently constituted, QHA is designed for use with streams and stream habitat characteristics. It does not contain a module for dealing with adfluvial populations once these enter a lake or reservoir. For small lakes perhaps the best strategy may be to simply treat them as a reach or small watershed. (If you are using 6^{th} field HUCs a small lake would fall within one HUC so no special arrangements would need to be made. Planners would simply complete the reference and current conditions tables for this HUC with the lake in mind.) The best strategy for dealing with large lakes or reservoirs may be to apply the QHA to streams and watersheds and then "couple" that product with an independent assessment of the lake or reservoir. These would be "knitted together" using professional judgment. The course of least resistance would be to consider large lakes and reservoirs in the same light as anadromous fish assessments consider mainstem and ocean conditions. That is, create an assumption (based on professional judgment and employing whatever empirical data may be available) regarding the amount of mortality that occurs in the lake environment and the probable causes, and integrate that into the thought process when developing protection and restoration scenarios. It is, of course, good practice to document any assumptions.

In some instances a subbasin may contain populations that migrate out of the natal subbasin into mainstem reaches. This is, of course, always the situation with anadromous fish but it also occurs with some resident fish. For example, adfluvial bull trout are known to migrate to the mainstem Snake or Columbia where they spend a significant amount of time before returning to spawning areas in subbasin tributaries. For purposes of QHA, adfluvial resident salmonids that utilize mainstem areas can be treated similar to fish that migrate between streams and lakes, that is, make an assumption concerning mainstem reach mortality. If QHA is used with anadromous salmonids, planners may make their own assumptions or use those to be developed by an interagency team. Remember, however, that QHA does not link life stages or reaches, as does EDT. This can be a significant limitation for species where migration between different habitats is significant or where connectivity of habitats over a life history is important.

While QHA currently does not specifically incorporate lakes or mainstem areas, it may be possible create a QHA module that does this. Essentially this would involve (1) identifying the habitat characteristics to be considered (these would probably be different from those used with stream reaches and may include such added considerations as predation and competition), (2) subdividing the lake or mainstem area into meaningful geographic units, and (3) rating reference and current conditions as described earlier. This would obviously have its limitations but for some applications it may be informative.

Will an assessment using QHA meet ISRP standards?

The ISRP has not, to our knowledge, endorsed any one assessment technique. However, QHA was designed with scientific review in mind. As we understand it, the ISRP is less concerned with the use of any specific model and more interested that the assessment use good science and a logical decision process. From our reading of existing ISRP subbasin reviews, we assume that the ISRP would prefer a purely quantitative approach. But, in reality, there are often practical limitations (time, resources, data availability, and the applicability of existing models, to name a few) that indicate the need for a more qualitative approach.

The QHA responds to two of the major criticisms of qualitative assessment approaches in that: (1) it channels expert judgment into a logical and sequential thought process, and (2) it provides a means to track and document decisions. In addition, just because this is labeled a qualitative approach does not mean that it ignores quantitative information. Quite the contrary, <u>planners who use QHA are urged to base their assessments on measurable data wherever and whenever these exist</u>.

It is also important to remember that, regardless of the analytical tool selected, professional judgment will play a part in all assessments, no matter how quantitative, in that results will need to be interpreted. Like other assessment techniques, both quantitative and qualitative, QHA simply structures the decision process; it does <u>not</u> make the decisions. That is left to subbasin planners based on their best judgment.

If decisions are reasonable, if it can be demonstrated that the decision process followed a logical process, and if planners make use of the best available data and scientific knowledge, the chances of meeting scientific standards are, we suspect, good. In the end, the quality of the conclusions of a planning process will reflect the quality of the thinking that went into it, the documentation of that thinking, and recognition of the limitations of the assessment. A flawed application of a quantitative model will not meet scientific standards, while a rigorous (and replicable) application of a more qualitative approach arguably will, especially if there is wide agreement among scientists and managers concerning the validity of findings.

GIS Applications

Introduction. The list of reaches or small watersheds developed by subbasin planners is the backbone of the QHA, and is the common element between reference and current conditions tables, restoration and protection rankings tables, and the tornado diagram. To the extent that these can be electronically linked to a spatial dataset of either linear stream lines or polygonal small watersheds, QHA findings can be displayed on maps and linked with other spatial data.

While GIS mapping is possible with either reaches or small watersheds, small watershed have certain advantages. First, if planners use 6th field HUCs they can make use of a pre-defined geographically referenced datalayer, thus making transfer between spreadsheet and spatial data layer easier than a custom-created set of reaches. Also, from a strictly visual perspective, polygons often "pop out" more readily on a map that do reaches.

GIS Uses in Analysis. There are numerous ways that GIS technology might be combined with spreadsheet information to aid in the technical analysis of QHA findings. Perhaps its major use would be to assist planners to visualize potential connections between various areas within the subbasin. Identifying clusters of reaches or small watersheds with similar characteristics is one obvious example. Another would be to analyze issues related to connectivity between populations or sub-populations.

Yet another use would be to "overlay" two or more factors or concepts. This could aid in identifying convergence of factors. (For example, what is the relationship between protection rankings and spawning habitat? This could be ascertained using the spreadsheet alone but the spatial perspective could add richness not possible in a table.) This ability to overlay might also provide a means to link QHA findings with other spatial data. For example, a map of QHA-derived protection opportunities could be combined with a land ownership, land use, and/or population density map to give an indication of relative risk. Another possibility might be to overlay information from the current conditions table with an applicable spatial datalayer in order to validate findings. For example, QHA pollution ratings could potentially be compared to a geographically referenced water quality dataset.

Next Steps. We hope to work with our regional partners to create examples of how QHA can be combined with GIS. As subbasin planners develop products using QHA and GIS we ask that you share them so that others might benefit from your ideas and experiences.

Is GIS Necessary? We have included this discussion of GIS to give planners an indication of some of the possibilities. However, please remember that QHA is not in any way dependent on GIS. While it makes sense to consider the possibilities afforded by GIS, both for analysis and presentation, it is important to remember that QHA was designed to be a simple, straightforward technique that can be applied with a minimum of technological sophistication.

Comments and Contacts

If anything in this user's guide (or the spreadsheet) is unclear, or if you detect inaccuracies, please let us know so that we can rectify these shortcomings. We also welcome suggestions for improvement.

Drew Parkin will serve as regional point of contact for QHA-related issues. For questions, comments, corrections, or technical support please contact him at: Drew_Parkin@msn.com.

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