The Vermont Agency of Natural Resources Reach Habitat Assessment (RHA)

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1.0 Introduction

The Vermont Agency of Natural Resources Reach Habitat Assessment (RHA) has been created primarily as an integral part of the Phase 2 Rapid Field Assessment in the existing Vermont Stream Geomorphic Assessment Protocols (VTANR, 2007). The RHA is also available for stand-alone usage such as when a geomorphic assessment has previously been performed or a habitat assessment is needed over a reach of particular interest.

The RHA builds on the previous habitat assessment in the Vermont protocols and other common rapid assessments (e.g., NRCS, 1998; e.g., Barbour et al., 1999) by fundamentally being based on stream processes and their link to resultant channel, bank, and cover features. Indicators of key physical ecological attributes (i.e., processes and characteristics for different geomorphic stream types) were identified for inclusion in the assessment that are necessary for aquatic organisms to carry out life cycle functions. The basis for development of the new RHA protocol was originally laid out in an outline by the Vermont Departments of Environmental Conservation and Fish and Wildlife (VTANR, 2005) (Appendix A).

Physical processes form habitat in a stream channel. Importation of woody debris, movement of sediment over a range of flows, formation of scour and depositional features due to channel morphology and flow variability, and changes on dynamic river banks all establish important habitat features. Combined with chemical constituents and biological interactions, physical habitat determines biological productivity and diversity; and drives the aquatic ecosystem. By taking a detailed look at the habitat resulting from the physical processes taking place in a stream it may be possible to understand how fluvial processes impact aquatic communities.

It is important to note that habitat assessment does not replace the need for monitoring biological communities. Metrics that describe biological populations are the ultimate response variables when determining biological integrity because species integrate conditions and their assemblage and scale represents overall health of an ecosystem. Physical habitat quality is an indication of a stressor on the biological community, and thus may be an effective tool to explain results of biomonitoring, guide future sampling, and develop restoration strategies to promote biological

recovery. Habitat assessment may also support basin planning and inform land use permitting in Vermont.

RHA protocol development began with research of potential parameters to describe deviations from reference habitat condition. In addition, assessment variables that would collectively describe the state of each parameter were researched. A literature review was conducted to confirm the known links between physical processes and habitat and to determine the best ways to assess both the ecological attributes and the cover components of stream habitat (Appendix B). The research led to identification of the primary pathways between physical process, measurement variable, and habitat component (Appendix C). Existing assessment methods were determined that would likely meet application requirements for both a moderate level of detail (i.e., thorough yet not comprehensive such as full habitat mapping) and a moderate assessment time (i.e., approximately 1 to 3 reaches assessed per day as with the existing Vermont protocols) (Appendix D). The RHA protocols evolved following field testing and refinement by the project team so the reader should expect to encounter some minor differences between the initial research and the current protocols described in the next section of this report. Research, existing data, professional judgment of the project team, and initial testing led to identification of variable scoring ranges to complete the habitat analysis (Appendix E). Given the limited information that is available on the expected amount and condition of habitat for each geomorphic stream type, we anticipate that the scoring ranges will be updated in the future as more RHA data are collected.

2.0 The RHA Protocol

Variables describing eight parameters are assessed on the new RHA forms.

- Woody debris cover
- Bed substrate cover
- Scour and depositional features
- Channel morphology
- Hydrologic characteristics
- Connectivity
- River banks
- Riparian area

Four different RHA field forms are available for the assessment that cover expected habitat in the most common stream types present in Vermont and much of the formerly glaciated United States (Appendix F).

Form #	Primary use		Secondary use	
1	Riffle-pool	B, C	Dune-ripple	E, F
2	Step-pool	A, B	Cascade and bedrock	A
3	Plan bed	B, C, other	None	None
4	Braided	D	Alluvial fan	B, C, D

Each of the field forms is unique due to differences in variables and/or their ranges expected for each stream type. The most recent versions of RHA field forms as well as the accompanying field notes, sketch tally, and cross section forms for both the phase 2 Vermont Rapid Field Assessment and stand-alone habitat assessment can be obtained from the Internet (http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassess.htm).

Several variables describing each parameter are evaluated by the assessor and the appropriate condition category box on the field form is checked. Some of the variables are directly determined from data recorded on the field notes and sketch tally forms in the Vermont ANR Stream Geomorphic Protocols (VTANR, 2007), while others require additional interpretation based on the integration of observations (See RHA instructions in Appendix G). The assessor then reviews the location of the check marks and decides how to score the parameter on a scale of 0 to 20 indicative of a level of departure from reference conditions.

Score	Condition	Departure from Reference
20-16	Reference	None
15-11	Good	Minor
10-6	Fair	Major
5-1	Poor	Severe

The variables at the top of the list under each parameter are quantitative and carry more weight when choosing the parameter score. The variables lower down the list are typically more qualitative and are best used to fine-tune the parameter score.

Note that the River Banks and Riparian Area parameters are scored individually for each side of the channel, and thus are scored differently using a 0 to 10 range so that their sum is 0 to 20 like all of the other parameters. In the end, scores from the eight parameters are added to obtain a total score, which is then compared to the idealized reference condition score of 160.

Detailed RHA instructions and additional parameter / variable background information will be available in future editions of the Vermont Stream Geomorphic Assessment Protocols. Please contact the Vermont River Management staff for technical assistance (http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassess-contact.htm).

3.0 RHA Pilot Study

A pilot study was conducted to begin to evaluate over-arching questions about physical processes, habitat condition, and aquatic communities (H1-H3), and confirm that the new RHA properly fits within the existing Vermont Stream Geomorphic Protocols (H4-H6).

H1. Biological communities in rivers and streams are correlated to the quantity and quality of habitat as created by the dominant physical processes associated with hydrologic, sediment, and wood regimes and the resultant range of hydraulic units occurring in each geomorphically defined stream reach.

H2. The dominant channel adjustment process initiated by erosion and deposition, as measured by the RGA, alters physical habitat and the dominant reference physical process associated with geomorphic setting (laterally and longitudinally) across a range of spatial scales – local, reach, and watershed.

H3. Via stratification by geomorphic stream type and utilization of variables representing the dominant physical processes and resultant cover features, the new RHA accurately reflects departures from reference habitat condition, as identified for geomorphic condition in the RGA, and improves upon the level of detection of habitat impairment found in the existing RHA protocol.

H4. The RHA protocol generates data with an acceptable level of precision upon repeated use by a single or multiple assessors over a range of study sites.

H5. The RHA protocol includes the most important variables and appropriate data ranges for each condition category for the geomorphic stream types that are dominant in Vermont.

H6. The new RHA protocol can effectively be performed in conjunction with other SGA measurements so that it meshes well with the existing methodologies, does not take an excessive period of time to perform and maximizes the return on useful additional habitat data with data collection requirements.

The pilot study design was set up to establish a long-term method to answer the first three working hypotheses that serve as over-arching strategies to improve the assessment and restoration of the physical and biological components of streams. Biomonitoring within a geomorphic context allows for clarification of the links between channel processes, habitat formation, and biological communities.

The pilot study sample plan expands traditional single- or multi-habitat biomonitoring that is fundamentally guided by stream geomorphic process. Each site identified for the pilot study was selected due to the presence of segments with different processes (i.e., incision, aggradation), patterns (i.e., riffle-pool, plane bed, braided), stage of channel evolution (i.e., stable, widening), or impairment (i.e., natural, channelized) (Appendix H). Rapid geomorphic assessments had been previously conducted at each of the pilot study sites. The new RHA was performed as part of this study, and biomonitoring was conducted at a representative set of the dominant bed/hydraulic features within each segment.

Initial testing (Appendix I) and the pilot study confirmed that the level of effort to perform the assessment and the resultant data are synchronized with the existing Vermont Stream Geomorphic Assessment Protocols. In addition, a comparison between the former and new Vermont ANR RHA protocols indicated similar overall site scores, yet more detail in the new protocol parameters and variables to understand impaired processes or cover types (Appendix J).

The results of the pilot study (Appendix K) indicate that the new RHA score is closely related to macroinvertebrate metrics. For example, the RHA score is significantly correlated to community score (VTDEC, 2004) for single-season collections ($r=0.73$) and multi-year averages (0.82). Data suggest that for the assessed sites water quality and habitat both play important roles in shaping the macroinvertebrate communities. Investigating the individual RHA parameter scores indicates that connectivity, river banks, and riparian areas are key factors leading to differences

in collected macroinvertebrate assemblages at the assessed sites. The presence of obstructions, bank erosion, and limited bank vegetative cover are stressors at some of the study sites with lower biological health.

Stepwise redundancy analysis (ter Braak and Smilauer, 1997, 1998) and variance partitioning (Leps and Smilauer, 2003) indicate that the majority of variation in macroinvertebrate community score and biotic index is associated with the riparian area health (67.5%) and the two bank variables of system obstructions and abundance of mass failures (17.9%).

Historical biomonitoring data indicates that the RHA score is well-correlated to mean macroinvertebrate metrics for a given stream type. Important stressors at the long-term study sites include obstructions, bank canopy, and woody debris recruitment potential. For a set of streams assessed in Chittenden County, important features that are limiting habitat quality in the non-attainment streams include reduced CPOM abundance, increased embeddedness, reduced riffle stability, the absence of large pools, increased channel entrenchment/incision, a high level of flow alteration, and the limitation of stable undercut banks.

The relationship between single-season fish metrics and RHA data is weak for pilot study sites for the 2007 field season. The index of biotic integrity (VTDEC, 2004) and the density of salmonids (excluding Atlantic salmon) are not significantly correlated to the overall RHA score, yet loose trends of increased community health with increasing habitat quality are apparent. Fish index of biotic integrity is significantly correlated with the connectivity parameter that is driven by the system obstructions variable (0.73). Salmonid density is related to bank vegetation coverage and type (0.68), as well as riparian vegetation buffer width (0.53) and riparian vegetation coverage and type (0.77). Data from the three small high-gradient streams occasionally differed from the cluster of data from moderate-sized high-gradient streams that made up the bulk of the study sites.

The single-season fish metrics appear to be more closely related to water quality than measures of habitat quality. Fish index of biotic integrity increases with decreases in total nitrogen (-0.93), total dissolved phosphorus (-0.67), sulfate (-0.82), and several other ions.

Stepwise redundancy analysis (ter Braak and Smilauer, 1997, 1998) and variance partitioning (Leps and Smilauer, 2003) indicate that the majority of variation in fish index of biotic integrity and total salmonid density is associated with the habitat variables of refuge area presence, the amount of exposed substrate, width:depth ratio, the presence of adjacent wetlands, and large woody debris size (32.2%); the concentration of total nitrogen (18.3%); and the elevation of the site (4.1%).

Habitat parameters and overall RHA score loosely tracked channel evolution model (F) stage. For example, the woody debris cover, channel morphology, and hydrologic characteristics parameters all tended to score highest for stable channels (I and V) and lowest for actively widening channels (II-IV). Evidence of this pattern is present to a lesser extent in the overall RHA score. Macroinvertebrate community score and salmonid density indicate lower community health for stages III and IV, the stages that tend to be most unstable and disconnected from floodplains with varying habitat conditions.

4.0 Moving Forward

The creation of the RHA is another addition to the growing body of knowledge about the essential link between physical processes and the resultant channel form that constitutes aquatic habitat. With the development of the new RHA, a fully integrated reach-based assessment of geomorphic and habitat condition now exists in the Vermont Stream Geomorphic Assessment Protocols (VTANR, 2007).

As the new RHA is used to assess more miles of stream reaches, a broader set of data will be available to better guide the management of aquatic resources. For example, once a joint reach geomorphic and habitat assessment is performed it is likely that specific habitat deficiencies (e.g., large pieces of LWD, deep pools, vegetated buffers) will be known and the altered processes (e.g., excessive incision or aggradation) leading to the impairment will be identified. This information is necessary to thoroughly identify a problem and begin to correct it through corridor planning and appropriate management (Kline, 2007). The combined geomorphic and

habitat data will also be useful in conjunction with biomonitoring data to identify potential factors driving the composition of sampled assemblages.

The pilot study initiated here is considered a jumping off point for a long-term study to continue exploring the relationships between physical and biological components of Vermont streams within a geomorphic context. Multiple years of data collection will be needed to account for expected natural variability in populations and rigorously test the main project hypotheses. Additional data will build upon the analysis initiated here and lead to more robust findings. Such a long-term project would generate improved geomorphic and habitat assessment protocols, expanded biomonitoring methods, improved understanding of assessed streams, detailed data to guide resource management and restoration, and a better understanding of the relationship between natural processes, aquatic habitat, and biological communities.

APPENDIX A: Vermont ANR Physical Habitat Assessment 2005 Protocol Development Project Outline

Purpose

The current 2004 ANR Stream Geomorphic Assessment (SGA) Protocols are limited in the degree to which they incorporate physical habitat evaluation. The ANR Stream Geomorphic Assessment Team, led by Mike Kline, DEC, and Christa Alexander, DFW, is now working to expand the physical habitat assessment components in each of the current phases of stream geomorphic assessment protocols:

Phase 1 – Currently the biological significance of several stream type parameters and stressors are discussed. We will build on this by having assessors develop a preliminary reference habitat type and preliminary categorical habitat impact ratings for each stream reach based on remote sensing and windshield survey protocols.

Phase 2 – Currently the Rapid Biological (Habitat) Protocols (RBPs) developed by EPA for high and low gradient stream types have been slightly modified, re-titled, and used as a Rapid Habitat Assessment (RHA). New RHAs specific to more varied stream habitat types will include evaluations (based on departure from reference or desired future condition) for key ecological attributes and aquatic life cycle requirements.

Phase 3 – Currently the handbook contains only place-holder sections for physical habitat data analysis and evaluation. Numerous quantitative measures used in physical habitat assessment are a part of the current ANR Phase 3 geomorphic protocols. Analytical and evaluation techniques for quantitative data will be completed to create a verification process for Phase 2 results.

The goal of this project will be to create a physical habitat evaluation process similar to that which has been created for the phased evaluation of stream geomorphic condition in the ANR protocol. Phase 1 will result in a reference or benchmark from which to measure and evaluate a set of stressors known to impact physical habitat. At the end of Phase 1, the assessor will better understand the distribution of sensitive habitat types at the watershed scale and which of those may be degraded. Phase 2 will be a detailed field exercise to determine the existing habitat type and facilitate a departure analysis from the reference or benchmark condition evaluated in Phase 1. This analysis will include examinations of the processes that form and maintain physical habitat, as well as the specific components of habitat such as adult cover, rearing, and foraging habitat needs. Phase 3 will draw on geomorphic survey data to help verify the departure analysis made in Phase 2. For instance, longitudinal and cross-section surveys will provide quantitative measures for pool bed form evaluations as an important component of a fish cover habitat assessment.

Peer Review

The Vermont habitat protocol development project will be carried out through 2004-2005 and will be aided by an:

ANR Internal Advisory Group – Rich Langdon (DEC), Rich Kirn (DFW), Doug Burnham (DEC), Steve Fiske (DEC), and Ken Cox (DFW)

External Peer Review Group – TBD

Proposed Applicability

Physical habitat data and evaluation produced by the SGA protocols should be applicable in the following resource management programs:

- VT DEC River Management Program's geomorphic-based river protection, management, and restoration project evaluation and design;
- VT DFW Fisheries Division's stream habitat protection, management, and restoration project evaluation and design;
- Physical habitat stressor identification in the evaluation of biological criteria in Water Quality Standards application, stormwater management, and 401 certification *(Important Note: Physical habitat (a stressor indicator) will not be used as a surrogate for biological integrity (a response indicator) in compliance monitoring. Stressor indicators should* ***not*** *be used to replace response indicators, rather they should be used to help explain response indicators, guide biological monitoring strategies, and develop remediation strategies—see Strategies Section.)*
- Identification of *stressed* and *altered* waters in existing and designated use support assessments, basin planning, trend monitoring, and reporting (305b)
- Act 250 criterion 1(E) Streams, 1(F) Shorelines, and 8(A) Wildlife
- Planning, design, replacement, and upgrade of transportation infrastructure
- Dam removal initiatives
- USFS Stream Habitat Management
- USDA Wildlife Habitat Incentives Program (WHIP)
- USDA/VT Conservation Reserve Enhancement Program (CREP)
- USFWS Partners for Fish and Wildlife Program
- Public education and technical assistance programs

Overview of Habitat Protocol

The following sub-sections of the protocol outline offer a draft set of physical habitat concepts which will be used to structure a literature search and facilitate discussions with internal and external advisors. The protocol outline includes detail for:

Stream types – that have distinct set of ecological attributes and physical habitat components. Separate Phase 2 RHAs would be developed for each stream type.

Aquatic Life Cycle Requirements – that consist of critical shelter, foraging, and reproductive habitat components within each stream type. The protocol will attempt to explain how adverse impacts or the loss of these components may

degrade ecosystem health. Key life cycle requirements provide a basis for categorical bio-physical stressor evaluations.

Physical Ecological Attributes – that describe the most critical physical processes and characteristics of each stream type. The protocol will attempt to explain how adverse impacts to these attributes may limit the development and maintenance of critical habitat components, reduce habitat diversity, and degrade ecosystem health. Key physical attributes provide a basis for categorical bio-physical stressor evaluations, threat analysis, and remediation strategies.

Indicators – are listed for each of the key physical attributes and define <u>what</u> will be evaluated as part of the categorical habitat evaluations. These parameters, for the most part, are current Phase 1, Phase 2, and Phase 3 parameters used in fluvial geomorphic assessments and will be re-developed and further defined to explain their use in physical habitat evaluation.

Threats – are defined as human-caused changes to the key physical attributes that may result in stress to the biological community. The types of human activity that may lead to significant changes are listed and will be used to explain <u>how</u> the departure from reference habitat conditions occurred.

Strategies – to include an initial set of stream resource protection, management, restoration, and education programs that will be used to address the identified threats (physical stressors) and achieve the desired future physical habitat conditions.

Stream Types

Similar to geomorphic stream types, reference stream habitat types will be preliminarily defined during the Phase 1 Remote Sensing Assessment. The reference habitat type will be confirmed using Phase 2 field indicators. The reference stream habitat type will dictate the Rapid Habitat Assessment (RHA) protocol and field form to be used to conduct a departure analysis of the existing habitat type, key ecological attributes (physical processes), and aquatic habitat components.

The following parameters will used to determine reference and existing stream habitat types. Gradient, bed forms, and dominant substrates are described for each of the five stream types in Table 1. Other stream type parameters are described in Appendix A.

Phase 1 and Phase 2 Habitat Typing Parameters

Gradient / Velocities
Stream and Valley Geometry
Watershed / Stream Size
Bed Feature Characteristics
Dominant Substrates
Hydrologic Characteristics
Sediment Regime – Size and Sorting
Cover Types
Riparian Canopy
Woody Debris and Organic Matter

Other key physical stream type determinants in Vermont include seasonal water temperatures and bio-geographical regions.

Table 1. Five Common Stream Habitat Types

Habitat Type	***Basic Physical Description***
Cascade	Generally occur in very steep channels, narrowly confined by valley walls. Characterized by longitudinally and laterally disorganized bed materials, typically bedrock, boulders, and cobbles. Small, partial channel-spanning pools spaced < 1 channel width apart common.
Step-Pool	Often associated with steep channels, low width/depth ratios and confining valleys. Characterized by longitudinal steps formed by large particles (boulder/cobbles) organized into discrete channel-spanning accumulations that separate pools, which contain smaller sized materials. Step-pool systems exhibit pool spacing of 1 to 4 channel widths.
Plane Bed	Occur in low to high gradient and relatively straight channels, have low to high width/depth ratios, and may be either unconfined or confined by valley walls. Composed of sand to small boulder-sized particles, but dominated by gravel and cobble substrates in reference stream condition. Channel lacks discrete bed features (such as pools, riffles, and point bars) and may have long stretches of featureless bed, dominated by runs.
Riffle-Pool	Occur in moderate to low gradient and moderately sinuous channels, generally in unconfined valleys, and have well-established floodplains. Channel has undulating bed that defines a sequence of riffles, runs, pools, and point bars. Pools spaced every 5 to 7 channel widths in a self-formed (alluvial) riffle-pool channel.
Dune-Ripple	Usually associated with low gradient and highly sinuous channels. Dominated by sand-sized substrates. Channel may exhibit point bars or other bedforms forced by channel geometry. Typically undulating bed does not establish distinct pools and riffles.

AQUATIC LIFE CYCLE REQUIREMENTS

The critical habitat components for any species, or community of species, would include physical characteristics of stream and riparian environments which provide for:

Cover – the hiding, refuge, and resting places within a stream typically associated with pools, bank cover, bed substrates, and woody debris. Also includes the temperature refuge required by cold water species.

Foraging – the presence of organic material carried in from upstream, originating from the riparian zone, or produced within the water column, providing food for the aquatic community. Also includes the bed forms and hydrology necessary to produce, retain and transport organics and provide for animal movement during foraging activity.

Reproduction – physical characteristics that provide for adult and juvenile migration, egg incubation, spawning, and rearing of aquatic organisms. Also includes areas open for colonization associated with the extent and frequency of physical disturbance.

The protocol will be developed to facilitate impact ratings and departure analyses for these critical habitat components. Appendix B contains a table showing how the Phase 2 RHA data may be used to evaluate life cycle requirements. Biologists working with certain species or communities may want to tailor the queries to review attributes unique to their management or research interests.

PHYSICAL ECOLOGICAL ATTRIBUTES

Within stream and riparian ecosystems, at the watershed scale, the life cycle requirements of aquatic life, terrestrial wildlife, and plant life are met or depend on the following processes and components of the physical environment:

Stream, Riparian, and Floodplain Connectivity – the unimpeded movement of materials (water, sediment, and organic material) and organisms both longitudinally up and down the watershed and vertically between the stream channel and its riparian area and floodplain.

Sediment Regime – the size, quantity, sorting, and distribution of sediments, which may differ between stream types due to their proximity to different sediment sources, their hydrologic regime, their stream, riparian and floodplain connectivity, and valley and stream morphology.

Hydrologic Regime – the timing, volume, and duration of flow events throughout the year and over time, which may be influenced by the climate, soils, geology, groundwater, watershed land cover, connectivity of the stream, riparian, and floodplain network, and valley and stream morphology.

Temperature Regime – the daily and seasonal instream water temperatures influenced by climate, riparian canopy, hydrologic regime (particularly groundwater components), and valley and stream morphology and aspect.

Large Wood and Organics Regime – the diversity, quantity, and physical retention of organic material available for biological uptake and physical refugia (moderating the expenditure of energy), which may be influenced by the primary productivity within the stream channel and riparian zone, watershed and floodplain connectivity, the hydrologic regime, and the stream and valley morphology.

The protocol will be developed to facilitate impact ratings and departure analyses for these critical attributes. Appendix B contains a table showing how the Phase 2 RHA data would be used to evaluate physical processes. Again, biologists working with certain species or communities may want to tailor the queries to review attributes unique to their management or research interests.

INDICATORS

Existing Phase 1, Phase 2, and Phase 3 parameters are grouped in Table 2 as sets of indicators associated with ecological attributes for evaluating the presence and condition of habitat components and physical processes. These indicators were used to devise the draft Rapid Habitat Assessments (RHAs) contained in Appendix B. The range of conditions used to conduct the assessment will be the subject of the literature search which is the next phase of this protocol development project.

Table 2. Remote Sensing and Field Indicators of Key Ecological Attributes

ECOLOGICAL ATTRIBUTES	INDICATORS (EVALUATION PARAMETERS)
Stream, Riparian, and Floodplain Connectivity the unimpeded movement of materials (water, sediment, and organic material) and organisms both longitudinally up and down the watershed and vertically between the stream channel and its riparian area and floodplain.	1. Road crossings 2. Dams, bypasses, diversions, and dam management 3. Channel incision, entrenchment (floodplain connectivity) 4. Channel over-widening (riparian connectivity, sediment/debris transport longitudinally) 5. Riparian / stream corridor vegetation/buffers 6. Waterfalls 7. Encroachment and channelization 8. Thermal and chemical barriers (effluent, instream ponds…)
Sediment Regime the size, quantity, sorting, and distribution of sediments, which may differ between stream types due to their proximity to different sediment sources, their hydrologic regime, their stream, riparian and floodplain connectivity, and valley and stream morphology.	1. Bed forms and bar characteristics and spacing 2. Embeddedness 3. Bank characteristics (stratigraphy, vegetation, erosion, and mass wasting) 4. Sediment sizes and channel roughness (wood) 5. Channel planform, profile, and energy gradient 6. Road crossings, dams (constrictions) 7. Channel incision, entrenchment, and width/depth ratio 8. Watershed / corridor land use and land cover 9. Soils and geology (colluvial processes) 10. Stormwater and road density/drainage
Hydrologic Regime the timing, volume, and duration of flow events throughout the year and over time, which may be influenced by the climate, soils, geology, groundwater, watershed land cover, connectivity of the stream, riparian, and floodplain network, and valley and stream morphology.	1. Riparian / stream corridor vegetation 2. Width / depth ratio 3. Channel incision or entrenchment 4. Road crossings (undersized bridges and culverts) 5. Watershed and corridor land use/land cover & road density 6. Flow modifiers (dams, stormwater, withdrawals, WWTP) 7. Soils, geology, wetlands, and groundwater 8. Channel gradient and drainage density 9. Bankfull discharge and flow frequency curves
Temperature Regime the daily and seasonal instream water temperatures influenced by climate, riparian canopy, hydrologic regime (particularly groundwater components), and valley and stream morphology and aspect.	1. Width/depth ratio 2. Pool depths 3. Bank vegetation, canopy and woody debris covers 4. Groundwater, springs, seeps, and trib influence 5. Bank armoring, bank slope (undercut) 6. Watershed / corridor land use and land cover 7. Impoundments, flow regulation (dams, diversions, and urban stormwater)

	8. Valley width, valley aspect, and elevation
Large Wood and Organics Regime the diversity, quantity, and physical retention of organic material available for biological uptake and physical refugia (moderating the expenditure of energy), which may be influenced by the primary productivity within the stream channel and riparian zone, watershed and floodplain connectivity, the hydrologic regime, and the stream and valley morphology.	1. Woody debris and debris jams 2. Percent canopy (solar exposure) 3. Riparian / instream vegetation (contribution POM) 4. CPOM and FPOM availability 5. Channel boundary conditions (e.g. bank overhangs and root wad exposures) 6. Entrenchment, width/depth ratio and wetted width 7. Velocity / depth combinations 8. Channel planform and gradient, bed form and spacing 9. Impoundments and road crossings 10. Channel modifications (windrowing, berming, dredging)

Threats

A subset of the indicators associated with ecological attributes in Table 2 are human activities known to degrade aquatic and riparian habitat. These are used to evaluate the condition of habitat components and physical processes. The following is an outline of a) the biological stress which may result from changes imposed on the ecological attribute; and b) the human activities that may degrade the ecological attribute and lead to biological stress. This analysis is critical in formulating management strategies to eliminate or reduce human stressors of the physical stream environment.

Stream, Riparian and Floodplain Connectivity – the unimpeded movement of materials (water, sediment, and organic material) and organisms both longitudinally up and down the watershed and vertically between the stream channel and its riparian area and floodplain.

a) Human-caused changes in stream, riparian, and floodplain connectivity result in biological stress, due to:
   - loss of cover habitat provided by undercut banks and overhanging riparian vegetation (stream/riparian interface)
   - loss of LWD and CWD recruitment and/or retention (stream/riparian/floodplain interfaces and longitudinal)
   - loss of access to spawning habitat (longitudinal)
   - loss of access to winter and summer temperature refugia (longitudinal)
   - shift in energy source form allochthonous to autochthonous inputs
   - genetic isolation (biological population stress) of both aquatic and terrestrial populations (longitudinal)
   - for some plant species, loss of frequent disturbance patterns in floodplains needed for colonization opportunities (stream/floodplain interface)

b) The types of human activities that may degrade stream, riparian and floodplain connectivity include:
   - changes to physical regimes and energy dynamics
   - dams, impoundments, and diversions
   - undersized or otherwise incompatible stream crossings

- channelization or stormwater inputs that lead to channel incision and widening
- encroachment of roads and other developments
- removal of riparian vegetation

Sediment Regime – the size, quantity, sorting, and distribution of sediments, which may differ between stream types due to their proximity to different sediment sources, their hydrologic regime, their stream, riparian and floodplain connectivity, and valley and stream morphology.

a) Human-caused changes in sediment regime result in biological stress, due to:
    - loss of spawning and cover habitats when large sized sediments become unavailable in the reach due to either becoming the embedding with finer sediments (e.g., silts and sands) or becoming deposited in upstream impoundments or backwaters
    - loss of habitat when bed forms, such as riffles, pools, and glides, are lost due to excessive build-up or scour of bed sediments
    - loss of habitat when depth-velocity combinations are lost due to the simplification of reach-scale hydraulics (i.e., loss of sinuosity and channel forms and floodplain features related to meandering process)
    - increased loading of certain water quality constituents attached to sediments
    - loss of habitat when bed substrates are frequently mobilized, reducing stable colonizing habitat

b) The types of human activities that may lead to changes in sediment regime include:
    - loss of watershed and floodplain connectivity and changes in other physical regimes and energy dynamics
    - land use activities that expose soils and result in an increase in sediment loading, including agriculture, silviculture, sand/gravel mining, and historic deforestation
    - removal of woody debris and the role it plays in sediment retention, especially in upland streams
    - removal of riparian vegetation and the introduction of exotics that lead to the increase of stream bank erosion and mass wasting processes
    - land use encroachments and developments protected by channelization practices that results in vertical channel adjustments (i.e., aggradation or degradation) and the loss of forms and features related to meandering
    - dams, diversions, and undersized stream crossings that alter the size and quantity of sediments supplied to downstream reaches

Hydrologic Regime – the timing, volume, and duration of flow events throughout the year and over time, which may be influenced by the climate, soils, geology, groundwater, watershed land cover, connectivity of the stream, riparian, and floodplain network, and valley and stream morphology.

a) Human-caused changes in hydrologic regime result in biological stress, due to:
    - loss of lotic habitats due to rapid inundation or dewatering

- increased energy demands and stress related to the increased frequency, magnitude and/or duration of discharge events
- increased concentration of certain water quality constituents when flows are reduced
- increased magnitude and/or fluctuations (pulses) of instream temperatures resulting in physiological stress (see "Temperature Regime" below); particularly where hydrologic regimes are altered by stormwater.

b) The types of human activities that may lead to changes in hydrologic regime include:
- loss of watershed and floodplain connectivity and changes in other physical regimes and energy dynamics
- land use activity and road density that increase impervious surface, drainage, and stormwater runoff
- dams, diversions (surface water withdrawals), and ditching
- groundwater withdrawals
- wetland and floodplain filling
- channelization practices and the removal of riparian vegetation

Temperature Regime – the daily and seasonal instream water temperatures influenced by climate, riparian canopy, hydrologic regime (particularly groundwater components), and valley and stream morphology and aspect.

a) Human-caused changes in temperature regime result in biological stress, due to:
- increased metabolic rates when temperatures increase
- lower dissolved oxygen concentrations and increased ion toxicity of certain water quality constituents
- lower reproductive success

b) The types of human activities that may lead to changes in temperature regime include:
- loss of watershed and floodplain connectivity and changes in other physical regimes and energy dynamics
- removal of riparian canopy vegetation and the loss of channel shading
- introduction or invasion of exotics that do not provide canopy and out-compete tree species on the stream banks
- stream bank armoring and mass retention of heat
- dams and diversions that affect groundwater inputs or the depth of the water column
- channelization practices and the loss of root binding of streambank soils which result in an over-widened channel
- removal of woody debris and other structures that result in localized scour and depth
- urbanization which limits infiltration and results in warmer runoff

Large Wood and Organics Regime – the diversity, quantity, and physical retention of organic material available for biological uptake and physical refugia (moderating the expenditure of energy), which may be influenced by the primary productivity within the stream channel and riparian zone, watershed and floodplain connectivity, the hydrologic regime, and the stream and valley morphology.

a) Human-caused changes in energy dynamics result in biological stress, due to:
   - reduced organics and nutrients originating from primary productivity in the riparian
   - reduced organics and nutrients originating from instream productivity and/or from upstream reaches in the watershed
   - loss of cover habitat when course particulate organic matter (CPOM) and large woody debris become unavailable to the system or fail to be retained in the reach

b) The types of human activities that may lead to changes in energy dynamics include:
   - loss of watershed and floodplain connectivity and changes in physical regimes
   - removal of riparian vegetation especially trees and other woody species that provide root wad and undercut bank cover when standing and instream cover as deadfall
   - introduction or invasion of exotics such as knotweed that limit the success and availability of other riparian plants to provide organics and large wood to the aquatic system over time
   - dams and undersized stream crossings
   - channelization practices which result in an over-widened channel or vertical channel adjustments (i.e., aggradation or degradation) which reduce the forms and features related to meandering

ANR Strategies

The primary purpose in developing ANR physical stream habitat assessment protocols is to provide high quality data to guide effective management strategies and to eliminate or reduce human stressors of the physical stream environment. This program is intended to augment existing ANR biological monitoring programs. Resource managers require biological data (response indicators) to determine impairments and directly monitor BMP effectiveness. They also require an evaluation of ecosystem stressors to understand the cause of the impairment and devise and implement effective watershed management plans. The following list of current ANR strategies will directly benefit from the evaluation of physical habitat stressors:

Stream Crossings

- Replace stream crossings that are undersized and otherwise incompatible (in regards to stream fluvial function and aquatic organism passage) in cooperation with VTrans and town road foreman.

- Replace or retrofit stream crossings which are poorly located from a river reach and watershed context to avoid conflicts with fluvial processes and degradation to ecological attributes.

Dams

- Reduce impediments to flow, sediment, woody debris, and fish passage by working in the re-licensing and certification processes of hydroelectric facilities and other impoundments.

- Reduce impediments to flow, sediment, woody debris, and fish passage by removing dams where feasible.

Stream Alteration

- Reduce channelization practices by working with the Agency of Agriculture and the USDA to apply revised agricultural best management practices.

- Reduce channelization and wood removal practices via state stream alteration permits and CWA 401 certifications.

River Corridor Encroachments

- Limit encroachment by assisting towns in the development of land use plans and zoning regulations to include buffers or setbacks that address fluvial erosion hazards, riparian vegetation management, wetland protection, and floodplain filling.

- Limit encroachment and drainage impacts by providing technical assistance and grants to towns for managing or upgrading roads and planning road infrastructure in sensitive watersheds.

- Limit encroachment by working with landowners, towns, land trusts, the Nature Conservancy, the Vermont River Conservancy, and other partners to purchase lands or easements and provide long-term river corridor protection.

- Limit encroachment and floodplain fills through Act 250 regulation via floodway determinations and buffer recommendations.

Stormwater

- Reduce channel enlargement flows and temperature impacts through stormwater management.

- Reduce channel enlargement flows by working with Forest and Parks and the Loggers Association to apply revised silviculture best management practices.

Riparian Buffers

- Enhance or restore buffers and native riparian vegetation by making educational materials readily available to landowners and providing technical assistance and grants to implement buffer demonstration projects.

- Create a state buffer policy and secure the signing of an executive order to ensure that all state agencies are working toward buffer restoration and protection to the greatest extent possible.

Erosion Control

- Reduce overland sediment discharges through the application of erosion control, agriculture, silviculture, and stormwater best management practices.

Phase 2 - Physical Habitat Process and Component-based Analyses from RHA's

List of RHA Evaluation Parameters

6.1 Woody Debris Cover
6.2 Bed Substrate Cover
6.3 Bank Cover
6.4 Scour Features
6.5 Depositional Features
6.6 Channel Morphology
6.7 Flow Status
6.8 Animal Movement and Connectivity
6.9 Bank Stability
6.10 Bank and Riparian Vegetation

RHA Evaluation Parameter	**6.1**	**6.2**	**6.3**	**6.4**	**6.5**	**6.6**	**6.7**	**6.8**	**6.9**	**6.10**
Key Ecological Attributes (Physical Processes)										
Longitudinal Connectivity		X		X	X		X	X		
Riparian/Floodplain Connectivity	X		X			X	X			X
Sediment Regime	X	X		X	X	X	X	X	X	X
Hydrologic Regime		X	X			X	X	X		X
Temperature Regime			X	X		X	X	X	X	X
Large Wood / Organics Regime	X	X	X	X	X	X	X	X	X	X
Aquatic Life Cycle Requirements (Habitat Components)										
Adult Salmonid Cover	X	X	X	X		X	X		X	X
Juvenile Salmonid Cover	X	X	X	X	X	X	X		X	X
Y-O-Y Salmonid Cover	X	X	X	X	X	X	X		X	X
Macroinvertebrate Cover	X	X	X	X	X	X	X		X	X
Spawning Substrates	X	X		X	X	X	X	X	X	X
Spawning Migration							X	X		
Temperature Refugia			X	X		X	X	X	X	X
Allochthonous Production	X		X			X	X		X	X
Autochthonous Production		X				X	X	X		X
Winter Habitat	X			X	X	X	X		X	X
Summer Habitat	X	X	X	X	X	X	X		X	X
Habitat Complexity										
Disturbance Regime	X	X		X	X	X	X	X	X	X
Habitat Heterogeneity	X	X	X	X	X	X	X	X	X	X
RHA Evaluation Parameter	**6.1**	**6.2**	**6.3**	**6.4**	**6.5**	**6.6**	**6.7**	**6.8**	**6.9**	**6.10**

APPENDIX B: Summary of Parameter and Variable Research

8.1 Woody Debris Cover (LWD pieces, debris jams, CPOM)

Initial Variables Researched

LWD: Count pieces that have L>6', D_{wide}>1', $D_{6'out}$>0.5'.
Debris jams: Count jams that have more than 1 LWD, and span, or nearly, the channel.
CPOM: Estimate percentage of debris that is smaller than LWD over pebble count area.

Summary

Many references old and new indicate the benefits of LWD to biological populations in streams. Fish use LWD for refuge during high flows, cover from predation, and feeding locations where macroinvertebrates are typically abundant (Mcmahon and Hartman, 1989; Shirvell, 1990). LWD serves as substrate for an array of invertebrates that feed directly on the woody debris or that use the wood structure to build retreats for filtering the water column. Some research has shown a link between increased fish diversity and LWD abundance (Bond and Lake, 2003). LWD also serves as important winter rearing grounds for fish (Solazzi et al., 2000). LWD also contributes to bed roughness (Gregory et al., 1991). Several studies on riparian areas have indicated that LWD is a good indicator of lateral connectivity and that LWD not only helps retention of organic material in a stream but also serves as retentive substrate for increased heterogeneity in the riparian vegetation (Pettit and Naiman, 2005). In addition to the biological benefits, LWD has been shown to have profound physical effects on river process, influencing sediment transport (Wallerstein and Thorne, 2004), local hydraulics (Daniels and Rhoads, 2004), and retention of organics (Allouche, 2002).

Much of the recent literature on LWD entails verifying the utility of LWD in stream rehabilitation efforts since this is a popular tool for improving fisheries that has been applied in diverse channel types, from small mountainous streams to larger sand bed rivers. The general consensus is that the applications of LWD are alone not enough for fish recovery as the applications often show limited improvements (Gregory et al., 1991; Larson et al., 2001). Researchers hypothesize that restoring the lateral connection between channel and floodplain, which would offer repeated sources of LWD, would be more beneficial and likely to produce biological improvement (Opperman and Merenlender, 2004). Achieving this level of supply and retention is often difficult given the level of incision typical in many streams. In addition, recent studies have called for a more clear understanding of the important aspects of the temporal dynamics of LWD, as well as the spatial distribution, to investigate the dynamic nature of the influence between LWD retention and habitat (Haschenburger and Rice, 2004).

Debris jam research is quite analogous to that covering LWD, and often overlaps. The benefits of jams and LWD are quite similar, with debris jams potentially offering more habitat heterogeneity and influence

on stream habitat given their larger size relative to the width of the stream channel. Debris jams are important refuge areas. Debris jams have substantial effects on sediment transport, holding back fines for prolonged periods of time. Studies on debris jams have shown that the maturity and size of riparian trees is an important indicator for the frequency of debris jams, and the presence of live trees leaning into a stream can allow a debris dam to last for a long time (Kreutzweiser et al., 2005; Opperman, 2005). Classification schemes now exist for debris jams as it has been shown that different types of jams and spatial orientations can have varying effects on stream habitat and biota (Abbe and Montgomery, 2003).

CPOM and its retention is a key part of the foodbase of streams. Research has shown a link between shredding macroinvertebrates and detritivors and the presence and abundance of CPOM (Cummins et al., 1989; Gonzalez and Graca, 2005). Feeding groups also vary temporally with changes in CPOM (Fenoglio et al., 2005). Oftentimes, CPOM gets processed into FPOM and colonized by fungi and other microbes prior to consumption (Allan, 1995). Thus, much of the recent literature has focused on CPOM retention so that ample processing can take place to become a viable food for macroinvertebrates (Lepori et al., 2005).

Variable Confirmation and Potential Revisions

The 'Woody Debris Cover' parameter (8.1), as evaluated based on LWD, debris jams, and CPOM raw data, covers large scale and visual small scale aspects of the heterotrophic (i.e., non-living organic matter) component of the flowing water food web. In its current form, this parameter is a good representation of many of the physical ecological processes, habitat components, and habitat complexity. Based on this research, riparian/floodplain connectivity, sediment regime, Y-O-Y Salmonid cover, spawning substrates, winter habitat, summer habitat, and disturbance regime were added to the list of factors that are indicated by the 'Woody Debris Cover' parameter.

One potential addition for this parameter could be the inclusion of the autotrophic component of the 1st trophic level. In certain river types marginal plants, leaf litter, macrophytes (emergent, floating leaved, submerged fine leaf, submerged broad leaf), mosses, macroalgae could be as important as CPOM to the foodbase. These large, rapidly observable primary producers can serve as important macroinvertebrate substrate and fish cover. In addition to inorganic substrates and woody debris of various sizes, Kemp et al. (1999) advocate identifying 'functional habitats' that include aquatic plants to understand habitat in a river. An autotrophic component could be justified for larger rivers in Vermont.

Note that some other variables that could be considered for inclusion into the RHA were uncovered here that are more likely placed under other RHA parameters. For example, the maturity of riparian trees was cited several times as being important to forming debris jams and LWD in the channel, yet this variable would likely fall under the 'River Bank' parameter. Each variable will primarily be discussed under the appropriate parameter.

Linking Woody Debris Cover to Physical Processes and Habitat Components

Key Ecological Attributes (Physical Processes)	
Longitudinal Connectivity	
Riparian/Floodplain Connectivity	LWD indicative of level of lateral inputs.
Sediment Regime	LWD and jams increase sediment retention and stability.
Hydrologic Regime	
Temperature Regime	
Large Wood / Organics Regime	Direct indicator.

Aquatic Life Cycle Requirements (Habitat Components)	
Adult Salmonid Cover	Holds, refuge, isolation, and feeding locations. Microhabitat.
Juvenile Salmonid Cover	Refuge and rearing grounds. Anti-predation and microhabitat.
Y-O-Y Salmonid Cover	Refuge and rearing grounds. Anti-predation and microhabitat.
Macroinvertebrate Cover	LWD/CPOM key for detritavores,shredders, retreat makers.
Spawning Substrates	LWD and jams influence the utility of good spawning gravels.
Spawning Migration	
Temperature Refugia	
Allochthonous Production	Coarse material Indicates lateral inputs from floodplain.
Autochthonous Production	
Winter Habitat	Winter refuge, microhabitat, and reduces anchor ice.
Summer Habitat	Thermal refuge.

Habitat Complexity	
Disturbance Regime	'Temporal dynamism' of coarse inputs and retention.
Habitat Heterogeneity	Bed roughness, retention, hydaulic diversification.

Research Notes

(Wallerstein and Thorne, 2004) - locations of LWD inputs, volumes of LWD stored in different reaches and number of jams per unit channel length are causally related to the morphological processes occurring during different stages of adjustment in these unstable, incised fluvial systems. jams trap more sediment than they mobilize. This suggests that LWD probably accelerates rather than retards recovery of a stable longitudinal profile and channel configuration following incision. Introduce an LWD classification system to characterize different types.

(Opperman and Merenlender, 2004) – LWD important to salmonids and sediment trapping. This paper shows that riparian vegetation and protection is more effective at restoring good instream cover in the form of LWD and CPOM rather than putting in instream structures.

(Bond and Lake, 2003) - lowland streams in Victoria, Australia, that have been degraded by severe sedimentation. Native fish were linked to micro-scale habitat features in the form of deeper water, and in close proximity to cover (typically either coarse or fine woody debris or vegetation).

(Talmage et al., 2002) - Percent run. percent boulder, percent woody debris, percent overhanging vegetation, percent sand, and frequency of erosion best described habitat and instream conditions. LWD was key for fish.

(Allouche, 2002) - cover is perceived at fish microhabitat and provides antipredation, visual isolation, hydraulic shelter
-cover effects nutrients, trophic dynamics, invert diversity
-whether cover addition really increases stream carrying capacity rather than simply redistributing the existing population remains controversial.**
-even in systems with sparse riparian corridors and little lwd,debris probably influence fish assemblage structure , diversity and abundance, but not really known.
-lack of cover can allow introduced fish to chase out natives.
-heterogeneous substratum granulometry constitutes the most frequent hydraulic cover.
-instream cover is used for hydraulic cover
-cover influences utility of spawning grounds*
-cover is essential for winter survival*

(Shields et al., 2003) – Installed LWD produced marginal improvements in habitat quality, little fish response. It seems as though the consensus in the literature is that LWD is important for fish, but the natural input process is key. Installing LWD and debris jams in incised channels does not seem to recover the complexity required for habitat improvement and fish/invert recovery. (Larson et al., 2001) saw some physical changes in PSL streams in a developed area but the biology did not respond. Again, natural process is key.

(May et al., 1997) riparian maturity is good LWD indicator.

(Gregory et al., 1991) – LWD is a key means of creating bed roughness for habitat complexity, sediment control, hydraulic refuge, and food sources.

(Cummins et al., 1989) CPOM key for shredding invertebrates, and good indicator of riparian connectivity and contribution to foodbase.

(Lepori et al., 2005) - Retentiveness and breakdown of coarse particulate organic matter (CPOM), two key ecological functions in low-order streams most likely to be affected by channelization.

(Kemp et al., 1999) - Look at distribution of functional habitats - links ecology, hydrology, and morphology and good for rehabilitation.
functional habitats (more diversity better): boulders/rocks, cobbles, gravel, sand, silt, tree roots, tree branches/veg, marginal plants, **leaf litter, woody debris, macrophytes (emergent, floating leaved, submerged fine leaf, submerged broad leaf), mosses, macroalgae**.

(Solazzi et al., 2000) – LWD inputs increased winter rearing habitat and released bottleneck for several types of salmonids in Alaska.

(Haschenburger and Rice, 2004) - Results highlight that the temporal dynamism of large woody debris (LWD) should be coupled with spatial considerations for effective stream restoration and management of streambed sediment.

(Sweka and Hartman, 2006) No increase in pools and brook trout after three years of lwd additions via felling trees. The full potential of added LWD to change stream habitat and influence on brook trout populations may take more time to develop than the 3 years post-manipulation period of this study.

(Abbe and Montgomery, 2003) – LWD jam classification based on type, orientation as the differences influence the effects of debris jams.

(Balian and Naiman, 2005) - This suggests that, in combination with the rapid lateral migrations of many alluvial rivers, the older riparian forests on those terraces are important and sustained sources of organic matter (especially large woody debris, LWD) that, over decades to centuries, shape the character of coastal rivers in the Pacific Northwest.

(Pettit and Naiman, 2005) – LWD in riparian area important to promoting more retention and heterogeneity in riparian area and channel.

(Kreutzweiser et al., 2005) – In these Boreal Shield forests, it appears that most riparian trees do not live long enough or grow to sufficient size to contribute functional LWD and influence stream morphology or pool formation.

(Opperman, 2005) – Live trees were important for dead LWD retention in hardwood forests. Public lands were more apt to have debris jams due to removal on private lands in CA.

(Daniels and Rhoads, 2004) - The results of this study indicate that LWD substantially modifies 3-D flow structure through low-gradient meander bends.

(Gonzalez and Graca, 2005) - CPOM mass was positively correlated with total density and with all functional feeding groups of macroinvertebrates excepting filterers.

(Fenoglio et al., 2005) - The temporal variation of CPOM influenced the distribution of functional feeding groups in the riverbed. In particular, shredder assemblages were widespread in the riverbed when CPOM was abundant, but when this resource became scarce and localized, their density was related to the availability of allochthonous organic detritus.

(Mcmahon and Hartman, 1989) – LWD offers cover and velocity refuge for fish.

(Shirvell, 1990) – Root wads offer cover and velocity refuge for fish.

8.2 Bed Substrate Cover (Embeddedness, cobbles+boulders, sand+gravels, and sediment mobility)

Initial Variables Researched

Embeddedness: Qualitative assessment in head or middle of riffle/run with cobbles.
Cobbles+Boulders: Zigzag pebble count.
Sand+Gravel: Zigzag pebble count.
Sediment stability: Qualitative assessment during pebble count.

Summary

There many definitions and methods of measuring embeddedness as reviewed by Sylte and Fischenich (2002). Embeddedness is the "the position of a large particle relative to the plane of the bed when that particle is partially buried in finer sediment" (Bunte and Abt, 2001), and typically measured rapidly by visual estimation.

Many studies have shown that excessive embeddedness can result from river corridor and watershed level impairments including reducing the width of naturally vegetative buffers (Nerbonne and Vondracek, 2001), trampling of banks from livestock (Kyriakeas and Watzin, 2006), and historical logging (Nislow and Lowe, 2003). Nislow and Lowe (2003) showed that embeddedness decreases with forest recovery, and thus this process could be happening in many watersheds in the northeast US. Bedload transport, embeddedness, and channel instability increased with the reduction of forest land cover (Sutherland et al., 2002).

Embeddedness has been correlated with the impairment of all trophic levels of stream biota. Griffith et al. (2002) found periphyton to be primarily a function of P, substrate coarseness, and embeddedness. Macroinvertebrate impacts have been linked to embeddedness in the agricultural (Kyriakeas and Watzin, 2006) and urban setting (Scarsbrook and Townsend, 1993; Richards and Host, 1994) , where interstitial fines reduce the presence of organisms intolerant to habitat change. Some researchers do not see the anticipated metric degradation describing macroinvertebrates associated with embeddedness indicating a different response by taxa to deposited sediment than to organic enrichment (Zweig and Rabeni, 2001). These authors thus created the Deposited Sediment Biotic Index (DSBI) to represent levels of fine sediment deposition and link to macroinvertebrate impacts. The index is analogous to HBI, where tolerance values are created and then a weighted average is calculated for a collected assemblage. DSBI is one way in which changes in bed substrate, say an increase in fines and thus embeddedness, is related to community health. Differences between sediment deposition and common biologic metrics could possibly be due to typical embeddedness measures not accurately describing the true level of embeddedness in the substrate that could better be represented by other indicators such as the percent fines (McHugh and Budy, 2005). However, this study found that the observed bias between embeddedness observations and actual measures was greatly reduced upon stratification via channel slope, which is planned for the new RHA via channel type. 10mm has been selected as a practical level of fines that is both observable and indicative of potential habitat degradation (Kondolf, 2000). An interesting side note is that during a study on mussel populations near reservoirs, (Combes and Edds

(2005) showed that substrate embeddedness and percent of silt in the substrate were not related to flood duration.

The main thread on the literature on embeddedness and fish is that embeddedness reduces the amount of clean gravel that can be used for spawning grounds, and thus often limits populations. This limitation is also associated with fines disrupting embryonic and juvenile life stages of salmonids (Chapman, 1988). Embeddedness has been used for developing habitat suitability criteria for brown trout in CT (Strakosh et al., 2003), microhabitat descriptions for bull trout in WA (Polacek and James, 2003), and to illustrate the effects of historic logging on brook trout in NH (Nislow and Lowe, 2003). In each case exemplified here embeddedness is linked to population impairment in trout.

Sediment size is often used as a covariate for studies looking at biological health in streams since there are clear relationships between particle size and assemblages of plants, macroinvertebrates, and fish. Particle size is a primary physical variable as its product with sediment load is proportional to the product of flow and channel slope (Lane, 1955). The change in these variables moving down a river, leading to the general decrease in particle size as channel width increases, mirrors the river continuum concept proposed by Vannote et al. (1980) indicating that biological communities also change in continuous ways moving downstream. The two components are integrally linked. Both of these fundamental studies suggest that particle size distribution is an important longitudinal aspect of rivers that influences biological assemblages.

Hill et al. (2000) identified substrate size to be correlated with periphyton biotic indices. Substrates and filamentous algal cover in stream beds, and riparian vegetative buffer were all important with relation to diatom species assemblages (Pan et al., 2004).

Substrate heterogeneity was most important in determining richness patterns for macroinvertebrates (Scarsbrook and Townsend, 1993; Richards and Host, 1994; Lammert and Allan, 1999), as were the percent rocky substrates and percent fines (Wang et al., 1997). Harper et al. (2000) make an interesting argument that the substrate variability is important for macroinvertebrate richness. During stream rehabilitation where clean gravel riffles were installed in a silted river, macroinvertebrate fauna showed higher similarity to the fauna found on the reference stony bottom sections due to immigration of taxa preferring stony substrate (Gortz, 1998). Another study (Gore et al., 1998) saw increased community diversity after cobble riffle installation after stabilization and colonization.

Age-0 bull trout were located over fines and gravel substrates in shallow, and highly associated with loose substrate, and used the substrate interstices for refuge cover (Polacek and James, 2003). The "relative abundance of fishes requiring clean cobble/gravel substratum for spawning was lower in disturbed streams, whereas relative abundance of mound-building cyprinids, their nest associates and fishes that excavate nests in soft sediments (centrarchids) was higher" (Sutherland et al., 2002).

Sediment stability offered an interesting line of research that is not only directly linked to hydrology and disturbance regime, but also closely linked to biological integrity in streams – thus offering a close link between physical and biological aspects of rivers. In a multi-scale habitat study, Miyake and Nakano (2002) identified subtle baseflow movements of substrate to be important to determining invertebrate diversity. This finding has important ramifications for unstable beds such as those where large aggradational features are present. A lower median substrate particle size and higher shear stress regime

were indicative of a higher disturbance frequency (Scarsbrook and Townsend, 1993). This study goes on to suggest that lower substrate diversity indicated that the availability of refugia was lower, and that pools were found to have a higher disturbance frequency and lower availability of refugia than riffles. This finding might be considered to be a bit contrary to popular thought on riffles versus pools. Invertebrate density was highest in stable patches in > 50% of all the patch type effects detected and lowest in fill patches in 75% of all detected effects (i.e. scour, fill, stable) (Effenberger et al., 2006). Matthaei and Townsend (2000) questioned the utility of floodplain refugia for macroinvertebrates as the study floodplain drained prior to main channel bed stabilization. This scenario could hold true for incised channels where large floods may barely access floodplains in some areas, and then the return to the channel with unstable substrate will subject animals to a hostile environment.

Variable Confirmation and Potential Revisions

The 'Bed Substrate Cover' parameter (8.2), as evaluated based on embeddedness, cobbles+boulders, sand+gravels, and sediment mobility raw data, is a valuable evaluation parameter representing many physical processes and life cycle requirements. Hydrology and adult Salmonid habitat were added to the existing links table (see below).

The selected raw variables appear to cover the three key aspects in the literature that define the streambed in terms of physics and biota – particle size abundance, embeddedness, and substrate stability. Some possible alternative options for raw data were identified that are worthy of discussion. McHugh and Budy (2005) suggest that visually observing percent fines could possibly be more accurate than embeddedness. This variable could easily be incorporated in the phase 2 field notes or quickly observed during the RHA, and thus may warrant further research in existing protocols and other sources.

It is complicated to measure streambed stability, which is related to the health of the biota, at a given point in time. How best can one represent such a dynamic process? Duncan et al. (1999) used aquatic bryophyte cover (moss) because the plants are good biological indicators of substrate stability. In some stream types moss covered rocks could be surveyed during pebble counts to understand recent bed movement and disturbance regime. Imbrication of particles and orientation could also be assessed to indicate bed stability (Bunte and Abt, 2001), and would most likely be very useful to gain an understanding of sediment transport characteristics. When the a-axis (longest axis) is oriented parallel to the flow direction (i.e., a-axis imbricated) high intensity sediment transport is taking place such as debris flows. B-axis imbrication, when the b-axis is parallel to the direction of flow, indicates particle movement in fluid flows in low to moderate sediment transport rates (Bunte and Abt, 2001). Imbrication may be a desirable variable since it can be investigated both in the channel and on bars to get an idea of the disturbance regime of two different sized flow events.

The information revealed during research on indicators used to evaluate bed substrate cover overlap with other parameters. In particular, scour and deposition features, and channel morphology, are closely aligned with bed substrate. Bed substrate cover material also tied into aquatic vegetation in several studies.

Linking Bed Substrate Cover to Physical Processes and Habitat Components

Key Ecological Attributes (Physical Processes)	
Longitudinal Connectivity	Sediment size sorting, slope creation.
Riparian/Floodplain Connectivity	
Sediment Regime	Direct indicator of particle size, fines, and bed stability.
Hydrologic Regime	Hyporheic exchange
Temperature Regime	
Large Wood / Organics Regime	Diverse and rough substrate can help retain more.
Aquatic Life Cycle Requirements (Habitat Components)	
Adult Salmonid Cover	Instream boulders.
Juvenile Salmonid Cover	Clean interstitial spaces and bed stabilty required.
Y-O-Y Salmonid Cover	Clean interstitial spaces and bed stabilty required.
Macroinvertebrate Cover	Clean interstitial spaces and bed stabilty required.
Spawning Substrates	Clean interstitial spaces and bed stabilty required.
Spawning Migration	
Temperature Refugia	
Allochthonous Production	
Autochthonous Production	Roughness for physcial abrasion processing.
Winter Habitat	
Summer Habitat	Roughness for fish cover while actively feeding. Invert repro.
Habitat Complexity	
Disturbance Regime	Bed movement, habitat rejuvenation.
Habitat Heterogeneity	Variable particle sizes, roughness.

Research Notes

(Nerbonne and Vondracek, 2001) Percent fines and embeddedness were negatively correlated with buffer width. Stream sites along grass buffers generally had significantly lower percent fines, embeddedness, and exposed streambank soil, but higher percent cover and overhanging vegetation when compared with sites that had grazed or wooded buffers.

(Kyriakeas and Watzin, 2006) Used median substrate size, percent hay/pasture area, and stream depth as covariates since particles key to inverts. The covariates significantly improved model fit and showed that multiple contributing factors influence community composition. Local impacts were greatest at sites where cows had access, probably because of sedimentation and embeddedness in the substrate.

(McHugh and Budy, 2005) paper on measurement of embeddedness and fines. Seems some difference between visual estimates and measurement for embeddedness, and not for fines.

(Combes and Edds, 2005) mussel study looking at diversity in the vicinity of reservoirs. Substrate embeddedness and percent of silt in the substrate were not related to flood duration in any river.

(Strakosh et al., 2003) Habitat suitability criteria (HSC) for depth, mean velocity, nose velocity, substrate, embeddedness, and cover were developed for brown trout greater than or equal to170 mm (Salmo trutta Linnaeus) on the West Branch Farmington River, CT, USA.

(Polacek and James, 2003) WA state. Microhabitat variables included water depth and velocity, distance from the stream bottom, habitat and refuge use, substrate type, and substrate embeddedness. Age-0 fish were located over fines and gravel substrates in shallow, low-velocity water near stream margins, but were located in shallower water at night. Bull trout were highly associated with loose substrate, and used the substrate interstices for refuge cover.

(Nislow and Lowe, 2003) Logging history (years since harvest) was negatively correlated with substrate embeddedness. suggesting that this aspect of physical habitat quality improves with forest recovery. NH brookie study.

(Sutherland et al., 2002) 3. Disturbed sites had five- to nine-fold more bedload transport than reference sites. Both embeddedness and streambed instability increased with increasing non-forested land cover. 4. Relative abundance of fishes requiring clean cobble/gravel substratum for spawning was lower in disturbed streams, whereas relative abundance of mound-building cyprinids, their nest associates and fishes that excavate nests in soft sediments (centrarchids) was higher. Relative abundance of fishes spawning in benthic crevices and gravel (BC + G) declined as the proportion of non-forested land cover increased. This study supports growing evidence that human-induced sedimentation alters stream fish assemblages.

(Griffith et al., 2002) For periphyton metrics, the first axis extracted by redundancy analysis correlated with total phosphorus, substrate coarseness and embeddedness, and riparian vegetation condition, whereas the second axis correlated with dissolved metals. For species abundances, the three axes extracted by canonical correspondence analysis (CCA) were correlated with (1) stream size and types of in-stream habitats; (2) total phosphorus, dissolved ions, and riparian disturbance by agriculture; and (3) sediment coarseness and embeddedness and riparian vegetation condition.

(Zweig and Rabeni, 2001) Shannon diversity index, Chironomidae richness, Chironomidae density, a biotic index, and % dominant taxon did not relate to increasing levels of deposited sediment! Evidence that the world does not function in solely a water quality framework. Tolerance values representing taxa responses to deposited sediment were developed for 30 taxa. Deposited-sediment tolerance values were not correlated with biotic index tolerance values, indicating a different response by taxa to deposited sediment than to organic enrichment. Deposited-sediment tolerance values were used to develop the Deposited Sediment Biotic Index (**DSBI**). The DSBI was calculated for all samples (n = 85) to characterize sediment impairment of the sampled streams. DSBI values for each site were highly correlated with measures of deposited sediment. Model validation by a resampling procedure confirmed that the DSBI is a potentially useful tool for assessing ecological effects of deposited sediment.

(Hill et al., 2000) Canonical correlation analysis revealed significant correlations between the 10 PIBI metrics and 4 significant environmental gradients related to general human disturbances (stream acidity, stream substrate composition, and stream and riparian habitat).

(Scarsbrook and Townsend, 1993; Richards and Host, 1994) substrate heterogeneity was most important in determining richness patterns. Embeddedness increased with ag., substrate size decreased with urbanization.

(Wang et al., 1997) % fines, % rocky substrate important for biotic integrity in WI streams.

(Harper et al., 2000) substrate variation key

(Lammert and Allan, 1999) Fish showed a stronger relationship to flow variability and immediate land use, while macroinvertebrates correlated most strongly with dominant substrate.

(Gortz, 1998) The fauna showed higher similarity to the fauna found on the stony bottom sections due to immigration of taxa preferring stony substrate

(Maul et al., 2004) results of this study: (1) suggest total solids, total phosphorus concentration, , ammonia concentration, and conductivity were important variables for structuring stream macroinvertebrate communities in northwest Mississippi,

(Gore et al., 1998) At optimum flows in sand and grave riffles only 15% of the wetted area, primarily across small gravel bars, was adequate to support high community diversity. Two artificial riffles, composed of large cobble and boulder keystones, with leading and trailing aprons of medium cobble and gravel, were placed at 35 m intervals in the test section. After hydrological stabilization and time for colonization by macroinvertebrates, the artificial riffles were re-analyzed. The simulation predicted that this reach contained significantly higher amounts of available benthic habitat at low flows (more than tripled), and over 40% of the total wetted area should support high benthic community diversity at optimal flows.

(Pan et al., 2004) substrates and filamentous algal cover in stream beds), and riparian vegetative buffer were all important with relation to diatom species assemblages.

(Miyake and Nakano, 2002) - **diversity of stream inverts at the REACH scale was determined by subtle substratum movements and by habitat preference
-at the habitat patch scale, particulate organic matter (POM) overwhelmed effects of substratum movement to dictate inverts.
-2 scale analysis confirms importance of cross-scale analysis
-during baseflow movements of substrate important to determining invertebrate diversity**
-Scales: Reach - 24 meters, habitat at 12 transects, 0.5 m increments across Patch - 2 quadrats at each transect = 24 patches in all.
-Measured erosion/deposition from bent steel pins (3.2 mm diameter)

(Scarsbrook and Townsend, 1993) A lower median substrate particle size and higher shear stress regime in Timber Creek were indicative of a higher disturbance frequency than in the Kyeburn. Substrate diversity was lower in Timber Creek than in the Kyeburn and indicated that the availability of refugia was lower in Timber Creek. In both streams, pools were found to have a higher disturbance frequency and lower availability of refugia than riffles.

(Effenberger et al., 2006) 3. Patterns of invertebrate density in the different bed stability types (i.e. scour, fill, stable) varied between floods, sampling dates and streams, but invertebrate density was highest in stable patches in > 50% of all the patch type effects detected and lowest in fill patches in 75% of all detected effects. Stable bed patches acted as refugia for Liponeura spp. and Leuctra spp. in the Schmiedlaine and for Hydracarina and Deleatidium spp. in the Kye Burn.

(Matthaei and Townsend, 2000) Conclude that inundated floodplain gravels provided temporary shelter for lotic invertebrates during the flood, but several animals were trapped as the flood plain dried, and those that managed to return to the baseflow channel were still exposed to bed-moving shear stresses. We doubt that floodplain gravels can act as true invertebrate refugia in our study river, primarily because of the unstable nature of its sediments.

(Duncan et al., 1999) We next related the 3 stability measures to aquatic bryophyte cover because these plants are good biological indicators of substrate stability. We observed a highly significant correlation ($p < 0.001$) between P-BF and bryophyte cover, a weaker correlation between the Pfankuch score and bryophyte cover ($p = 0.023$), but no significant relationship between cover and the Instability Index. These results suggested that our method is a useful and potentially powerful tool to accurately quantify substrate movement in steep headwater streams.

8.3 Scour and Depositional Features (Plunge/pocket pool frequency, pool depth, turbulent cover, step/riffle structure, step/riffle spacing, deposition)

Initial Variables Researched

Step-pool/riffle-pools: Visual qualitative estimate of frequency.
Pool depth: Abundance of pools with some level of desirable water depth.
Turbulent cover: Proportion of water surface with turbulent cover.
Step-pool or riffle-pool structure: Qualitative assessment of form and completeness.
Step-pool or riffle pool spacing: Estimate spacing per channel width.
Channel deposition: Description of deposition locations.

Summary

Much of the literature on the hydraulic features of pools presents topics associated with formation of pools in the step-pool channel types. Plunge pools are typically associated with the step-pool systems (Chin and Wohl, 2005), primarily formed by deposition of large wood (Sweka and Hartman, 2006) and containing local downstream scouring due to the plunging flows. Pools that are primarily formed via scour include those formed by bends and contractions. In stable systems, these scour pools would tend to be part of the typical riffle-run-pool-glide bed feature pattern. Although scour pools often have deposition

during low flow periods, scour is the process that ultimately forms and maintains them and creates an important habitat unit. Scour and depositional aspects of pools are closely linked as the two processes occur in tandem around river beds during varying stages of the flood hydrographs (Matthaei et al., 1999).

The deposition of large woody debris and its retention is essential for the formation of step-pools (Kreutzweiser et al., 2005). Pool area and depth are linked to large woody debris and the channel width and bed roughness (Sweka and Hartman, 2006). Like pools in larger rivers where scour is the primary maintenance process, step-pools also go through scour-deposition cycles. The hydraulics and form of step-pool systems are quite variable (Chin and Wohl, 2005). Steps create plunging flow that dissipates energy in headwaters, and pools retain sediment under most flow conditions. It is the combination of the LWD retention and sediment capture that make step-pools primarily depositional features. Pools are cleaned during high flow periods when the discontinuous flow patterns in step-pools approach a more connected flow pattern and sediment and debris transport increases. During these high flow periods, the steps themselves are fortified, moved, or eliminated based on large debris inputs and transport (Chin and Wohl, 2005).

Step-pool spacing is a key geomorphology variable and important for habitat. Step-pools are important refuge areas for high flow periods, and thus more abundant pools means more access during stressed times. A 20-60 cm pool depth is recommended for trout to be useful as hydraulic refuge in different seasons (White and Brynildson, 1967). In a study exploring the effects of LWD placement, Larson et al. (2001) saw a narrowing of pool spacing after installation, although there was limited change in sediment capture and biology. The authors hypothesize that continued watershed sediment inputs overwhelmed the local step-pool patchwork created. Pool area was found to increase much more in low-gradient streams than in high-gradient streams following LWD placement, where the difference was thought to be the existing hydraulic controls common in high-gradient streams such as boulders and bedrock (Hilderbrand et al., 1997).

Riffle-pool form and distribution are important habitat aspects on many streams. Together, these bedforms create the necessary habitat for a variety of conditions. The hydraulic patterns that are a function of bed features influence each trophic level of he aquatic food web. "The disappearance of bed differentiation and riffle-pool sequences have produced a diminution of bed roughness and an increase of the competence of the river," (Assani and Petit, 2004) and thus retention of organics and sediment regime are fundamentally altered when riffle-pool features are altered. Bed feature diversity, which results in velocity-depth diversity (Hall et al., 2002), is important for access to hydraulic refuge (Negishi et al., 2002). Riffle-pool quality typically reflects watershed land use change, and can be reduced with increasing agricultural development (Sullivan et al., 2004a). Riffle-pool spacing is also indicative of channel stability and thus offers some insight to the anticipated stability of the substrate that is being used by benthic flora and fauna.

Pools are critical river habitat features that offer fish refuge from high flows and isolation to avoid predation (Bond and Lake, 2005). Fish have pool and cover zone requirements where excessive fines must be removed via maintenance by scour (Champoux et al., 2003). The maximum depth measurement is related to the volume of habitat available to aquatic biota such as fish (Hall et al., 2002). Local-scale variations in turbulence and sediment transport have strong implications for fish energetics and reproduction success, and a key issue for scour is egg pocket depth for gravel-bed spawners (de Boer et

al., 2005). Minor increases in the depth of scour could significantly reduce embryo survival (Montgomery et al., 1996).

Some habitat rehabilitation efforts gauge their success via the abundance of pools (Moerke et al., 2004). The authors found that sedimentation was still smothering good pool habitat, and thus riffle-pool creation only offered a temporary patch for a system process that went fundamentally unchanged. Smothering by increased sediment sources has also been attributed to entrainment and delivery associated with hydroelectric facilities (Assani and Petit, 2004). Scour and fill patterns are influenced by sediment supply and location within the channel network, channel form roughness, and peak flows (Bigelow, 2005). The dynamics of fine sediment in mountain rivers influence habitat, channel stability, and sediment yield (Rathburn and Wohl, 2003). Interstitial spaces and pockets are important for life cycle functions including fish spawning, fish resting, and macroinvertebrate foraging.

While studying former rehabilitation practices to create pools for fish cover, Thompson (2002) found pool depths to be too shallow for effective refuge and winter fish cover. Residual pool depth was used to remove the influence of varying discharge levels from depth observations, where an RPD of 20-60 cm is ideal for trout habitat in low flows (White and Brynildson, 1967; Lisle, 1987). Booth (1996) looked for thalweg pool depths larger than the bankfull channel width for a salmon habitat assessment. Flow deflectors are supposed to promote scour and pool deepening via contraction of the channel edges (Biron et al., 2004).

Flow reduction creates smaller pool volumes due to the absence of scouring flows and pool sedimentation (Thompson, 2006). This was especially true for coarse bed streams. The author discusses the importance of scour for fish – "Pools are particularly important features that provide some spawning gravel at their downstream end and low flow habitat for fish. Although high flow scour can excavate a deep depression in coarse substrate, low flow deposition of new sediment creates shallower pools."

Deep pool abundance and pool/glide/eddy quality were amongst the group of variables that showed good discriminatory power, particularly for higher order streams, for habitat quality. The pool/glide eddy quality variable is based on the variety and spatial complexity of slow or still water habitat within the sample segment (Hall et al., 2002). In incised streams, once the primary nickpoint moves upstream and degradation takes place, pool habitat is typically reduced as sediments are not well sorted and bed features tend to merge towards a uniform plane-bed (Shields et al., 1993).

Pools are not only critical habitat features for fish, but important for smaller organisms as well. In fact, pools have been identified as locations of high microbial activity in rivers (Lefebvre et al., 2006). Some macroinvertebrates that cannot withstand high flow velocities also depend on pool habitat.

In an interesting review of the theory of "ecosystem engineering," Wright and Jones (2006) discuss how organisms such as spawning fish and caddisflies can influence bed stability while carrying out life cycle functions. It is not clear if this would hold for many of Vermont's mountain rivers given their high stream power and high flow velocities, but the thought of a circular link between bed features and the erosion and deposition processes that form them, habitat, organisms, and back is thought-provoking.

Turbulent cover is typically covered in the literature as a minor part of the above larger themes on scour and deposition. Turbulent riffles are known locations of high macroinvertebrate diversity (Barbour et al.,

1999), and where juvenile fish seek refuge amongst the bed roughness. Many more scientific references to turbulence refer to physical processes that form river channels and bed features such as meander initiation (Rhoads and Welford, 1991) and an overview of erosion and sedimentation (de Boer et al., 2005). Turbulent flow also leads to variations in nutrient processing (Lefebvre et al., 2006).

The result of larger scale processes, bed feature (e.g., step-pools and riffle-pools) characteristics directly form useable aquatic habitat associated with a distribution of velocity-depth combinations, substrate sizes, and smaller scale processes and patterns of disturbance.

One aspect of fine sediment deposition that could be important for habitat is the likelihood that trace metals and other pollutants may be inclined to attach to fines. Streams with high fine deposition rates could have reduced useable habitat area, even in potentially otherwise useful areas such as behind boulders and logs. For example, the concentration of zinc and lead increases as sediment grain size decreased (Stone and Droppo, 1996). The delivery of contaminants via sediment transport can originate in developed areas or due to a previous spill or former small-scale industrial practices in the watershed.

Beyond the periodic smothering of small habitat feature with fines, large scale deposition of coarse material is also problematic for habitat. Depositional features suggest the movement of large quantities of sediment that can impair habitat. Direct physical abrasion, complication of life-cycle functions, and smothering and bed homogenization can all occur when large depositional features are present. Bed stability tends to generally decline when depositional features are present, as is evident from the unconsolidated nature of deposited coarse grains. Frequent substrate movements have a detrimental effect on macroinvertebrates and fish (Allouche, 2002; Miyake and Nakano, 2002), although some level of "intermediate disturbance" is desirable to maintain good habitat (Townsend et al., 1997). Landwehr and Rhoads (2003) explore the structure of deposited bars and see stratification and the inclusion of soil layers indicative of overbank flows and subsequent deposition. The most diverse fish assemblages are located in areas where stable bars with vegetation are present. This study essentially discusses the habitat consequences of various stages of channel evolution. As an incised channel laterally adjusts and creates new floodplains and progresses from stage III to IV to V, stability increases and thus habitat should improve. Landwehr and Rhoads (2003) see that in low-gradient farm ditches. Fryirs and Brierley (2001) show that sediment storage and sensitivity is directly related to geomorphic types and valley control, and indicate that river rehabilitation potential is largely linked to sediment abundance and sensitivity to change.

Variable Confirmation and Potential Revisions

The 'Scour and Deposition Features' parameter (8.3), as evaluated based on plunge/pocket pools, pool depth, turbulent cover, step/riffle structure, step/riffle spacing, and channel deposition is useful for describing the important aspects of degrading and aggrading features. The research indicates that scour and depositional features actually represent habitat features important to many life cycle requirements. In addition to the original links, longitudinal connectivity, large wood/organics regime, juvenile Salmonid cover, YOY cover, macroinvertebrate cover, spawning substrates, winter habitat, summer habitat, and disturbance regime were added to the existing links table (see below).

Rather than a straight abundance of pools that are maintained via scour, it might be useful to add the quality of pool/glide/eddy (and riffle/run) sequence following the work of Hall et al. (2002). This could improve understanding of fine deposition in pools that limit habitat potential, and highlight important habitat features for fish and insects.

Residual pool depth (Lisle, 1987; Thompson, 2002) could be substituted for maximum pool depth to remove the influence of discharge, if that variable can be incorporated into the phase 2 field notes.

The description of deposition is important to aquatic habitat and thus this raw variable adds important information. One potential improvement is to incorporate some indicator of stability. Sediment consolidation is one possible variable that would add a stability factor. Several studies mentioned using the amount of vegetation on the bars to approximate stability. A stability indicator would help determine if intermediate disturbance (i.e., feature and bed mobilization and habitat change) beneficial to habitat maintenance is being achieved or exceeded by unstable conditions.

Linking Scour and Deposition Features to Physical Processes and Habitat Components

Key Ecological Attributes (Physical Processes)	
Longitudinal Connectivity	Bed feature formation, sediment continuum, debris delivery.
Riparian/Floodplain Connectivity	
Sediment Regime	Sediment generation and attenuation, downstream features.
Hydrologic Regime	
Temperature Regime	Cool summer refuge, ice free in winter, more thermal mass.
Large Wood / Organics Regime	Retention of organics, snags, jams.
Aquatic Life Cycle Requirements (Habitat Components)	
Adult Salmonid Cover	Refuge areas. Resting. Food.
Juvenile Salmonid Cover	Refuge areas. Resting. Food. Bed stability
Y-O-Y Salmonid Cover	Refuge areas. Rearing. Margins for shelter. Bed stability.
Macroinvertebrate Cover	Refuge areas. Rearing. Margins for shelter. Bed stability.
Spawning Substrates	Stable bed, interstices, spawning pocktet depth.
Spawning Migration	
Temperature Refugia	Cool summer refuge, ice free in winter, more thermal mass.
Allochthonous Production	
Autochthonous Production	
Winter Habitat	Ice free areas w stable temperature. Isolation from predators.
Summer Habitat	Cool summer refuge. Higher DO in cool water.
Habitat Complexity	
Disturbance Regime	Refuge from floods and low flows. Erosion/deposition.
Habitat Heterogeneity	Diversity of bed features. Roughness variation. Hydraulics.

Research Notes

(Bond and Lake, 2005) – "Because sedimentation has depleted the number of permanent refuge pools in these creeks, recovery rates of the fauna (i.e., resilience) are likely to be slow." Pools important for refuge and need to be cleaned out via scour to not accumulate sediment.

(Moerke et al., 2004) – channel re-alignment improved habitat (e.g., more pools, fewer fine sediments). Biological response did take place, but not consistently likely due to continued sedimentation.

(Assani and Petit, 2004) – hydrologic modification for hydro-electricity led to a reduction in the number of riffles and pools due to continued entrainment and smothering by fines.

(Champoux et al., 2003) – fish have pool and cover zone requirements. Too many fines are bad. Need scour to clean beds. This is really getting at the frequency of storm events and the grain size distribution. How much bed will be mobilized and on what frequency? The frequent movement of larger particles can fill pools, while fines can clog pools without enough channel competency.

(Bigelow, 2005) - scour and fill patterns were likely influenced by sediment supply and location within the channel network, channel form roughness, and possibly multiple peak flows.

(Thompson, 2002) – while studying the influences of old rehabilitation practices, the author explores pools. Log dams limit vertical incision, and pools were too shallow for winter cover, an important fish feature. Uses residual pool depth = depth of pool bottom – depth of downstream riffle head. RPD removes influence of Q on depth measurements. (Lisle, 1987) suggests a rpd of 20 to 60 cm, where 60 is ideal. Pool depth is important for large fish cover in winter and summer for better environmental conditions and protection from predation.

(White and Brynildson, 1967) – 20-60 cm pool depth important for trout to ensure adequate low flow habitat

(Booth, 1996) – as part of a rapid channel assessment protocol looked for occurrences of pool depth larger than bankfull depth in the thalweg.

(de Boer et al., 2005) - There exists a strong potential for feedback mechanisms between the structure of flow and the organization of the bed. A gravel-bed river represents a heterogeneous habitat for fish. Local-scale variations in turbulence and sediment transport have strong implications for fish energetics and reproduction success. Key issue for scour is egg pocket depth for gravel bed spawners.

(Montgomery et al., 1996) - even minor increases in the depth of scour could significantly reduce embryo survival. Spawning coarsens bed and reduces mobility, which can ultimately limit future spawning.

(Thompson, 2006) - Results indicate that a reduction in flow creates smaller volume pools. For finer substrates, # of pools and depths differed for 50 and 80% flow reduction, while for more coarse unsorted material there were no changes in pools size since sediment transport was reduced. Pools and riffles are natural bedforms that produce variations in width and depth along channels deemed critical for aquatic habitat. Pools are particularly important features that provide some spawning gravel at their downstream end and low flow habitat for fish. Although high flow scour can excavate a deep depression in coarse substrate, low flow deposition of new sediment creates shallower pools.

(Lefebvre et al., 2006) – "pools are spots of high microbial activity in streams."

(Hall et al., 2002) - deep pool, and pool/glide/eddy quality, were amongst the group of variables that shower good discriminatory power, particularly for higher order streams. The pool/glide eddy quality variable is based on the variety and spatial complexity of slow or still water habitat within the sample segment. The quality of pools is a direct result of the balance between erosion and deposition in natural systems. Many warmwater fish and invertebrate species are habitat specialists and are eliminated when pool habitats become degraded (Rankin 1995). The maximum depth measurement is related to the volume of habitat available to aquatic biota such as fish. Stream volume has been reported to influence fish community characteristics such as abundance per square meter, species richness and IBI scores (Hall *et al.*, 1999).

(Biron et al., 2004) - Paired current deflectors are structures that are installed on each bank of a river to locally reduce the width of the channel, thereby creating flow acceleration and promoting scouring.

(Wright and Jones, 2006) – emerging concept of ecosystem engineering by organisms thought to influence bed stability and rates of erosion. Not sure of relevance to vt streams, but if holds indicates a mostly unknown link between biota and bed. For example, net-spinning caddisfly and bed stability (Cardinale et al., 2004).

(Shields et al., 1993) - 1. Incised stream channel aquatic habitats typically are severely degraded. After the primary knickpoints or knickzones have passed, base flows are limited to shallow channels flanked by sandy berms within the enlarged high-flow channel. Riparian vegetation, woody debris and *pool habitat* are in short supply, and stream systems become disengaged from their floodplains.

(Matthaei et al., 1999) – scour/deposition occurred in patch work during flood. Riffle bed moved in top 10 cm so there was ample invert refuge below.

(Kershner et al., 2004) – deeper pools better for fish and less fines in tail of pool.

(Sweka and Hartman, 2006) – pool area and depth are linked to LWD. However, this study did not see pool area increase after LWD additions, the authors hypothesized that the steep and coarse bed streams precluded additional pool formation. Maybe need stratification based on gradient for this variables.

(Chin and Wohl, 2005) – step pool review paper. Step pools where size of bed material (rocks and LWD) are large relative to the channel width. Steps create both plunges and pools, and form tumbling flow that helps energy dissipation in headwaters. Step-pools formed by high magnitude, low frequency storms and adjusted during bankfull and other moderate events. Sediment transported in step pools during high flows has its origins both in mass wasting from the headwater watershed and from transport downstream from upstream pools. Hydraulics in step-pools is highly variables, and mostly a function of form (steps and lwd).

(Kreutzweiser et al., 2005) – lwd needs to be large to form pools.

(White and Brynildson, 1967) – 20-60 cm pool depth important for trout to ensure adequate low flow habitat

(Larson et al., 2001) – another study looking at pool formation with lwd. Limited biological response, and some physical change. pool spacing narrowed after LWD installation. All urban project sites exhibited fewer pools than has been reported for forested streams. In project reaches where the objective was to control downstream sedimentation, only limited success was observed. Source not patch for bed feature restoration due to continual influence from watershed!

(Hilderbrand et al., 1997) - Pool area increased 146% in the systematic placement in low-gradient streams. Conversely, the high-gradient stream changed very little after LWD additions, suggesting that other hydraulic controls such as boulders and bedrock override LWD influences in high-gradient streams. Wood = pools.

(Rathburn and Wohl, 2003) - Fine sediment dynamics in mountain rivers are of concern because of implications for aquatic habitat, channel stability, and downstream sediment yields. Clogs the interstices of spawning gravels within pools along mountain rivers with impacts to aquatic organisms. Resting and spawning habitat for fish, and invert habitat.

(Stone and Droppo, 1996) – more zinc and lead with decreasing grain size. Has important habitat ramifications for streams with high deposition of fines.

(Landwehr and Rhoads, 2003) – this paper ultimately talks about channel evolution stage III and IV where floodplain formation takes place in wide channels at low elevations via deposition. Deposited layers are mixed, with some coarse grained material, some fines, and even some organics – likely generated after overbank floods and deposition of soil. These bars are also vegetating with grasses, indicating the importance of getting some organic soil into the river and onto forming floodplains. The study found the most diverse fish assemblages in the channel with depositional features leading to new floodplain creation as compared to wide, featureless channels.

(Fryirs and Brierley, 2001) – sediment storage related to geomorphic types and thus valley control. Rehabilitation potential largely linked to sediment sensitivity to change.

8.4 Channel Morphology (Width/depth ratio, entrenchment and incision ratio, channel alteration)

Initial Variables Researched

Width/Depth ratio: Bankfull width divided by mean bankfull depth obtained during cross section and channel measurements.
Entrenchment and Incision ratios: ER equals the floodprone width (i.e., width at 2x maximum bankfull depth) divided by the bankfull width and IR equals the low bank height by the maximum bankfull depth. Measurements made from cross section and channel measurements.

Channel alteration: Identification of dredging, straightening, bar scalping/gravel mining, and other direct alterations to the channel.

Summary

Channel morphology is virtually synonymous with aquatic habitat given that morphological form and processes describe channel stability, sensitivity to change, and anticipated future trajectory. Habitat quality and heterogeneity were closely tied to stream stability, with geomorphically stable reaches supporting better habitat and more EPT macroinvertebrates than unstable reaches (Sullivan et al., 2004b). In this study, channel overwidening process (i.e., large w/d ratio) correlated to embeddedness+, flow status-, bank stability- and vegetative cover-. Clarke et al. (2003) advocate and eco-hydromorphic approach to river restoration where spatial and temporal heterogeneity are key aspects of a system where natural processes can take place. Channel morphology is not only the product of on-going river processes, but related to watershed land use. For example, some forested river corridors have been shown to have high w/d ratios, where shallow coarse substrates have increased aeration and thus higher intra-gravel DO. Several studies have identified channel morphology to be "drivers of physical habitat quality for aquatic species" in urban streams (e.g., Booker, 2003). Sullivan et al. (2004a) found channel morphology to be correlated to fish IBI score. The quality of spawning gravels (i.e., cleaner gravels with more DO) for Atlantic salmon has also been related to various aspects of channel morphology (Coulombe-Pontbriand and LaPointe, 2004).

Width/depth ratio is a fundamental dimensionless indicator of channel size and general shape. Numerous studies have shown the importance of channel width and depth to habitat quality. Variation in width is essential for creating heterogeneous habitat form such as found in riffle-pool systems that help create diverse patterns of local hydraulics (Thompson and Hoffman, 2001). Early habitat models such as the river continuum concept (Vannote et al., 1980) identified expected communities based on channel width and depth, and now it is clear that deviation from expected width and depth for a stream of a given geomorphic type is useful for exploring habitat quality (DAngelo et al., 1997). Kemp et al. (1999) use water depth-velocity to describe habitat diversity and prescribe improvements with restoration.

Width/depth ratio is indicative of fundamental aspects of river channels. Width/depth ratio correlated best with discharge in mountain streams (Wohl et al., 2004). Width/depth ratio, velocity, and bank stability, were related to watershed influences of both land cover and geologic setting (Fitzpatrick et al., 2001). In a study of small stream in WI, width was found to be an important factor for predicting stream water temperature (Gaffield et al., 2005). Svec et al. (2005) used width/depth ratio, entrenchment ratio, and slope to improve prediction of flow duration (ephemeral, intermittent, or perennial). Width/depth ratio is also related to the effectiveness of obstructions to induce scour in step-pool systems (Buffington et al., 2002).

In addition to correlations with variables describing physical processes, width/depth ratio is often related to biological assemblage diversity and abundance. Width/depth ratio was correlated to total biomass and density of brown trout (Baran et al., 1993). The location of Apache trout could be predicted with a set of variables that included width/depth ratio (Cantrell et al., 2005).

While comparing the visual assessments used by the USEPA, USDA, and BLM (i.e., RBP, SVA, and PFC), Ward et al. (2003) found that site characteristics (entrenchment ratio, substrate size, channel width

to depth and slope) were significantly associated with assessment outcomes. The authors then stratified by Rosgen type to control for the effect of these site-specific effects on assessment outcome to better allow for comparison of riparian/stream health assessments across streams. This paper illustrates the necessity of stratification by stream type in order to assess habitat health, or departure from the expected conditions given the watershed, valley, river corridor, and channel conditions expected. In predicting whether a channel would be stable, aggrading, or degrading, Doyle et al. (2000), present a potential additional means of stratification as habitat quality and potential will vary based on the fundamental geomorphic process taking place at a site.

The search of the scientific literature revealed no papers addressing the variable incision ratio. Although used frequently in the stream assessment community, incision ratio is a valuable inclusion in the RHA that offers a more detailed, depth-based, understanding of where a channel is sitting with relation to its top of bank and floodplain than offered from entrenchment ratio alone. As the research moves towards existing habitat protocols and setting thresholds, an effort will be made to find more information on incision ratio.

The identification of channel alterations (i.e., dredging, straightening, bar scalping/gravel mining, and others) is a clear choice for a raw variable to help assess the channel morphology parameter while scoring habitat quality. Countless studies and texts present evidence on the various types of impairments associated with channel alteration. In his book *California Rivers and Streams*, Mount (1984) presents overviews of human-induced changes to river systems.

Gravel excavation fundamentally changes channel morphology as sediment starved water has more erosive force (Kondolf, 1997; Kondolf et al., 2001). The effects of mining gravel can last for very long time periods once initiated adjustment processes are under way. Gob et al. (2005) saw bedload mobilization take place at less than half of the bankfull flow as unconsolidated material was prone to movement. Sediment transport and sorting changes led to the undeveloped bed features and a reduction of habitat quality. Incision and access to floodplain were main problems following gravel mining. Similar effects have been seen flowing hydraulic mining for minerals as well (James, 1999), where sediment and stage-discharge relationships are altered. Morris et al. (2006) saw channel morphology to be correlated well with the degree of channel dredging.

Channelization impacts stream channels in a negative way. CPOM retention decreases, ultimately changing the channel structure and productivity (James and Henderson, 2005; Lepori et al., 2005). Straightened channels tend to lack features such as backwaters and inundated habitats that are essential refugia for invertebrates and fish during floods (Negishi et al., 2002). Channelization and gravel mining often result in incision following headcut movement, which can reduce habitat heterogeneity, increase instability, eliminate floodplain access, and shift fish community structure (Shields et al., 1998). Landwehr and Rhoads (2003) highlight the impacts associated with the aggradational features created from channelization. Channelization was the variable that mostly influenced fish assemblage health (IBI) (Sullivan et al., 2004a). Straightening and smoothing of channels was performed to prepare streams for efficient transport of harvested logs, which had a detrimental impact on habitat that can be irreversible over long time periods in some instances (Nilsson et al., 2005).

The armoring of banks impacts channel morphology via laterally fixing meander bend migrations. This indicates that channel morphology is closely linked to lateral connectivity, via armoring and incision. In addition to channel morphology, riprap influences channel evolution, water chemistry and biology in a variety of ways (Fischenich, 2003). "Streambanks with riprap have fewer undercut banks, less low-overhead cover and are less likely than natural stream banks to contribute large woody debris to the stream" (Schmetterling et al., 2001). Although riprap has been shown to have some benefits to juvenile fish in severely degraded streams, it impairs habitat for other age classes.

Variable Confirmation and Potential Revisions

The 'Channel Morphology' parameter (8.4), as evaluated based on width/depth ratio, entrenchment and incision ratio, and channel alteration is essential for proper description of habitat. Juvenile Salmonid cover, YOY Salmonid cover, macroinvertebrate cover, spawning substrates, allochthonous production, autochthonous production, winter habitat, and summer habitat were added to the existing links table (see below). With those additions, channel morphology has some connection to virtually every ecological attribute and aquatic life cycle function in an aquatic ecosystem.

Based on the scientific literature, the 'Channel Morphology' parameter is a good representation of channel shape, process, and disturbance. The present variables include measures of channel width and depth, floodprone width, bank height, and channel alterations. No specific geomorphic variable was identified in the literature that repeatedly was discussed to be more important to habitat than w/d and ER. A review of other channel morphology variables in the phase 2 field notes also did not reveal potential additions.

The research on the channel morphology confirmed the need for stratification to create an adequate RHA. Beyond stream type (i.e., Schumm's or Rosgen's), an RHA could also be created for dominant processes (stable, aggrading, degrading). An RHA for each of these stream types will then identify departure from expected conditions. The dominant process would likely adjust the thresholds as habitat potential would be dictated by current process. Furthermore, the research on channel morphology suggests that the level of channel incision is another way to stratify observation streams, due to important changes in habitat associated with the level of floodplain access, hyporheic exchange, and bed feature formation. (More on this to come during the next tasks.)

Linking Channel Morphology to Physical Processes and Habitat Components

Key Ecological Attributes (Physical Processes)	
Longitudinal Connectivity	
Riparian/Floodplain Connectivity	Entrenchment,incision, floodplain inundation frequency.
Sediment Regime	Erosion/aggradation after incision, bars, bed features.
Hydrologic Regime	Effective discharge, flood timing, in-corridor storage.
Temperature Regime	Channel width, bank stability, vegetation.
Large Wood / Organics Regime	Channel roughness increases retention, inputs from buffers.
Aquatic Life Cycle Requirements (Habitat Components)	
Adult Salmonid Cover	Diverse and stable bed features, channel stability.
Juvenile Salmonid Cover	Diverse and stable bed features, channel stability.
Y-O-Y Salmonid Cover	Diverse and stable bed features, channel stability. Refuge.
Macroinvertebrate Cover	Diverse and stable bed features, channel stability.
Spawning Substrates	Clean, stable gravels. High DO.
Spawning Migration	
Temperature Refugia	Channel diversity and roughness. Diverse bed features
Allochthonous Production	Incision dictates delivery rates.
Autochthonous Production	CPOM retention and processing based on channel conditions.
Winter Habitat	Diverse and stable bed features, channel stability.
Summer Habitat	Diverse and stable bed features, channel stability.
Habitat Complexity	
Disturbance Regime	Intermediate disturbance for maintenance. Channel stability.
Habitat Heterogeneity	Diverse bed features and channel refugia.

Research Notes

(Sullivan et al., 2004b) - Habitat quality and heterogeneity were closely tied to stream stability, with geomorphically stable reaches supporting better habitat than unstable reaches. Geomorphic and habitat assessment scores were highly correlated. Percent EPT correlated with the overall habitat assessment scores as well as with individual measures of geomorphic condition and habitat quality, but invert densities did not differ between stable and unstable. May be some issues on study design here, but study suggests that channel morphology influences macroinvertebrates. Channel overwidening (large w/d) correlated to embeddedness, flow status, bank stability, and vegetative protection. Key aspect of this paper for new RHA is that it suggests the types of impairment differ for four geomorphic adjustment processes observed (i.e., degradation, aggradation, overwidening, and planform). We should at least stratify by two adjustment process groups per channel type to set appropriate thresholds.

(Weigel et al., 2003) – "forest-dominated catchments corresponded with high dissolved oxygen, width/depth, number of instream logs and shade. Sites with high width/depth, or shallow sites, have increased aeration if the substrate is coarse. This greater width/depth may be directly related to high dissolved oxygen levels." Saw close relationships between width/depth ratio and riparian land cover (i.e., amount of forest).

(Clarke et al., 2003) – "Consistent with the ethos of the Water Framework Directive, an eco-hydromorphic approach to river restoration is proposed here. This approach views spatial and temporal heterogeneity as fundamental characteristics of fluvial systems and advocates recreating a framework within which natural processes, such as sediment transport and nutrient dynamics, can occur."

(Booker, 2003) – "In urban rivers, flow regime and channel morphology are the drivers of physical habitat quality for aquatic species."

(Thompson and Hoffman, 2001) – riffle-pool important habitat features via variation in width. Increase channel heterogeneity. This study predicts pool size and relates it to channel characteristics in and above the pool. Upstream channel with is important to pool size, as is exit slope and width expansion. Local hydraulics are also important.

(Kemp et al., 1999) - use depth-velocity occurrence matrices for each functional habitat to predict changes due to physical restoration. Suggests importance of flow depth, and its proportion to width.

(DAngelo et al., 1997) – note the importance of confinement and width/depth ratio to habitat quality. Confinement seems to be mentioned in order to stratify habitat, implying one would expect different habitats in confined versus unconfined streams. The potential for change and future trajectory is certainly different based on CEMs. One interesting point related to channel morphology is that it served as the basis for early habitat models. The river continuum concept (Vannote et al., 1980) is ultimately stratified by channel size and watershed location. Thus, in our initial stratification there will be geomorphic consideration for stream types, and then we zoom in to a smaller scale to see if the variables for that type depart from expected conditions.

(Wohl et al., 2004) - width/depth ratio correlate best with discharge in mountain streams.

(Fitzpatrick et al., 2001) – reach-scale characteristics, such as width/depth ratios, velocity, and bank stability, were related to watershed influences of both land cover and geologic setting.

(Baran et al., 1993) - Width/depth was related to total biomass and total density of brown trout.

(Cantrell et al., 2005) - larger width, lower width : depth ratio, more eddy flows, and more cover in the form of overhanging vegetation, debris, and boulders were significant predictors for locations of Apache trout in mountain streams.

(Buffington et al., 2002) - Effectiveness of obstructions to induce scour in step pool systems also depends on channel characteristics, such as channel gradient, width:depth ratio, relative submergence (ratio of flow depth to grain size), and the calibre and rate of bed material supply. (Note that this author helps clarify the original language used in the RHA regarding scour and depositional features.)

(Gaffield et al., 2005) – stream width found to be important factor to predicting small stream temperature for managing cold water fisheries in WI.

(Sullivan et al., 2004a) – found channel morphology to be correlated to IBI score. Morphology is a component of the QHEI.

(Coulombe-Pontbriand and LaPointe, 2004) – Fines and morphology of spawning reaches may be a significant factors controlling the intensity of inter-gravel flow through redds and the consequent selection of spawning sites for Atlantic salmon in Canada.

(Svec et al., 2005) – Ultimately used width:depth ratio, entrenchment ratio, and slope to predict flow duration (ephemeral, intermittent, or perennial). Much better than the blue line from USGS topo.

(Ward et al., 2003) – while comparing the rbp, sva, and pfc visual assessments found that site characteristics (Entrenchment ratio, substrate size, channel width to depth and slope) were significantly associated with assessment outcomes. This presents a problem since these are not always indicative of riparian/stream health, but of channel type. They stratified by Rosgen type to control for the effect of these site-specific effects on assessment outcome, allowing for comparison of riparian/stream health assessments across streams.

(Doyle et al., 2000) – looked at predicting stable, aggrading, or degrading channels. Quantitave methods better than qualitative ones. Likely good way to stratify RHA per given channel type. 5 channel types x 3 dominant processes = 15 forms? (need to get this paper in library)

(Moody and Troutman, 2002) – found that correlation between Q (DA) and W and D scale with integral distance (the distance downstream between cross sections). This has important effects for hgr use, and illustrates variability in morphology below the scale typically employed. Robust statistics due to large data set.

(Gob et al., 2005) – gravel extraction fundamentally changes geomorphology. Bedload mobilized at 0.4 bankfull discharge rate. Depth is lower. Habitat fundamentally changed as sediment sorting and bed development features changed. Incision was a main difference, limiting access to flooplain.

(Kondolf, 1997; Kondolf et al., 2001) – gravel mining (and dams) create sediment starved water. Main result is incision, destabilization of bed and its features, and coarsening of bed material and loss of good spawning gravels. Geomorphology changed as sediment continuity off balance.

(James, 1999) – hydraulic mining increases sediment load and knocks streams out of equilibrium. "Systematic changes in stage-discharge relationships reflect channel morphological changes that are relevant to flood risk assessments, stability of engineering structures on floodplains, and geomorphic interpretations."

(Negishi et al., 2002) - The lower persistence of the macroinvertebrate assemblage in the channelized sections during floods was attributable to the lower availability of flow refugia such as backwaters and inundated habitats. Lateral heterogeneity of stream channels should be considered in stream restoration and management.

(James and Henderson, 2005) – stream straightening substantially changed CPOM type and retention that ultimately influences stream structure and productivity.(Lepori et al., 2005) saw this as well.

(Shields et al., 1998) – "Channel incision has major impacts on stream corridor ecosystems, leading to reduced spatial habitat heterogeneity, greater temporal instability, less stream-floodplain interaction, and shifts in fish community structure." Creating complexity via wood and rock structures improved habitat via increased pool depth and useable area in formerly aggradational parts of the stream.

(Morris et al., 2006) – channel morphology correlated well with the degree of channel dredging.

(Davies et al., 2005) – headwater clear cutting streams had more logs, were more entrenched, and less complex morphologically, with a lower proportion of pools and bars, than control streams.

(Nilsson et al., 2005) – Log driving led to many impacts associated with straightening, smoothing, and daming to build up head for moving timber. This study suggests that returning some of the roughness and complexity to the channel is the way to go about rehabilitation. "The geomorphic and hydraulic/hydrologic alterations are supposed to favor production, diversity, migration and reproduction of riparian and aquatic organisms." Large boulder fields, outcrops, and big log jams are difficult to ultimately return as the processes to create these features have been altered.

(Landwehr and Rhoads, 2003) – covers the depositional processes following channelization, to accompany the better-known erosional processes. Looked at a farm ditch and saw incision after straightening and then bar formation as the channel regained some sinuosity and access to floodplains. The authors suggest that allowing the ditch to meander and create floodplain will allow it to be more stable, improving drainage function and habitat quality.

(Sullivan et al., 2004a) – channelization was the main variable that influenced fish IBI.

(Schmetterling et al., 2001) - Riprap may provide some habitat in severely degraded streams, but it does not provide the intricate habitat requirements for multiple age classes or species provided by natural vegetated banks. "Streambanks with riprap have fewer undercut banks, less low-overhead cover and are less likely than natural stream banks to contribute large woody debris to the stream." Bank armoring influences channel geomorphology as the natural process of lateral migration is not permitted to take place so energy dissipation takes on other forms.

(Fischenich, 2003) – bank armoring effects channel morphology, evolution, chemistry, and biology in many ways.

8.5 Hydrologic Characteristics (wetted width/bankfull width, substrate exposure, adjacent water features, flow alterations)

Initial Variables Researched

Wetted width/bankfull width: Current wetted channel width divided by bankfull width from cross section and channel measurements.
Substrate exposure: Estimate amount of substrate not under water.
Adjacent water features: Identify nearby springs, seeps, or wetlands (abundant, some, none)
Flow alteration: Identify known changes to flow (withdrawals, land use, extreme morphology).
(Note that flow status is identified as low, moderate or high in phase 2)

Summary

The links between hydrology, hydraulics, channel morphology, physical habitat, and biological populations are clear in the relevant scientific literature. Instream flow studies explore criteria for organisms in the channel, but also incorporate geomorphic change and habitat quality. Flow and sediment are the primary variables for rivers (Lane, 1955), and thus it is not a surprise that flow is a good indicator of habitat type and biodiversity potential (Harper et al., 2000) and flow restoration is a key issue for improving river biota (Strange et al., 1999). Flow variation leads to morphological change (Gaeuman et al., 2005; Thompson, 2006), adjustment of nutrient cycling and habitat type (Pusch and Hoffmann, 2000), and variations in the direction and magnitude of hyporheic exchange (Brunke and Gonser, 1997). Barrineau et al. (2005) showed the importance of flow status on winter trout habitat as groundwater surface water interactions influenced the availability of ice-free habitat.

The frequent use of flow-based methodologies to determine habitat suitability for fish (i.e., IFIM, PHABSIM, MESOHABSIM) have clearly illustrated flow preferences and requirements (e.g., Strakosh et al., 2003). Low flows frequently impair Salmonid populations, and in particular stress juveniles (Bowen et al., 2003). Lotic fishes switch from shallower, high-velocity habitats in summer to deeper, low-velocity habitats in winter, and use shallower, low-velocity habitats during periods of high discharge (Gillette et al., 2006).

Macroinvertebrates have been shown to have a close relationship to hydrology and hydraulics. Depth-velocity criteria were established for macroinvertebrates where EPT taxa were related to water velocity, depth and substrate (Gore et al., 2001). Merigoux and Doledec (2004) saw the distribution of nearly 70% of the macroinvertebrate taxa collected to be significantly related to hydraulic parameters.

As the primary background variable in flowing water systems, flow has been used as a composite indicator of change due to urbanization (Booth et al., 2004). "Dense human settlements, commercial and industrial centers, and transportation corridors in urban areas influence every attribute of stream ecosystems: the paths, timing, and volume of runoff that generates streamflow; the supply and size of sediment and organic material delivered to stream channels; the thermal and chemical characteristics of stream water; the structure, form, and materials of stream channels and aquatic habitats; and the demographics of the biological populations forming stream and riparian communities. Ecological

restoration may not be feasible for most urban streams as some elements of stream ecosystems cannot be re-established in urban areas, while others can only be re-established to a limited degree or geographic extent." (Konrad, 2003)

Although the importance of flow to habitat is clearly established in the literature, relatively little information exists on variables to be used in rapid assessment work. In fact, the ratio of wetted width to bankfull width was not encountered once in the peer-reviewed literature. This parameter offers a dimensionless measure of useable habitat area that incorporates hydrology and channel morphology. Ultimately, substrate exposure indicates the surface area of habitat that is useable for aquatic organisms. In general, less bed is equal to less habitat. Furthermore, of the available bed, organisms have ideal habitat that influences their abundance and community composition. For example, in the Farmington River in Connecticut, brown trout prefer to hold in a depth of 0.6-1.2 m, stay within 0.2 m of the bed, and to swim in a 0.1 to 0.4 m/s velocity (Strakosh et al., 2003). Mullner and Hubert (2005) modeled maximum July water temperature using perennial stream length, wetted width, and midrange basin elevation as independent variables. The use of wetted channel width clearly indicates its importance to habitat, and in this case temperature regime. In the review of bankfull width it was clear that this variable is important to many habitat aspects including flow duration, bank stability, temperature regime, and others that influence biota.

The presence of adjacent water features such as nearby springs, seeps, or wetlands can aid in determining flow status. Knighton and Nanson (1994) used waterholes to study floodplain dynamics in anastomosing channels that originated due to cohesive glacial deposits. The presence of springs, weeps, and wetlands not only indicate flow levels, but can also add information to bank stability questions as pore pressure changes due to water flow from banks can reduce stability (see research on bank cover).

Flow alterations influence virtually every aspect of a river, as discussed above in the alteration of hydrology and thus all other components of aquatic ecosystems. Alterations can be as straight forward as a withdrawal of water or as complex as changes due to land cover. Land use is closely correlated with hydrology and thus identification of both watershed and river corridor land use activities are important for full understanding of potential flow alterations. For example, farming (Allan et al., 1997), logging (Lewis et al., 2001), and urbanization (Booth et al., 2004) have all been shown to influence system hydrology. More studies are showing the need for multi-scale land use management where river corridor land use influences habitat and local features, while watershed land use effects large scale geomorphic trends and water quality (Black et al., 2004; Potter et al., 2004; Schiff and Benoit, 2006 (in review)). Flow alteration can also take place due to extreme geomorphology such as incision, aggradation, and channel avulsions.

Variable Confirmation and Potential Revisions

The 'Hydrologic Characteristics' parameter (8.5), as evaluated based on wetted width/bankfull width, substrate exposure, adjacent water features, and flow alterations aptly represents flow status. Based on the research on these raw variables and the changes in habitat with flow status, longitudinal connectivity, riparian/floodplain connectivity, sediment regime, adult Salmonid cover, juvenile Salmonid cover, YOY Salmonid cover, allochthonous production, winter habitat, summer habitat, and habitat heterogeneity were all added to the existing links table (see below). With those additions, flow status indicates some aspect of every ecological attribute and life cycle requirement of the system considered here.

It is a bit surprising that minimal work has been done on trying to assess flow status, event though there is a clear link between flow status and aquatic ecosystem structure and function. The literature seems to suggest that hydrologic analysis from gauge data and other field measurements are essential, and thus the implication is that rapid assessment may not be preferred. Nevertheless, flow status, as used in the EPA-RBP (Barbour et al., 1999), is important to include in the new RHA given the fundamental link to many characteristics of flowing water habitats.

A possible addition to the 'Hydrologic Characteristics' parameter is to try and incorporate a temporal aspect to capture the dynamics of the flow status even though a 'snapshot' observation is being made. Observations during low flow would show poor substrate coverage, while those at higher flows would show better substrate coverage. Normalizing by bankfull width, as is done for wetted channel width, is one way to do this as thresholds can be set that underscore stream type and typical inundation patterns. Perhaps the exposed substrate raw data can be converted to a percentage range of exposed substrate within the bankfull channel to better frame this variable in a geomorphic context.

Identification of flow alterations seems critical to proper assessment of flow status, and the potential changes to the dynamic hydrology of the system. Flow status in terms of how full the bank is and how much the substrate is covered is truly a response of this altered watershed hydrology and channel adjustment. Recent literature also cites the importance of land use in the river corridor, and thus a raw variable may want to be used to represent this mechanism of flow alterations. Transportation corridors, agriculture, silviculture, and urbanization are especially problematic for a river if they are present close to the channel. Focus on river corridor land use could be incorporated into the variable representing the presence of water features such as springs, weeps, and wetlands. These indicators of hydrology are alone not frequently mentioned in the literature with regard to flow condition, and thus expanding this variable could be justified.

One topic that was frequently mentioned in the literature that is not addressed in this parameter is the presence of and connection to hydrologic and hydraulic flow refuge. Several studies showed that in times of low flows or floods fish and macroinvertebrates retreat to less stressful locations typically located away from main channel currents and in side channels, deep pools, or pockets/crevices with relatively low flow velocities. Even if flow status is poor in a given site, if there is access to habitats with better flow status than fish will likely move there and macroinvertebrates could initiate drift or move a short distance along the streambed to access better habitat. Consideration should be given to incorporating a raw variable that describes access to quality habitat with good flow status.

The importance of flow status, or 'Hydrologic Characteristics', as a fundamental aspect of rivers suggests that it may be best to present this parameter first in the sequence, since it is likely a driver of other parameters. In fact, all of the parameters are closely dependent on hydrology. At this point it seems hydrology and channel morphology should be the first two parameters in the RHA.

Linking Hydrologic Characteristics to Physical Processes and Habitat Components

Key Ecological Attributes (Physical Processes)	
Longitudinal Connectivity	Access to flow refuge.
Riparian/Floodplain Connectivity	Access to near-bank habitat, and cover. Floodplain connection.
Sediment Regime	Erosion and deposition change with flow.
Hydrologic Regime	Direct indicator of system and local hydrology.
Temperature Regime	Flow depths, turbulence.
Large Wood / Organics Regime	Inputs, processing, and transfer of organics.
Aquatic Life Cycle Requirements (Habitat Components)	
Adult Salmonid Cover	Access to quality holds, eco-hydraulics.
Juvenile Salmonid Cover	Developmental pressures and access to suitable habitat.
Y-O-Y Salmonid Cover	Developmental pressures and access to suitable habitat.
Macroinvertebrate Cover	Bed area, hydraulics, refugia.
Spawning Substrates	Bed area, hydraulics.
Spawning Migration	Habitat connectivity, movement cues, temperatures.
Temperature Refugia	Flow depths, hydraulics.
Allochthonous Production	Access to bank and riparian areas for inputs.
Autochthonous Production	Instream processing, connectivity, abrasion.
Winter Habitat	Ice free holds, temperature regulation.
Summer Habitat	Temperature regulation, cold-water holds.
Habitat Complexity	
Disturbance Regime	Hydraulic refuge, frequency of floods and low flows.
Habitat Heterogeneity	Flow complexity, hydraulics, cover.

Research Notes

(Gore et al., 2001) – instream flow not only important for fish, but for macroinvertebrates as well. Beyond phabsim work for fish, inverts offer means of assessing the adequacy of instream flows for benthic organisms, and in this study the inverts were a key bottleneck for fish. Depth-velocity important for near-bed biota. They create habitat suitability curves for ept and invert diversity as a function of velocity, depth, and substrate.

(Pusch and Hoffmann, 2000) – flow abstraction and minimum flow requirements while re-filling groundwater aquifers following mining. Flow reduction influences almost every aspect of the river including nutrient cycling, geomorphology, and habitat. More light penetration, macrophytes, and lower DO are discussed. Used ecologically based summer/winter flow requirements to set flow standards.

(Strange et al., 1999) – flow restoration central issue for improving river biota.

(Harper et al., 2000) – flow is a good indicator of habitat type and biodiversity potential.

(Brunke and Gonser, 1997) – hyporheic zone important location for water exchange and habitat refuge.

(Thompson, 2006) – pool dimensions change and geomorphology with flow decrease.

(Gaeuman et al., 2005) – flow variations lead to complex morphology changes, that directly influence biota. See combination of degradation and aggradation over different bed particle sizes. Dynamics are important.

(Booth et al., 2004) – hydrology is key for urban stream restoration as it is the sum of primary impacts such as tia, withdrawals, and more. Improvement of flow regime and the river corridor condition are top priorities for rehabilitation.

(Merigoux and Doledec, 2004) - The distribution of nearly 70% of the taxa collected was significantly related to the hydraulic parameters assessed. Flow and hydraulics are essential for habitat, and this study shows that hydraulic structure has a direct influence on macroinvertebrates.

(Konrad, 2003) - "Dense human settlements, commercial and industrial centers, and transportation corridors in urban areas influence every attribute of stream ecosystems: the paths, timing, and volume of runoff that generates streamflow; the supply and size of sediment and organic material delivered to stream channels; the thermal and chemical characteristics of stream water; the structure, form, and materials of stream channels and aquatic habitats; and the demographics of the biological populations forming stream and riparian communities. Ecological restoration may not be feasible for most urban streams as some elements of stream ecosystems cannot be re-established in urban areas, while others can only be re-established to a limited degree or geographic extent." Like reference to island bio-geography as low flows can isolate good habitats.

(Bowen et al., 2003) – low flow areas important for juvenile fish influenced by hydrology and hydraulics. Too little flow can disrupt fish biology.

(Strakosh et al., 2003) – brown trout habitat suitability criteria based on water depth, fish depth, mean velocity, and nose velocity.

(Knighton and Nanson, 1994) – in anastomosing channels, waterholes in floodplain indicative of flow status. Formed on creek due to geology – cohesive banks.

(Barrineau et al., 2005) – trout use in winter influenced by groundwater interactions that influenced ice levels. Flow status important for winter habitat!

(Mullner and Hubert, 2005) – Created model predicting maximum July water temperature (MJT) from perennial stream length, wetted width, and midrange basin elevation. Flow status clearly important to summer habitat and this was related to Salmonid use of habitats.

(Gillette et al., 2006) - lotic fishes switching from shallower, high-velocity habitats in summer to deeper, low-velocity habitats in winter, and of using shallower, low-velocity habitats during periods of high discharge. In terms of flow status, these various habitat types need to be present to be sure to have access to refugia.

8.6 Connectivity (reach blockage)

Initial Variables Researched

Reach blockage: Aquatic species, sediment, organic matter qualitative assessment

Summary

Dams are the primary obstructions discussed in the scientific literature, and specifically the alteration of natural flow regime, with respect to migration barriers in rivers. Dams tend to generally homogenize natural flows via increasing low flows and decreasing peak flows downstream of an impoundment (Magilligan and Nislow, 2005). However, the variability of low flow events has been shown to increase as well (Stanford et al., 1996). The increase in smaller flows can have profound effects on habitat as the potential exist to increase the number of effective discharges that has been shown to lead to channel widening, changes in bed features, and an increase in gravel bars (Assani and Petit, 2004). Thus, through changes in morphology via hydrologic modification, habitat is significantly altered downstream of dams.

The discontinuities created via dams, other barriers, and even geomorphic changes associated with tributary confluences have been conceptualized in the serial discontinuity concept (SDC) (Ward and Stanford, 1995a). "According to the SDC, dams result in upstream-downstream shifts in biotic and abiotic patterns and processes; the direction and extent of the displacement depend on the variable of interest and are a function of dam position along the river continuum" (Ward and Stanford, 1995a). "Stream regulation reduces annual flow amplitude, increases baseflow variation and changes temperature, mass transport and other important biophysical patterns and attributes. As a result, ecological connectivity between upstream and downstream reaches and between channels, ground waters and floodplains may be severed. Native biodiversity and bioproduction usually are reduced or changed and non-native biota proliferate" (Stanford et al., 1996).

Dams block the flow of sediment. "The continuity of sediment transport is interrupted by dams or removal of sediment from the channel by gravel mining, the flow may become sediment-starved (hungry water) and prone to erode the channel bed and banks, producing channel incision (downcutting), coarsening of bed material, and loss of spawning gravels for salmon and trout (as smaller gravels are transported without replacement from upstream)" (Kondolf, 1997). Clearly dams alter habitat for fish and other aquatic organisms beyond being a barrier to migration and local movement. Pizzuto (2002) described the profound changes to channel morphology associated with dams that include alteration of channel evolution, form, and dominant processes.

With the alteration of flow of water and sediment, changes in geomorphology, and resultant change in habitat, dams impair biological communities. As a barrier to movement, dams limit populations as the full range of life cycle functions can not be performed. Dams tend to result in the extinction of several historic species as they can no longer access spawning grounds (Gehrke et al., 2002). The authors go on to indicate that the movement of juveniles is a primary problem around dams. A study of spotted char (Morita and Yamamoto, 2002) showed that population sizes were smaller upstream of dams. In addition, the disappearance of more species upstream of dams was related to increasing isolation period, decreasing

watershed area (i.e., habitat size), and decreasing gradient. This finding indicates that fish will eventually go extinct if fish passage is not restored via dam removal or fish ladder.

Although the movement of anadromous salmonids and other fish is a main thread of literature on dams, it has been shown that dams impact all trophic levels. Tiemann et al. (2005) observed a reduction of EPT taxa by small dams, which the decline was correlated with velocity and % gravel. Dams have also been observed to influence primary productivity via trapping of organic material and nutrients (Snyder and Minshall, 2005). Macroinvertebrates and fish did not have ample food to support large populations. The combination of serving as a barrier and initiating departure from natural channel form and process leads to habitat changes associated with dams that ultimately limit biological populations.

Flow restoration and fish passage are two types of restoration favored when dam removal is not feasible. Flow restoration is a common goal for regulated rivers (Bragg et al., 2005). Richter et al. (1996) present the indicators of hydrologic alteration method where ecologically important flow distribution variables are set for recovery. In terms of dams, it is important to consider the downstream distance of effects and potential for recovery (Stevens et al., 1997).

The habitat changes that can be started with dam construction can sometimes limit habitat even after dam removal (Doyle et al., 2005). For example, a channel that responds to a dam by incising and widening can not reverse its evolutionary track once the dam is removed. Granted the barrier to movement will be addressed, yet recovery is not a given. Geomorphic condition is an essential component of dam removal to better understand the potential for recovery (Doyle et al., 2005). For example, Stanley et al. (2002) saw rapid geomorphic change and habitat improvement in a drained impoundment following dam removal, however downstream reaches showed little geomorphic and ecological response. Thomson et al. (2005) saw some decline in macroinvertebrates and small aquatic plants downstream of a small dam removal for a year during which sediment was being eroded from the former reservoir.

Variable Confirmation and Potential Revisions

The ‘Connectivity’ parameter (8.6), as evaluated based on reach blockage represents local physical blockages for sediment, organisms, and debris. Based on the research and the changes in habitat with connectivity, large wood / organics regime, spawning substrates, autochthonous production, and habitat heterogeneity were all added to the existing links table (see below).

The proximity to barrier was noted as an important feature for habitat, and could add to this parameter. Although potentially not directly a function of migration barrier and movement blockage, it could serve useful to the characterization of habitat to know how close the site under study is to a barrier. This could inform the RHA about potential for disrupted flow, sediment transport, and debris movement that influence local habitat. At larger spatial scales, it may serve useful to know a density of barriers in the system being assessed. This could be important for setting thresholds that are species specific. For example, Bettinger and Bettoli (2004) found that brown trout can move more than 5 km to spawn in fall, and 2-5 km other times. Several barriers within 5 km could reduce a population’s ability to reach ample spawning sites. A density of barriers would serve as a larger component of this parameter. Finally, the effects of barriers vary based on their size and whether they are natural or artificial, so including a potential variable to indicate ‘naturalness’ could add to this parameter. In summary, the refined

connectivity parameter could include three variables: a. reach obstruction abundance and distance to closest, b. stream barrier density, and c. size and natural or man-made.

Linking Connectivity to Physical Processes and Habitat Components

Key Ecological Attributes (Physical Processes)	
Longitudinal Connectivity	Barrier to movement of organisms, sediment, and debris.
Riparian/Floodplain Connectivity	
Sediment Regime	Blocks sediment, scour downstream.
Hydrologic Regime	Changes in effective discharge, general flow homogenization.
Temperature Regime	Heating for small dams, cooling for hypolimnon release for larger.
Large Wood / Organics Regime	Debris retention.
Aquatic Life Cycle Requirements (Habitat Components)	
Adult Salmonid Cover	
Juvenile Salmonid Cover	
Y-O-Y Salmonid Cover	
Macroinvertebrate Cover	
Spawning Substrates	Bed incision downstream reduces spawning gravels.
Spawning Migration	Migration barriers (natural and anthropogenic)
Temperature Refugia	Changes temperature regime based on mechanics.
Allochthonous Production	
Autochthonous Production	Inputs from upstream trapped. Zone of limited FPOM.
Winter Habitat	
Summer Habitat	
Habitat Complexity	
Disturbance Regime	Homogenization of disturbance/flow.
Habitat Heterogeneity	LWD, bed roughness reduction.

Research Notes

(Magilligan and Nislow, 2005) – dams modify hydrology on small and large rivers. Increases low flows following impoundment and lowers peak flows. Flow homogenization.

(Assani and Petit, 2004) - Reduction in peak discharge, and a significant increase in the number of efficient discharges (0.6 bankfull) leading to a doubling of the width of the channel in 45 years, a reduction in the number of riffles and pools, an increase in the number of gravel bars and islets and an increase in bedrock outcrops in the channel. The reduction of sinuosity and the disappearance of bed differentiation and riffle/pool sequences have produced a diminution of bed roughness and an increase of the competence of the river. Thus relatively small floods can remove the armored layer. Each of these habitat changes has profound impacts on biota beyond the blockage of movement and migration.

(Stanford et al., 1996) – "Stream regulation reduces annual flow amplitude, increases baseflow variation and changes temperature, mass transport and other important biophysical patterns and attributes, As a result, ecological connectivity between upstream and downstream reaches and between channels, ground waters and floodplains may be severed, Native biodiversity and bioproduction usually are reduced or

changed and non-native biota proliferate." Use ecological theory to develop recovery strategy that includes peak flow restoration (floodplain reconnection), base-flow stabilization to revitalize food-webs in shallow water habitats, restore seasonal temperature patterns, maximize dam passage to allow recovery of fish meta-population structure.

(Ward and Stanford, 1995a) – "According to the SDC, dams result in upstream-downstream shifts in biotic and abiotic patterns and processes; the direction and extent of the displacement depend on the variable of interest and are a function of dam position along the river continuum."

(Poole, 2002) – serial discontinuity concept. Indicates the discontinuities at tributaries that can influence water, morphology, and biota. This fluvial landscape theory as differing habitats as a mosaic of patches seems to apply to dams as well. Dams and other barriers create changes in habitat and then some recovery that can be viewed in a geomorphic context.

(Kondolf, 1997) – "The continuity of sediment transport is interrupted by dams or removal of sediment from the channel by gravel mining, the flow may become sediment-starved (hungry water) and prone to erode the channel bed and banks, producing channel incision (downcutting), coarsening of bed material, and loss of spawning gravels for salmon and trout (as smaller gravels are transported without replacement from upstream)."

(Pizzuto, 2002) – dams cause profound changes to geomorphology. Channel evolution is altered due to changes in flow and sediment supply. Aggradation, degradation, bank stability, are all influenced by dams. Removal often leads to upstream migration of a head cut and incision, bank failure, and new floodplains at lower elevations. Looking at dam removal effects of bed morphology and evolutionary track.

(Gehrke et al., 2002) – this study identifies the impacts of dams as barriers for fish. Downstream fish were more abundant than upstream. Several species went extinct as they could not use the fish ladders. Juveniles of many species backed up below the dam.

(Morita and Yamamoto, 2002) – charr study showing "barrier effect" of dams. Spotted char disappearance was promoted with increasing isolation period, with decreasing watershed area (i.e., habitat size), and with decreasing gradient. Indicates that fish will eventually go extinct.

(Stevens et al., 1997) - *Dam-related effects on water clarity, flow and water temperature overrode geomorphological influences on habitat availability.* These results generally support the SDC, in that recovery of the benthos did not take place over distance in this large river ecosystem; however, geomorphological differences in substratum availability between reaches mediated dam and tributary effects on water clarity and benthic AFDM. Distance for recovery is important. May want to include a system estimate of blockages.

(Tiemann et al., 2005) – small dams bad for EPT taxa. Correlated with velocity and % gravel.

(Katopodis, 2005) – interesting rehabilitation tools for fish passage and habitat.

(Snyder and Minshall, 2005) - Dam was retaining significant quantities of nutrients and organic material and phosphorus was limiting periphyton accrual downstream from the reservoir. Lack of autotrophy due to dam and thus macroinvertebrates and fish did not have ample food.

(Richter et al., 1996) – Indicators of hydrologic alteration method where ecologically important flow distribution is set as target for flow recovery.

(Bragg et al., 2005) – hydrologic alteration influences biology. Two studied at differing scales. Biota locally and hydrology in catchment. Emphasize hydrologic variables for recovery and policy.

(Doyle et al., 2005) – dam removal can lead to improvement or not, depending on other disturbances and how degraded system is. Macroinvertebrates had quickest recovery while mussels had longest. The potential for full or partial recovery is likely driven by the sensitivity of particular organisms, the characteristics of the dam removed, and the local geomorphic conditions of the watershed. Important for assessing impacts and potential.

(Stanley et al., 2002) - Thus, dam removal caused relatively small and transient geomorphic and ecological changes in downstream reaches, and apparently rapid channel development to an equilibrium form within the impoundment, associated with both dam removal and the subsequent June flood. These muted changes and rapid recovery likely result from the relatively large channel size and the small volume of stored sediment available for transport following dam removal.

(Thomson et al., 2005) – saw some decline of inverts and small plants downstream following dam removal due to sediment movement.

(Bettinger and Bettoli, 2004) – brown trout tagged and can move more than 5 km to spawn in fall, and 2-5 km other times. Maybe use to set density limits of barriers for dams.

8.7 River Banks (Amount of bank erosion and revetments, abundance of mass failures, bank texture, undercut banks, roots and bank vegetation abundance, near-bank flow status, canopy cover, and vegetation composition)

Initial Variables Researched

Percentage of bank erosion: Length and average height of active erosion between toe and top of slope measured during phase 2. Also measured length/type of revetments (riprap, walls, other)
Abundance of mass failures: One, multiple, or none and height measured during phase 2.
Bank texture: Size of dominant particles on the lower 1/3 and upper 2/3 of bank (between toe and bankfull) measured during phase 2.
Undercut banks: Presence of over hanging bank (angle between water and bank between toe and bankfull is less than 90 degrees), and water depth and stability.

Roots and bank vegetation abundance: Estimate abundance between bankfull and 5' beyond top.
Flow status: Qualitatively assess extent water in contact with banks and depth.
Bank canopy: Percentage of canopy closure over channel (stand in middle) and over channel margin (stand at toe of bank) as estimated during phase 2.
Bank composition: Type of vegetation on bank (bankfull to top of bank plus 5 feet beyond) based on estimation of dominant and subdominant types based on area of coverage.

Summary

Bank stability, cover, and vegetation are closely related and are combined into the 'River Banks' parameter (8.7).

Gravitational and hydraulic forces act on bank material to determine bank stability and erosion rates (Simon et al., 2000). Precipitation and flood events can lead to bank failure via weight increase of bank material, loss of cohesion, seepage reducing frictional strength, toe material entrainment in flow, and wetting/drying. Once banks become unstable, these processes tend to occur for smaller and smaller flow events (Simon et al., 2000).

Banks are stabilized via consolidation of bank sediment, cementing by fines, and binding of the sediment by root masses (Millar and Quick, 1993). Fine root density is important for bank stabilization (Wynn et al., 2004). The authors found that herbs had denser root cover in the upper 30 cm of bank, with finer roots then trees, while there was no detectable difference between root density for herbs and trees at larger depths. Simon and Collison (2002) measured soil strength and found larger increases associated with herbaceous roots than tree roots. In addition to this mechanical strengthening, the authors highlight the hydrologic (not hydraulic) influences on bank stability. In particular, interception, evapotranspiration, near-surface moisture due to increased infiltration, and surcharge due to tree weight all influence bank stability beyond binding by roots (Simon and Collison, 2002). The study showed that during wet periods, the hydrology around trees can have a destabilizing effect on banks, although the roots still work to ultimately increase stability. The implications are that bank stability is dynamic with hydrology and influences erosion processes.

The rate of bank-line retreat is determined by lateral erosion rate, near-bank bed-degradation rate, sediment grain size, and difference between flow depth and bank height (Chen and Duan, 2006). It is clear that bank stability is the ramification of processes at multiple spatial and temporal scales. Near-bank hydraulics and secondary currents contribute to the degree of bank stability (Thorne et al., 1998; Kotoky et al., 2005). Bank stability is a reach-scale indicator linked to riparian and watershed land use (Fitzpatrick et al., 2001). Bank stability is closely related to local bed stability (Millar and Quick, 1993).

Bank stability was used in a recently developed rapid habitat assessment for non-wadeable streams to complement popular wadeable stream methods such as the EPA's RBP (Wilhelm et al., 2005). During their study on habitat and fish population (IBI), Price and Birge (2005) saw unexpected patterns where fish health was the same at control and remediation sites, while habitat as scored via the RBP was worse at the remediation sites. The authors suggest habitat limiting fish populations, and also that protective and riparian vegetation are "key deficiencies in rehabilitation programs" that reduce bank stability and increase the chances of bank erosion. Nerbonne and Vondracek (2001) indicate that the lack of difference

in RBP or IBI scores across buffer types suggests that biotic indicators may not respond to local changes, and **that other factors not measured may be important**, or that greater improvements in watershed condition are necessary for changes in biota to be apparent. These authors recommend grass buffers for promoting bank stability.

Bank stability has been used as an indicator of urbanization (May et al., 1997), to assess the reduction of erosion due to rotational grazing (Lyons et al., 2000), and to track habitat rehabilitation success (Galli, 1998). An increase in the amount of bank erosion and stream width has been linked to a change from bedfast ice and floating ice, where the later physically removes bank material (Best et al., 2005).

Erosion is a natural process, unless excessive due to disturbance, and important to maintaining stable banks and bed. Piegay et al. (2005) advocate using an erodable river corridor concept to give a channel ample room to move laterally. (This seems quite analogous to the FEH work presently taking place in VT.) Erosion is also important for lateral inputs of structural wood habitat (SWH) that are important habitat components (Koehn et al., 2004). This acknowledgement of the importance of some erosion for habitat creation confirms work showing the many impacts associated with bank armoring using riprap such as reduction of bank vegetation, undercut banks, and overhanging cover (Schmetterling et al., 2001). In general, excessive erosion reduces habitat quality via excessive sedimentation, reduced cover, and typically less stable habitat features.

Landslides can degrade aquatic habitat via introduction of large amounts of sediment that can smother features (Vanacker et al., 2003). Spatial and temporal scale of landslides is important to the frequency of disturbance to the channel. Miller et al. (2003) highlight the range of impacts from short term, intense sediment events to initiating changes in channel morphology, destruction of riparian area, change in sediment transport, and increase in solar heating. The authors showed that bull trout presence seemed to be more likely where landslides did not occur. Landslides tend to increase with logging in steep terrain (Miller and Sias, 1998), changes in hydrology and land use (Vanacker et al., 2003), and fire (Miller et al., 2003).

Landslides do not only impair habitat, but can also supply rivers with important habitat components. Former landslide areas were shown to be important for prediction of steelhead redds as the slides introduced necessary coarse gravels in the study river (Steel et al., 2004). Wood from upslope areas are important habitat features and significant volumes can be input during landslides that can influence sediment storage, macroinvertebrate habitat, and fish cover (Reeves et al., 2003). The authors identified that about half of the wood in the river came from upslope areas, likely introduced via landslides.

Bank texture, or grain size, is an important parameter that determines the erosion rates of banks (Kotoky et al., 2005). This fact is evident in that bank particle size has been used in several protocols to identify bank erosion hazards (e.g., Rosgen and Silvey, 1996). Excessive bank erosion directly impairs habitat via sedimentation and destabilization of features, but also influences the overall geomorphic nature of a channel. Bank texture is fundamental to the stream width and the extent of lateral adjustment, and thus geomorphic process (Simon et al., 2000; Anderson et al., 2004). As discussed in the research on channel morphology, these processes have profound and far-reaching effects on habitat for aquatic species.

The scientific literature on the raw data variables for specifically describing bank cover elements is represented in both the physics and biology of rivers. Bank stability, lateral migration, and channel width

are central themes in geomorphology and physical processes papers, while biology-based studies emphasize useable, stable near-bank habitat and the response of local macroinvertebrate and fish assemblages to bank conditions. In general, the majority of the recent research on river banks implies that an integral relationship exists between riparian vegetative cover, bank vegetative cover, stable near-bank habitat (such as undercut banks), channel width, and channel stability.

Undercut banks are important habitat features for both fish and macroinvertebrates (Myers and Resh, 2000). As with large woody debris, undercut banks are key cover components that offer protection against predators, visual isolation reducing competition, and hydraulic shelter (Allouche, 2002). Undercut banks have been related to increased salmonid density in mountain streams (Horan et al., 2000). Undercut banks are often analogous to overhanging vegetation. Hunter (1991) indicates that at least 6 inches of overhang over 50% of streambanks in a study reach is ideal for trout. The benefits of undercut banks to fish are more substantial with increasing water depth and bank stability. In a study on the effects of riprap, Schmetterling et al. (2001) found that armored banks have less undercut banks and overhanging vegetation, ultimately reducing the formation of near-bank habitat useable by adult trout.

Undercut banks, and overhanging vegetation, have also been identified as being important to macroinvertebrates. For example, the egg masses of a specific caddisfly were concentrated at or above the water surface on substrata near the bank in pools, where undercut banks, overhanging vegetation and rocks shaded attachment sites and provided wind protection (Hoffmann and Resh, 2003). Undercut banks have been shown to be important refuge locations for macroinvertebrates in mountain streams during warmer parts of the year. While forming only 8.5% of the area of aquatic habitat within the study reach submerged undercut banks were estimated to contain 44% of the aquatic insects in July and 30% in August (Rhodes and Hubert, 1991).

While studying crayfish habitat, Parkyn and Collier (2004) found that habitat stability was linked to the width and vegetative extent of the riparian zone in forest streams that in turn increased undercut banks, bank stability via tree roots, and pools. This study illustrates that river banks often manifest the riparian condition and in turn create near-bank habitat and contribute to important river processes. "The productivity of riparian plants, especially trees, influences streamside community characteristics as well as the forms and fluxes of organic matter to adjacent streams - thereby strongly impacting patterns of channel morphology, water flow, sedimentation, and habitat in rivers" (Balian and Naiman, 2005).

One interesting aspect of the streambank literature covers the relationship between large-scale process and local bank condition. Bank and buffer vegetation influence stream width, which are ultimately linked to the watershed scale (Fonstad and Marcus, 2003; Anderson et al., 2004). To this end, Couper (2004) advocates and long-term, longitudinal view of bank condition and stability rather than the usual patchwork view. "Proper handling of the bank retreat problem depends on correct identification of the actual cause of bank erosion, which may be associated with local scour, general scour, lateral instability or system-wide degradation" (Thorne and Abt, 1993).

The literature on the many positive aspects of bank (and riparian) vegetation is extensive. "Instream habitat structure and organic matter inputs are determined primarily by local conditions such as vegetative cover at a site" (Allan et al., 1997). Numerous studies confirm the importance of vegetative cover to aquatic habitat and biological populations in each trophic level in rivers. The link between vegetative cover and the geomorphic nature is well-established, and thus vegetation near channels is fundamental to

structuring habitat via mediation of channel form, and also responsible for influencing on-going processes. "At the reach-segment scale valley morphology was the primary factor controlling the stream ecosystem, but anthropogenic alteration of riparian vegetation seems to override geomorphological controls on the trophic structure (Maridet et al., 1998)." Because of the clear recognition of the many habitat benefits for river biota associated with vegetative cover, re-vegetation of banks and riparian buffers is a popular rehabilitation practice via both active re-planting and passive exclusionary fencing. Some measure of bank and riparian vegetative cover are typically found in most existing rapid habitat assessment protocols (i.e., RBP, QHEI, etc…).

Canopy cover is an important ramification of bank and riparian vegetation. Canopy cover influences the amount of incident solar radiation reaching a stream, and thus the amount of primary productivity taking place (Gregory et al., 1991). These authors stress the importance of this autotrophic aspect of the first trophic level of stream in addition to the lateral input of non-living organic matter (heterotrophic inputs) from vegetated buffers. Canopy cover thus is closely linked to the base of the aquatic food web. Canopy cover has profound effects on all river biota, generally being positively correlated with the abundance and diversity of diatoms (Kutka and Richards, 1996), periphyton (Griffith et al., 2002), macroinvertebrates (Heino et al., 2004), and fish (Smith and Kraft, 2005; VanDusen et al., 2005). In addition, canopy cover is related to physical aspects of streams such as bankfull channel width (Balanson et al., 2005).

An important thread of the literature related to bank/buffer vegetation and canopy is temperature regulation via shading. Overhanging vegetation offers shade and thermal refuge, in addition to shelter, visual isolation, and food sources. In general, overhanging vegetation is an important habitat feature for coldwater fish (Cantrell et al., 2005), warmwater fish (Talmage et al., 2002), macroinvertebrates (Hoffmann and Resh, 2003), aquatic plants, and non-living organic matter input.

Bank and buffer vegetation type and density are important for bank stability (Simon and Collison, 2002). Wynn and Mostaghimi (2006) showed that in winter months the presence of herbaceous cover and roots reduced the number of freeze-thaw cycles increasing stability over tree-covered banks and riparian areas. Thus it is clear that just as overhanging vegetation is an important contribution of trees and shrubs, herbs serve important roles in habitat as well. In a study of the abundance of two benthic fishes, Inoue and Nunokawa (2005) showed that macroinvertebrates were not significantly different in streams with grass and forested buffers, indicating another factor other than vegetative cover (i.e., substrate heterogeneity) was controlling this fish food.

Buffer and bank vegetation studies now cover all different land use types, including urbanization. In a study of rehabilitation measures to improve habitat in impacted streams, Thompson (2002) mentions that revetments have had the adverse effect of eliminating bank vegetation and the important aspects of habitat that it serves. In a study on riprap (Schmetterling et al., 2001), this same concern of eliminating bank vegetation due to common bank armoring practices to protect infrastructure in the river corridor is mentioned.

Variable Confirmation and Potential Revisions

The 'River Banks' parameter (8.7), as evaluated based on amount of bank erosion and revetments, abundance of mass failures, bank texture, undercut banks, roots and bank vegetation abundance and

composition, flow status, and bank canopy cover is an important aspect of overall bank habitat condition representing stability, cover, and vegetation. Based on the research, temperature regime, hydrology large wood / organics regime, adult salmonid cover, juvenile salmonid cover, Y-O-Y salmonid cover, macroinvertebrate cover, spawning substrates, temperature refugia, allochthonous production, winter habitat, summer habitat, and habitat heterogeneity were all added to the existing links table (see below).

The research specific to bank stability raises some interesting points for the RHA. How much erosion is good or acceptable, and at what point does it start to impair habitat? This seems to be addressed well by the phrase, "bank erosion typical of natural conditions." Valley mass failures also are important and seem to follow the trend of identifying a density of slides in a valley. One other consideration for the landslides variable is time since slides. The temporal aspect of slides is quite important to habitat and thus time since disturbance could help understand the potential impacts on habitat. The literature clearly identifies habitat benefits of some slides, and thus some qualitative information could serve useful to identify if the slide added minimal fines and lots of lwd, or if it added tons of fines. This could be beyond the scope of the RHA, but something to consider when thinking about variables linked to bank stability and habitat.

Bank texture is an important variable in terms of bank stability and channel width. However, other important aspects of bank mechanics are not included here, namely root density, particle cohesiveness (partly in dominant texture), near bank hydraulics, and local hydrology. To prioritize, near bank hydraulics seems to be quite critical. Maybe inclusion of general bed feature or water velocity range and angle of attack on banks could be added to the raw variable. Angle of attack would not only add information about bank erosion potential, but would also be indicative of channel/bank adjustment as impinging flows are typically associated with channels undergoing significant adjustment.

The selected raw variables describing bank cover represent central physical and biological themes in the literature related to near-bank habitat and stability. One possible addition is to emphasize 'overhanging' vegetation to, in combination with undercut bank, collectively assess overhanging cover (Hunter, 1991). This is present in the roots and bank vegetation raw data, but may want to be grouped with the undercut bank, since coupled with the depth of water in the undercuts and the stability of the bank, these variables are used to describe the various aspects of bank cover in the biology literature. This would isolate the key habitat feature from the bank stabilization mechanisms.

The frequent differentiation of vegetation type when investigating the effects of bank vegetation and root density may justify separating trees, shrubs, and herbs when describing bank/root vegetation. The literature shows varying influences on bank stabilization between herbs and trees, and thus it may be useful to identify percentage ranges for each. This information would be useful in the future as the relationships between each vegetation type are explored more for their different effects on habitat, and possibly by stream type. This could also help guide implementation projects to fill out sparse vegetative layers.

The hydrologic effects of bank vegetation are presently not addressed. A qualitative assessment of hydrologic processes (e.g., interception likely, possible, absent; seepage likely, possible, absent; ET likely, possible, absent, etc…) could be performed, and coupled with the mechanical influence (root abundance, compaction) give a more holistic picture of bank stability.

No information on flow status relevant to bank cover was encountered in the recent scientific literature. Although not explicitly stated in the reviewed literature, it is assumed that the extent of the wetted channel will influence useable habitat in the channel and near-bank areas. This variable seems a bit redundant with the water depth question in the undercut bank variable.

The sampling of the extensive research on bank vegetation raises some options for changing the RHA to possibly incorporate additional important aspects of bank vegetative cover. The bank canopy cover variable is a good indicator, in addition to channel canopy. These two components of cover are addressed in the literature qualitatively but frequently not separated when measured. This will likely be most important for larger rivers, as the distance between channel centerline and bank increases beyond the typical width of the bole of a riparian tree.

Finally, a measure of the percent of invasive plants could be added to the bank vegetation variables as it would be important to catalogue their presence.

Linking River Banks to Physical Processes and Habitat Components

Key Ecological Attributes (Physical Processes)	
Longitudinal Connectivity	
Riparian/Floodplain Connectivity	Near-bank vegetation, stable floodplain interface.
Sediment Regime	Sediment input from bank and slides. Floodplain attenuation.
Hydrologic Regime	Vegetation regulates local hydrolgy at channel/bank interface.
Temperature Regime	Shading, deeper water, thermal refuge, overhangs, undercuts.
Large Wood / Organics Regime	Wood inputs, riparian/bank roughness, retention.
Aquatic Life Cycle Requirements (Habitat Components)	
Adult Salmonid Cover	Undercuts, cover, isolation, food rich locations.
Juvenile Salmonid Cover	Hydraulic refuge, hide from predation, roughness.
Y-O-Y Salmonid Cover	Hydraulic refuge, hide from predation, roughness.
Macroinvertebrate Cover	Refuge, thermal retreat, snags, interstices, cover.
Spawning Substrates	Quantity and type of sediments.
Spawning Migration	
Temperature Refugia	Shading, deep undercuts, overhangs.
Allochthonous Production	Vegetation input and retention, CPOM.
Autochthonous Production	Autotrophy controls via light, processing of CPOM.
Winter Habitat	Bank erosion linked to winter habitat (ice) processes, ice scour.
Summer Habitat	Cool water retreat, higher DO, cover.
Habitat Complexity	
Disturbance Regime	Frequency of slides, amount of lateral adjustment, runoff control.
Habitat Heterogeneity	Complex near-bank area, undercuts, roughness, smothering.

Research Notes

(Thorne and Abt, 1993) – "Proper handling of the bank retreat problem depends on correct identification of the actual cause of bank erosion, which may be associated with local scour, general scour, lateral instability or system-wide degradation."

(Simon et al., 2000) Gravitational forces acting on in situ bank material act in concert with hydraulic forces at the bank toe to determine rates of bank erosion. Seepage is important process in many banks. A stable bank can be transformed into an unstable bank during periods of prolonged rainfall through:
1. *increase in soil bulk unit (specific) weight,*
2. decrease or complete loss of matric suction, and, therefore, apparent cohesion,
3. generation of positive pore-water pressures, and, therefore, reduction or loss of frictional strength,
4. *entrainment of in situ and failed material at the bank toe, and*
5. *loss of confining pressure during recession of stormflow hydrographs.*

Once banks unstable, small flows can move material.

(Simon and Collison, 2002) - Tree roots were found to increase soil strength by 2-8 kPa depending on species, while grass roots contributed 6-18 kPa. Slope stability analysis based on data collected during bank failures in spring 2000 (following a very dry antecedent period) shows that the mechanical effects of the tree cover increased factor of safety (f-s) by 32 per cent, while the hydrologic effects increased F-s by 71 per cent. For grasses the figures were 70 per cent for mechanical effects and a reduction of F-s by 10 per cent for the hydrologic effects. However, analysis based on bank failures in spring 2001 (following a wetter than average antecedent period) showed the mechanical effects of the tree cover to increase F-s by 46 per cent, while hydrologic effects added 29 per cent. For grasses the figures were 49 per cent and -15 per cent respectively. During several periods in spring 2001 the hydrologic effects of the tree cover reduced bank stability, though this was always offset by the stabilizing mechanical effects. *The results demonstrate the importance of hydrologic processes in controlling streambank stability, and highlight the need to select riparian vegetation based on hydrologic as well as mechanical and ecological criteria.*

(Wynn et al., 2004) – fine root density key for bank stabilization. Herbaceous – 75% fine root density in top 30cm of bank and it is thicker there than for woods. Forest cover has only 55% in top 30 cm and thus it is spread throughout the bank. Forest could be able to resist bank failure.

(Millar and Quick, 1993) The bank-stability criterion accounts for the increased stability of the channel banks due to consolidation of the bank sediment, cementing by fines, and binding of the sediment by root masses. Two key parameters D50bank, and the modified friction angle of the bank sediment phi'. A sensitivity analysis of the two parameters indicate that the bank stability can exert a large influence on the channel geometry. This is supported by testing the theory on published field data. The bank sediment size was assumed to equal the bed sediment size, and the variation of the friction angle phi' was investigated. The estimated phi' values are seen to increase systematically with the bank vegetation density. The results indicate that increased bank stability induced by the vegetation has a significant influence on channel geometry; the vegetated channels are narrower, deeper, and less steep. For well-developed bank vegetation, the channel widths, depths, and slopes were found to be in the order of 0.6, 1.4, and 0.9 times their respective unvegetated channel dimension.

(Thorne et al., 1998) – near bank hydraulics and secondary currents are important for determining rates of bank erosion. Heliocoidal flow.

(Fitzpatrick et al., 2001) – the reach scale indicator of bank stability linked to riparian and watershed land use.

(Millar and Quick, 1993) – bank stability influences bed stability.

(Chen and Duan, 2006) - The rate of bank-line retreat is determined by lateral erosion rate, near-bank bed-degradation rate, sediment grain size, and difference between flow depth and bank height.

(Kotoky et al., 2005) – scale and degree of shear important in bank erosion as to mechanistic reasons it takes place. (Couper, 2004) saw this as well.

(Wilhelm et al., 2005) – used bank stability in non-wadeable assessment

(Price and Birge, 2005) – RBP worse at remediation sites while fish IBI did not differ. RBP not resolving habitat differences again. "The most apparent deficiencies in habitat restoration involved protective and riparian vegetation, resulting in diminished bank stability, increased prospects for bank erosion, moderate downstream siltation, and consequences of stream channelization."

(Nerbonne and Vondracek, 2001) - The lack of difference in RBP or IBI scores across buffer types suggests that biotic indicators may not respond to local changes, **that other factors not measured may be important**, or that greater improvements in watershed condition are necessary for changes in biota to be apparent. Grass buffers may be a viable alternative for riparian management, especially if sedimentation and streambank stability are primary concerns.

(May et al., 1997) – decreasing bank stability used as indicator of urbabnization.

(Lyons et al., 2000) - After statistically factoring out watershed effects, stations with IRG or grassy buffers had the least bank erosion and fine substrate in the channel. Continuous grazing stations had significantly more erosion and, with woody buffers, more fine substrate.

(Galli, 1998) – used bank stability as a variable to track rehabilitation success for habitat.

(Best et al., 2005) - Propose a conceptual model wherein the downstream transition from bedfast ice to floating ice is responsible for an observed step change in channel size due to enhanced bank erosion in large channels by floating ice.

(Piegay et al., 2005) – erosion is natural process and important for rivers when not excessive. Use erodable river corridor concept to help identify where river will want to move. Analogous to RMP FEH work.

(Koehn et al., 2004) - "The association between eroding banks and structural wood habitat (SWH) suggests that bank erosion may be an important determinant in the formation of SWH aggregations."

(Schmetterling et al., 2001) – riprap works in only most degraded streams to add some juvenile cover, but not useful for broad range of fish and process restoration. Reduces bank and riparian overhanging vegetation. Riprap banks have less undercut bank areas.

(Miller and Sias, 1998) – relate landslides to effects of logging in relation to hydrology and slope. Cutting trees from toe of slope changes in recharge and hydrologic distribution, and incision of small

streams in logged area important for slope stability and predicting mass wasting. Landslides impair fish habitat and can initiate geomorphic changes.

(Vanacker et al., 2003) – landslides degrade aquatic habitat via introduction of large quantities of sediment. Hydrology, ground water, soil strength, soil wetness, and land use are all important for slope stability and possibly predicting land slides.

(Steel et al., 2004) – landscape variables key for steelhead redd distribution, one of which was landslide origin geology. This study helped prioritize fish passage projects since they were able to predict benefits of removal at the landscape scale. Amount of alluvium was most important.

(Reeves et al., 2003) – study indicates that wood and debris from upslope areas contribute significantly to habitat in streams. This influences sediment storage and inverts, in addition to fish habitat. About half of the wood volume in the stream came from upslope sources, likely from landslides. Upslope derived wood was mostly within the bankfull channel, while streamside wood was mostly along banks and above bankfull channel.

(Miller et al., 2003) – interesting discussion of time and space variability of landslides. The importance of slides for channel maintenance are discussed, in addition to the often short term impacts associated with landslides and large sediment events. Fires increase likelihood of landslides, as does large precipitation events like rain on snow. Can really change morphology of river via alteration of riparian area and direct scour of channel. Bull trout presence seemed to match non-landslide areas quite well.

(Anderson et al., 2004) – stream width a function of bank texture. Erodability determines geomorphic process and extent of lateral adjustment.

(Simon et al., 2000) – failing bank material, and its cohesiveness to resist erosion, important for lateral adjustment and channel width.

(Kotoky et al., 2005) – particle sizes on bank important for erosion rates.

(Rosgen and Silvey, 1996) – adjust behi based on bank texture. For example, behi gets a low score if banks are comprised of boulders Plus 10 for gravel….

(Myers and Resh, 2000) – undercut banks important for both fish and macroinvertebrates.

(Allouche, 2002) – as with lwd, undercut banks are key cover components that offer protection against predators, visual isolation reducing competition, and hydraulic shelter.

(Horan et al., 2000) - At the reach scale, the density of adult cutthroat was positively related to elevation, the percentage of undercut banks, and mean substrate particle size and negatively related to residual pool depth and the extent of large woody debris. UT mts.

(Hoffmann and Resh, 2003) - 2. "Hydatophylax sp. egg masses were generally found at or above the water surface on substrata near the bank in pools, where undercut banks, overhanging vegetation and rocks shaded attachment sites and provided wind protection."

(Schmetterling et al., 2001) – riprap works in only most degraded streams to add some juvenile cover, but not useful for broad range of fish and process restoration. Reduces bank and riparian overhanging vegetation. Riprap banks have less undercut bank areas.

(Rhodes and Hubert, 1991) – WY mts. Macroinvertebrates collected from submerged undercut banks in fall were similar to those collected from riffles and pools. In July inverts were all substantially more numerous in samples from undercut banks than from riffles or pools. While forming only 8.5% of the area of aquatic habitat within the study reach submerged undercut banks were estimated to contain 44% of the aquatic insects in July and 30% in August.

(Parkyn and Collier, 2004) – "Habitat stability was linked to the riparian zone in forest streams where undercut banks, tree roots, and pools were important habitats for crayfish."

(Anderson et al., 2004) – bank and buffer veg influence stream width, which is watershed scale dependent.

(Couper, 2004) – space and time of bank erosion really typically viewed in patchwork. Need good long view.

(Thorne and Abt, 1993) – "Proper handling of the bank retreat problem depends on correct identification of the actual cause of bank erosion, which may be associated with local scour, general scour, lateral instability or system-wide degradation."

(Fonstad and Marcus, 2003) - banks fail due to watershed energy and not local alterations entire basin and not individual failure is functional unit.

(Allan et al., 1997) – "Instream habitat structure and organic matter inputs are determined primarily by local conditions such as vegetative cover at a site, whereas nutrient supply, sediment delivery, hydrology and channel characteristics are influenced by regional conditions, including landscape features and land use/cover at some distance upstream and lateral to stream sites."

(Maridet et al., 1998) – Riparian vegetation structure important for trophic structure. At the riffle-pool (10(0) m) scale, instream morphological units appear to control the spatial partitioning of trophic resources and their consumers. "At the reach-segment scale (10(1) to 10(2) m), valley morphology was the primary factor controlling the stream ecosystem, but anthropogenic alteration of riparian vegetation seems to override geomorphological controls on the trophic structure."

(Ladson et al., 1999) – in their index of stream condition included the following variables for stream side zone. Types of plants; spatial extent, width, and intactness of riparian vegetation; regeneration of overstorey species, and condition of wetlands and billabongs.

(Fitzpatrick et al., 2001) – "Watershed and buffer land cover, geologic setting, reach riparian vegetation width, and stream size affected the fish IBI, invertebrate diversity, diatom IBI, and number of algal taxa." This study of scale links land cover, river corridor, buffer, and possibly even bank vegetative cover.

(Cantrell et al., 2005) – overhanging vegetation important for prediction of abundance of apache trout.

(Hoffmann and Resh, 2003) – overhanging vegetation important for macroinvertebrate reproduction.

(Talmage et al., 2002) – overhanging vegetation important for warm water fisheries habitat.

(Wynn and Mostaghimi, 2006) - Riparian vegetation is frequently used for stream bank stabilization, and this study shows that the type of vegetation mediates temperature fluctuations and freeze-thaw cycles that contribute to bank stability, particularly on the upper bank. Warmer months ET is higher in herbaceous cover and thus soil water tension is higher. In winter months, herbs reduced the number of freeze-thaw cycles increasing stability over tree-covered banks/riparian areas. Suggests herbs essential for bank stability.

(Anderson et al., 2004) – Vegetation controls channel size. In larger streams widths are narrower in channels with thick woody bank vegetation than with grass lined or nonforested banks. The converse is true (herbaceous veg leads to smaller widths) in smaller streams apparently due to interactions between woody debris, shading, understory vegetation, rooting characteristics, and channel size.

(Thompson, 2002) – revetments remove needed vegetative cover.

8.8 Riparian Area (canopy cover, buffer width, buffer composition)

Initial Variables Researched

Channel canopy: Percentage of canopy closure over channel (stand in middle) and over channel margin (stand at toe of bank) as estimated during phase 2.
Buffer width: Dominant two buffer width ranges recorded during phase 2 (not an average).
Buffer composition: Type of vegetation on bank (bankfull to top of bank plus 5 feet beyond) and in buffer based on estimation of dominant and subdominant types based on area of coverage.

Summary

The literature on the many important aspects of riparian areas is extensive. "Instream habitat structure and organic matter inputs are determined primarily by local conditions such as vegetative cover at a site" (Allan et al., 1997). Numerous studies confirm the importance of vegetative cover to aquatic habitat and biological populations in each trophic level in rivers. The link between vegetative cover and the geomorphic nature is well-established, and thus vegetation near channels is fundamental to structuring habitat via mediation of channel form, and also responsible for influencing on-going processes. "At the reach-segment scale valley morphology was the primary factor controlling the stream ecosystem, but

anthropogenic alteration of riparian vegetation seems to override geomorphological controls on the trophic structure (Maridet et al., 1998)." Because of the clear recognition of the many habitat benefits for river biota associated with vegetative cover, re-vegetation of riparian buffers is a popular rehabilitation practice via both active re-planting and passive exclusionary fencing. Some measure of riparian vegetative cover are typically found in most existing rapid habitat assessment protocols (i.e., RBP, QHEI, etc…).

Canopy cover is an important ramification of bank and riparian vegetation. Canopy cover influences the amount of incident solar radiation reaching a stream, and thus the amount of primary productivity taking place (Gregory et al., 1991). These authors stress the importance of this autotrophic aspect of the first trophic level of stream in addition to the lateral input of non-living organic matter (heterotrophic inputs) from vegetated buffers. Canopy cover thus is closely linked to the base of the aquatic food web. Canopy cover has profound effects on all river biota, generally being positively correlated with the abundance and diversity of diatoms (Kutka and Richards, 1996), periphyton (Griffith et al., 2002), macroinvertebrates (Heino et al., 2004), and fish (Smith and Kraft, 2005; VanDusen et al., 2005). In addition, canopy cover is related to physical aspects of streams such as bankfull channel width (Balanson et al., 2005).

An important thread of the literature related to buffer vegetation and canopy is temperature regulation via shading. Shade from riparian vegetation was identified to be an important control on summer stream temperatures and thus a management priority for coldwater fish (Gaffield et al., 2005). Overhanging vegetation offers shade and thermal refuge, in addition to shelter, visual isolation, and food sources.

The riparian buffer width is a common metric used to define the near-channel component of habitat quality. For example, Ladson et al. (1999) use width, plant type, spatial extent, intactness, regeneration of overstory, and wetland condition to define the "stream side zone." Munne et al.(2003) create an index of riparian quality (QBR) based on total riparian vegetation cover, cover structure, cover quality and channel alterations, including a ranking of roads or other means of fragmentation in the riparian corridor. Buffer width is a popular variable as its connection to habitat quality and stream biology has been established in a variety of settings. Stream reaches with wide forested buffers tend to have more macroinvertebrates, organic matter processing, and nitrogen uptake per unit channel length than deforested reaches (Sweeney et al., 2004). Meleason et al. (2003) found both width of forest and the age of the trees to be important to stream habitat. Reach riparian buffer width was one variable of a group that influenced fish, invertebrates, and small plants (Fitzpatrick et al., 2001).

Much of the early buffer research took place in watersheds where agriculture was abundant, in order to identify the effects of land use change from natural trees, shrubs, and herbs. Much of this research began to show differences between the performances of buffers of differing vegetations types, in particular trees versus herbs. For example, stream sites along grass buffers had less fines and embeddedness and more cover and overhanging vegetation than grazed or wooded buffers (Nerbonne and Vondracek, 2001). Pasture streams had fewer native species and more bank erosion (Townsend et al., 2004). The evidence in the literature does not clearly indicate whether grass or wooded buffers are better for protecting stream health. Given that trees, shrubs, and herbs have been shown to each be related to positive aspects of habitat, it seems logical to advocate some combination approach to buffer maintenance where ideally each level of the plant layer exists in some location in the buffer to perform its role in habitat protection. Correll (2005) suggests the use of multiple buffers for floodplain protection consisting of an outer grass strip and internal forest for near the channel.

Buffer vegetation type and density are important for bank stability (Simon and Collison, 2002). Wynn and Mostaghimi (2006) showed that in winter months the presence of herbaceous cover and roots reduced the number of freeze-thaw cycles increasing stability over tree-covered banks and riparian areas. Thus it is clear that just as overhanging vegetation is an important contribution of trees and shrubs, herbs serve important roles in habitat as well. In a study of the abundance of two benthic fishes, Inoue and Nunokawa (2005) showed that macroinvertebrates were not significantly different in streams with grass and forested buffers, indicating another factor other than vegetative cover (i.e., substrate heterogeneity) was controlling this fish food.

Another reason that vegetative diversity and roughness in the buffer is important is to promote regeneration of new plants over time. Disturbances following floods that remove trees, shrubs, and herbs make way for pioneers at each level that is an important process for future channel health (Parsons et al., 2006). In several studies on riparian ecosystems, LWD is identified as a critical substrate for housing propagules and promoting re-growth following disturbance (Pettit and Naiman, 2005). In addition, surface groundwater interactions are important for promoting succession and diversifying the riparian zone (Tabacchi et al., 1998). (The severing of this connection in heavily incised channels could be important to future channel condition.) This in turn supplies new plant material to nearby banks. In addition to benefits to stream health such as shading, debris input, shelter, and bank stability, debris piles that remain out of the active channel after disturbance can be preferentially used as refuge by birds and small mammals (Steel et al., 1999).

Recent studies have shown important links between channel width and riparian vegetation type. Anderson et al. (2004) show that for larger streams channel width is narrower for woody bank vegetation than for grass or non-forested banks. For smaller streams, width is narrower for stream with grass buffers. This study implies that the influence of bank cover type is scale dependent.

"The extent to which buffers can restore riparian and stream function and species composition is not well understood (Parkyn et al., 2003)." Although this multi-disciplinary study identified improvements in water clarity and channel stability with planting and livestock fences as compared to grazed buffers and banks, macroinvertebrates did not directly respond to vegetative recovery. (The same was seen for concentrations of nutrients and indicator bacteria.) Macroinvertebrate assemblages were more closely related to water temperature, and the authors suggest that re-vegetation efforts must attain a threshold where the canopy closes over enough stream length upstream to allow for cooler water temperatures due to shading. Opperman and Merenlender (2004) studied changes in riparian vegetation and streams with livestock exclusionary fencing and found that rehabilitated buffers had channels with narrower width, more heterogeneous long profile, more LWD, and lower summer temperatures. The authors state, "Riparian restoration in exclosures has resulted in quantitatively improved habitat characteristics and qualitatively different channel morphologies as compared with control reaches," yet caution that this may only apply to their region due to given sediment loads and frequent overbank flooding. Exclusionary fencing has also been shown to reduce pollution export from a heavily grazed pasture (Line et al., 2000). Resistance to completely taking land out of use for buffers drove a study on intensive rotational grazing (IRG) (Lyons et al., 2000) that showed IRG buffers reduced sedimentation and increased bank stability over grazed buffers, and even were similar to complete exclusion buffers. This implies that a management options exists other than taking land completely out of use to improve stream habitat.

Buffer and bank vegetation studies now cover all different land use types, including urbanization. Buffer vegetation followed gradient of urban watershed land use where diversity decreased, fragmentation increased, and exotics increased with urbanization (Moffatt et al., 2004).

The importance of riparian zones to river systems has been known for some time. In addition to the many habitat benefits discussed above, riparian zones can protect rivers from the influences of watershed land use change and protect water quality (Naiman and Decamps, 1997). The fundamental link between the condition of the riparian zone, banks, channel morphology, and many important habitat features (Naiman et al., 1993) makes it an important aspect of the RHA.

Variable Confirmation and Potential Revisions

The 'Riparian Area parameter (8.8), as evaluated based on canopy cover, buffer width, and buffer composition can be associated with many ecological attributes and life cycle requirements of river habitat. Based on this research adult salmonid cover, juvenile salmonid cover, Y-O-Y salmonid cover, macroinvertebrate cover, spawning substrates, winter habitat, summer habitat, and habitat heterogeneity were all added to the existing links table (see below).

The sampling of the extensive research on riparian areas raises some options for changing the RHA to possibly incorporate additional important aspects of riparian vegetative cover. Research indicates that in addition to width and type of vegetation, density, age of trees, and connectivity of vegetation patches could be important additions. Density of each plant layer would give an indication of herbaceous component that could stabilize banks via roots and the tree component offering near-bank features such as thermal refuge and wood input. (This same type of variable is useful for the bank vegetation to understand bank stability mechanics.) Age of trees, or size of trees, is important as this determines shading extent and the ability to enter the channel and remain in place to serve as instream habitat structure. Large trees are also important for creating roughness in the riparian buffer to promote succession and growth.

Connectivity of naturally vegetated patches in the valley could add a larger scale view of the nature of the river corridor. Many studies suggest that the upstream buffer condition influences the current site in terms of temperature, geomorphology, and wood inputs.

Finally, a measure of the percent of invasive plants could be added to the riparian vegetation variables as it would be important to catalogue their presence.

Linking Riparian Area to Physical Processes and Habitat Components

Key Ecological Attributes (Physical Processes)	
Longitudinal Connectivity	
Riparian/Floodplain Connectivity	Floodplain location, bank stability.
Sediment Regime	Filtering of inputs and source control (bank retention).
Hydrologic Regime	ET, long flow paths, storage.
Temperature Regime	Shading, overhanging vegetation, canopy.
Large Wood / Organics Regime	Wood inputs, riparian/bank roughness, retention.
Aquatic Life Cycle Requirements (Habitat Components)	
Adult Salmonid Cover	Wood for holds, shade, cover from predation.
Juvenile Salmonid Cover	Roughness near bank, refuge, shade, isolation.
Y-O-Y Salmonid Cover	Roughness near bank, refuge, shade, isolation.
Macroinvertebrate Cover	Interstices, overhanging vegetation, near-bank stability.
Spawning Substrates	Clean gravels, magnitude of flow disturbance.
Spawning Migration	
Temperature Refugia	Shading, overhanging vegetation, canopy.
Allochthonous Production	Lateral wood inputs, CPOM, delivery rate.
Autochthonous Production	Autotrophy controls via light, processing of CPOM.
Winter Habitat	Freeze-thaw cycles, scour pools.
Summer Habitat	Thermal refuge, shade, cover.
Habitat Complexity	
Disturbance Regime	Runoff control, flow magnitude, bank stability.
Habitat Heterogeneity	Roughness inputs, riparian diversity, bed features.

Research Notes

General

(Naiman and Decamps, 1997) – riparian zones important for river systems, to ameliorate influences of land use and protect water quality. (Naiman et al., 1993) flood disturbance important process. Riparian zones closely linked to channel morphology as later adjustment related to vegetated cover.

(Gregory et al., 1991) - riparian veg and LWD influence morphology and thus habitat. Studies a 3-d zone of vegetation type out to limits of flooding and to top of canopy. -riparian veg. is one of the most dynamic areas in landscape, and diverse due to diverse soil in floodplain. Later fluxes key for river. Heating linked to riparian and bank vegetative cover determining primary productivity caused by length of forested channel upstream, veg width and density, groundwater. most of foodbase is from adjacent terrestrial systems to streams.

(Allan et al., 1997) – "Instream habitat structure and organic matter inputs are determined primarily by local conditions such as vegetative cover at a site, whereas nutrient supply, sediment delivery, hydrology and channel characteristics are influenced by regional conditions, including landscape features and land use/cover at some distance upstream and lateral to stream sites."

(Maridet et al., 1998) – Riparian vegetation structure important for trophic structure. At the riffle-pool (10(0) m) scale, instream morphological units appear to control the spatial partitioning of trophic resources and their consumers. "At the reach-segment scale (10(1) to 10(2) m), valley morphology was the primary factor controlling the stream ecosystem, but anthropogenic alteration of riparian vegetation seems to override geomorphological controls on the trophic structure."

canopy

(Kutka and Richards, 1996) - Diatom assemblages from natural substrata showed strong correlations to % canopy coverage.

(Griffith et al., 2002) – riparian vegetation condition important for small aquatic plants.

(Heino et al., 2004) - Sampling design incorporated a set of fully nested scales. Scraper abundance varied most at the scale of stream sections, probably mirroring variation in canopy cover.

(Smith and Kraft, 2005) – Study in the Be-moc basin NY looking at link and habitat influence on fish. Important local habitat variables included the proportion of fine substrate, canopy cover, in-stream vegetation, and water temperature.

(VanDusen et al., 2005) – Brook trout linked to time since logging and used habitat score to understand why. Could not create clear mechanistic picture of what was going on. (did not have access to this article and need to see which habitat protocol was used.) Fine sediment abundance was negatively related to stream canopy cover.

(Balanson et al., 2005) - Strong significant correlations between canopy coverage and bankfull width were observed. An interesting note is their QHEI score did not relate to IBI. Possibly due to other important factors related to physical processes.

Buffer width

(Ladson et al., 1999) – in their index of stream condition included the following variables for stream side zone. Types of plants; spatial extent, width, and intactness of riparian vegetation; regeneration of overstorey species, and condition of wetlands and billabongs.

(Munne et al., 2003) - index of riparian quality (QBR) based on total riparian vegetation cover, cover structure, cover quality and channel alterations. Excludes grasses from cover? Includes ranking of roads or other mean of fragmentation in the riparian corridor. Cover quality a function of geomorphic nature of channel and amount of native trees. QBR classified into 5 groups for scoring. This work shows little bias when multiple users do the assessment. *(We may want to do something like this for the RHA. This article has some good references for creating assessments.)*

(Sweeney et al., 2004) – Riparian deforestation causes channel narrowing, which reduces the total amount of stream habitat and ecosystem per unit channel length and compromises in-stream processing of pollutants. Wide forest reaches had more macroinvertebrates, total ecosystem processing of organic

matter, and nitrogen uptake per unit channel length than contiguous narrow deforested reaches. This study primarily addresses forested buffer width.

(Fitzpatrick et al., 2001) – "Watershed and buffer land cover, geologic setting, reach riparian vegetation width, and stream size affected the fish IBI, invertebrate diversity, diatom IBI, and number of algal taxa." This study of scale links land cover, river corridor, buffer, and possibly even bank vegetative cover.

(Meleason et al., 2003) – forest age important for wood inputs to streams, in addition to buffer width.

Shade/temp/overhanging

(Gaffield et al., 2005) – shade from riparian vegetation was identified as one of the important controlling variables for summer stream temperatures. Important for coldwater fish management.

(Cantrell et al., 2005) – overhanging vegetation important for prediction of abundance of apache trout.

(Hoffmann and Resh, 2003) – overhanging vegetation important for macroinvertebrate reproduction.

(Talmage et al., 2002) – overhanging vegetation important for warm water fisheries habitat.

Ag /pasture streams and veg.

(Nerbonne and Vondracek, 2001) – Agriculture streams. Stream sites along grass buffers generally had significantly lower percent fines, embeddedness, and exposed streambank soil, but higher percent cover and overhanging vegetation when compared with sites that had grazed or wooded buffers.

(Townsend et al., 2004) - Pasture streams had a smaller representation of endemic riparian plant species, particularly tussock grasses, higher bank erosion, a somewhat deeper layer of fine sediment.

(Dabney et al., 2006) – studies the relationship between buffer and field edge in agriculture setting. Both must be integrated for better river health, and nutrient removal and habitat improvement. Both should limit runoff rate and sediment yield.

Types/stability

(Simon and Collison, 2002) – riparian and bank vegetation important for bank stability. This work quantifies increased bank stability with vegetative cover.

(Wynn and Mostaghimi, 2006) - Riparian vegetation is frequently used for stream bank stabilization, and this study shows that the type of vegetation mediates temperature fluctuations and freeze-thaw cycles that contribute to bank stability, particularly on the upper bank. Warmer months ET is higher in herbaceous cover and thus soil water tension is higher. In winter months, herbs reduced the number of freeze-thaw cycles increasing stability over tree-covered banks/riparian areas. Suggests herbs essential for bank stability.

(Inoue and Nunokawa, 2005) – indicates that buffer deforestation not as important as substrate heterogeneity to benthic fishes. Inverts were limited food source but same in grass and forested buffers so their abundance patterns found to be not linked to buffer condition.

(Correll, 2005) – discusses the habitat benefits of buffers and the creation of buffers that serve their functions well. Idea of multiple buffers for floodplain protection. Outer grass strip and internal forest for near the channel.

buffer growth Lwd/disturbance

(Pettit and Naiman, 2005) – lwd piles in riparian areas important for allowing more vegetation to grow. Substrate.

(Parsons et al., 2006) – flood cleared some riparian species, and cleared way for pioneers. Effects varied by species and by location in buffer, bank or channel. Mature buffers created a lot of lwd important for trapping propugules.

(Tabacchi et al., 1998) - surface and groundwater linkages are the predominant controls of landscape connectivity within riparian systems. Disturbances key for making space for pioneers and leading to succession to create a diverse plant structure in riparian zones. Establishment is key and this happens on a more frequent basis in smaller headwater streams. Vegetation is sink for sediment and nutrients.

(Steel et al., 1999) – birds and small mammals preferentially use lwd piles in buffers.

Channel size

(Anderson et al., 2004) – Vegetation controls channel size. In larger streams widths are narrower in channels with thick woody bank vegetation than with grass lined or nonforested banks. The converse is true (herbaceous veg leads to smaller widths) in smaller streams apparently due to interactions between woody debris, shading, understory vegetation, rooting characteristics, and channel size.

(Opperman and Merenlender, 2004) – looked at livestock fences to see changes in riparian veg and stream. Note that some studies have not showed clear improvement. Channels within exclosures (following passive recovery of vegetation) were narrower, had greater heterogeneity in long profile elevation , more LWD and debris jams, and lower late-summer water temperature "Riparian restoration in exclosures has resulted in quantitatively improved habitat characteristics and qualitatively different channel morphologies as compared with control reaches. The ability of vegetation to improve channel morphology in this region is probably due to frequent overbank flooding and high sediment loads."

Land use

(Moffatt et al., 2004) – buffer vegetation followed gradient of urban land use in watershed. Diversity decreased, fragmentation increased, and exotics increased with urbanization.

rehabilitation

(Parkyn et al., 2003) – "the extent to which buffers can restore riparian and stream function and species composition is not well understood." Generally, streams within buffer zones showed rapid improvements in visual water clarity and channel stability, but nutrient and fecal contamination responses were variable. Inverts did not improve solely as a function of buffer improvement. Inverts were more closely related to water temperature implying that until canopy closure occurred or enough upstream buffer was improved to cool waters there would be limited biological response.

(Line et al., 2000) - Livestock exclusion and subsequent riparian vegetation establishment was effective at reducing pollutant export from an intensively grazed pasture.

(Lyons et al., 2000) – looked at intensive rotational grazing as an alternative to complete exclusion to maintain healthier buffers and save farmers money. IRG buffers reduced sedimentation and increased bank stability over grazed buffers. They behaved similar to complete exclusion buffers. Fish and invert habitat improved with irg.

(Thompson, 2002) – revetments remove needed vegetative cover.

APPENDIX C: Summary of Initial RHA Parameters and Variables

RHA Evaluation Parameters	Measurement Variables	Physical process, measurement variable, and habitat component pathway
Woody Debris Cover	***density of LWD pieces (#/100ft)***	Input from riparian forests or longitudinal input from upstream locations due to the processes associated with in channel sediment storage and the lateral migration of a stream within its valley. Large wood creates substrate for insect colonization, stores fine sediments, and leads to hydraulic diversity offering shelter, feeding locations, and rearing grounds for adult, Y-O-Y, and juvenile fish.
	density of debris jams (#/100ft)	Accumulated from wood input to the channel from upstream locations at locations of limited (sediment and wood) transport capacity. Debris jams creates substrate for insect colonization and diversifies local hydraulics offering shelter and feeding locations for adult, Y-O-Y, and juvenile fish. Deep scour associated with debris jams create Important refuge locations.
	CPOM abundance	Allochthonous and autochthonous inputs of organics and their retention in low velocity stream areas create the heterotrophic base of the aquatic food web for detritovourous invertebrates, shelter for invertebrates, and concentration of food sources for fish.
Bed Substrate Cover	***embeddedness (%)***	Suspended fine sediment inputs throughout the watershed exceed the stream's transport capacity during low flow periods (including the flood recession periods) and settle then clog the course sediment interstices impairing gravel spawning fish, Y-O-Y shelter, and insect habitat. Embedded sediments are more resistant to entrainment and may lead to sediment discontinuity and erosion processes downstream.
	cobble+boulder (%), sand+gravel (%)	Substrate size is a function of watershed characteristics, primarily geologic materials, discharge, channel slope and confinement that influence sediment transport rate, distribution, sorting, bed roughness, and hydraulic patterns. Plants and invertebrates are closely linked to sediment size, as are fish shelter and reproduction.
	sediment stability	Consolidation of particles and the amount of substrate movement due to hydrology (timing and intensity of runoff) and local hydraulics (stream power relative to boundary resistance) influences the permanence of habitat, which determines the periodicity of habitat features influencing aquatic plants, invertebrates, and fish.

Scour and Deposition Features	***abundance of deep pools***	The differential resistance of bed and bank materials creates opportunity for plunge and convergent flows and the differentiation of bed features along the longitudinal channel profile creating deep scour pools that serve as thermal refugia for fish during low flows, locations of visual isolation from overhead predation, low-velocity flow refugia, and winter habitat.
	turbulent cover (%)	Longitudinal distribution and lateral sorting of sediments leads to bed feature differentiation in the channel profile and creates riffles and plunging flows that are well-oxygenated areas beneficial to invertebrates and fish. Turbulence creates fish cover through with visual isolation, clean gravel-spawning sites, and interstitial refuge for invertebrates and Y-O-Y.
	bed feature distribution/pattern	Turbulence and secondary lateral currents cause the selective entrainment, transport and deposition of bed and bank materials producing systematic sorting of grain sizes between scour pools and riffle bars. Watershed, corridor, and channel characteristics lead influence the size, frequency, and distribution of bed features with a range of water velocity-depth combinations, substrate sizes, and local hydraulics necessary for cover, refuge, and reproduction of plants and animals.
	diversity of hydraulic units	Sorting and distribution of sediment and organic materials create micro and meso-bed forms resulting in hydraulic (depth-velocity) conditions favorable for creating macroinvertebrate or Y-O-Y fish habitat.
Channel Morphology	***width/depth ratio***	Watershed and valley characteristics, channel boundary resistance, and location within the longitudinal profile set the geomorphic context for a given channel, of which width to depth ratio is fundamental measure. Width/ratio is indicative of mean channel depth and thereby the hydraulic efficiency of the stream to move the sediments supplied to the channel which influences instream habitat due to creation of hydraulic patterns locally and over the length of a river reach.
	entrenchment and incision ratio	Watershed and valley characteristics determines where a channel sits vertically relative to its floodplain. Changes in floodplain connection have a profound affect on stream power and sediment transport characteristics influencing the development and distribution of habitat-relative bed forms. Increased sediment transport as a result of incision results in deposition and embeddedness in downstream locations. Lateral connectivity and the periodicity of floodplain inundation define organism access to slow water locations important for fish rearing and retreat during high water.
	channel alteration	Channelization, bank armoring, gravel excavation, and fixed grade control all influence channel morphology, hydraulics, and sediment and large wood regimes. Altered macro-, meso- and micro-habitats influence all aquatic flora and fauna.

Hydrologic Characteristics	***wet width/bankfull width***	Watershed hydrology in combination with channel morphology collectively determine the amount of wetted useable habitat available for all trophic levels, as well as channel stability and the temperature regime present.
	substrate exposure (%)	Watershed hydrology, substrate composition, and channel morphology collectively determine the amount of wetted useable substrate habitat available for all trophic levels, as well as channel stability and the temperature regime present.
	adjacent wetlands	Watershed hydrology, fine sediment storage and lack of drainage infrastructure in the valley bottom allow riparian wetland formation that buffers the river channel, protects bank integrity, mediates inflow via storage, and creates sources of organic inputs all of which are important for invertebrates and fish.
	flow alterations	Adjustment of natural flow magnitude and frequency initiates geomorphic changes (alteration of the channel morphology ad sediment regime) that in turn influence reach and local hydraulics that change habitat.
Connectivity	***density of reach obstructions***	The presence of dams and natural obstructions limit animal movement and population dispersal of most fish. Plant, invertebrates and fish habitat changes take place due to altered hydrology and sediment transport with more obstructions influencing reach hydraulic patterns.
	proximity to obstructions	Obstructions alter temperature regime, dominant food type, sediment transport, hydrology, and hydraulics, with more significant deviations form typical habitat the closer to an obstruction. These changes influence plants, invertebrates and fish habitat.
	density of system obstructions	The presence of dams and natural obstructions limit animal movement and population dispersal of most fish. Plant, invertebrates and fish habitat changes take place due to altered hydrology and sediment transport with more obstructions influencing reach hydraulic patterns.
	floodplain access	Lateral isolation of a river channel from its floodplain due to channelization, berming, or incision limits access to fish rearing locations and hydraulic refuge during high flows. Floodplain access also mediates habitat formation via energy dissipation via flow and sediment attenuation.
	backwater and refuge access	Sediment supply, channel slope and floodplain forming processes create slow water areas in abandoned channels and other features formed and accessed during various flood stages providing refuge to juvenile fish

River Banks	***vegetation type and abundance***	Roots of trees, shrubs and herb species increase bank stability (via bank and floodplain roughness and channel boundary resistance), allowing formation of better near-bank habitat consisting of undercuts and overhanging vegetative cover. Bank vegetation provides shade that is important for invertebrates and fish in warmer seasons.
	amount of erosion (%)	Increased bank erosion rates reduce habitat quality by increasing disturbance regime and adding fines to habitat features. The result is a reduction in productive aquatic habitat.
	abundance of mass failures	Through large inputs of sediment, mass failures degrade plant, invertebrate, and fish habitat. Gravel-spawning success is reduced with more mass failures. Such events can introduce very large amounts of colluvium into the system leading to widespread channel adjustment and habitat degradation.
	abundance of undercut banks	The combination of stable banks, suitable near-bank hydraulics, and system hydrology collectively produce deep, cool undercut banks. These locations are important retreats for invertebrates and fish during high flows or warm temperatures. Visual isolation.
	overhanging vegetation	Stable banks and ample riparian and bank vegetation create overhanging vegetation that is important for invertebrate reproduction and fish cover. Overhanging vegetation shades the river channel and also is a source of organics to support the lower food web.
	water adjacency	Hydrology and sediment sorting and distribution determine the availability and concentration of flows adjacent to the stream banks. Invertebrates and fish can only access undercuts and shelter locations under vegetation if the channel has ample water depth near the banks.
	bank and channel canopy	Riparian and bank vegetation form canopy cover the is important for fish cover, setting up thermal refuge, and winged-adult invertebrate habitat. Canopy also supplies the channel with organics inputs to the food web, which leads to beneficial channel roughness.
Riparian Area	***vegetated buffer width***	Preservation of natural vegetation in the river corridor improves habitat via shading the channel, supplying organics, and attenuating fine sediment and high flows. The result is improved habitat for invertebrates and fish with larger buffer widths.
	vegetation type and abundance	The diversity of vegetation in riparian buffers increases diversity of root structure, ground surface roughness, and the general stability of the riparian zone. Each of these improves near bank habitat and the attenuation functions of vegetated buffers that influence all physical regimes and habitat components.
	land cover	Through influencing watershed hydrology and sediment load, land cover can manifest itself as habitat change. Altered flow rate and sediment regime influences meso-habitats that ultimately affect small scale habitats for plants, invertebrates, and fish.

APPENDIX D: Summary of Initial RHA Measurement Methods

RHA Evaluation Parameters	Measurement Variables	Proposed Phase 2 RHA Method	Possible Phase 3 Methods
Woody Debris Cover	***Density of LWD pieces (# / 100 ft)***	Sketch approximate LWD location, and tally each piece according to diameter and length size classes on new tally form to get density and size distribution. Length is relative to bankfull width and width is measured at the large end of the LWD. Qualitatively assess wood recruitment potential.	Record several measurements of wetted width to get estimate of reach surface area (and volume with depth). Survey/measure LWD to get actual surface area and volume as a percentage of the reach.
	Density of debris jams (# / 100 ft)	Sketch and count according to existing size criteria on new tally sheet.	Survey/measure debris jams to get actual surface area and volume as a percentage of the reach.
	CPOM coverage (% of reach surface area)	Sketch and estimate percent reach coverage on new tally sheet.	Survey/measure CPOM patches to get actual surface area and volume as a percentage of the reach.
Bed Substrate Cover	***Riffle and margin embeddedness (%)***	Mean of embeddedness (embedded depth divided by total depth) of 3 representative particles in riffles and 3 representative particles in channel margins during pebble count. Record measurements on Cross-Section Worksheet, and means in Field Notes under 2.12.	Mean of embeddedness (embedded depth divided by total depth) of 20 representative particles in riffles and 20 representative particles in channel margins during pebble count.
	Cobble+boulder (%), sand+gravel (%)	Determine from pebble count. Particle size percentages currently recorded in Field Notes under 2.12.	Determine percentages from pebble counts at multiple locations and stratified by bed feature type as currently done in phase 3.

	Sediment stability (% of mobile bed particles)	Riffle stability index (RSI). Estimate the diameter size class of several of the largest mobile particles on the bed and bar nearest to the study riffle where the pebble count is initiated, as done in current phase 2. Now enter data on cross section worksheet, and continue to enter mean bed and bar particle size in Field Notes under 2.13. RSI is the mobile fraction, or the percent finer reading recorded from the cumulative distribution from the riffle pebble count.	Regime measurements at each cross section and comparison to particle count data currently done in phase 3, and possibly done in phase 2 if observer takes a good slope measurement.
Scour and Deposition Features	***Pool size and abundance***	Sketch approximate pool locations and surface area as currently done. Record depth and width ranking for each pool on new tally sheet and determine pool density. Width is relative to bankfull width. Qualitatively assess pool cover quality.	Survey pool depth contours and max depth to calculate area and volume over reach. Measure RPD at each pool.
	Bed feature longitudinal pattern	Qualitatively assess the longitudinal organization of features (e.g., riffle-run-pool-glide pattern), with attention to the expected thalweg location within each feature. (This is done from a physical perspective in the current RGA.)	Limits of each bed feature currently surveyed in phase 3.
	Hydraulic units (% of reach) and depth-velocity diversity	Sketch approximate location of riffles and pools over reach as currently done. Estimate a percent reach coverage on new tally sheet. Qualitatively score depth-velocity combinations directly on new RHA form.	Survey extent of hydraulic units, with particular attention to the distribution of different depth-velocity combinations.
Channel Morphology	***Width / depth ratio***	Perform as currently done in phase 2.	Calculated at each cross section as currently done in phase 3 survey.
	Entrenchment and incision ratios	Perform as currently done in phase 2.	Calculated at each cross section as currently done in phase 3 survey.

	Channel alteration	Perform as currently done in phase 2.	Identify and survey local response to channel alteration. These are likely already known from phase 1 and 2 assessments.
Hydrologic Characteristics	***Wet width / bankfull width ratio***	Bankfull width and wetted width are currently measured at the phase 2 cross section. Added space for wetted width data in the Cross-Section Worksheet. Subtract out the length of exposed bars for the wetted width measurement.	Currently measured at every cross section during phase 3 survey.
	Substrate exposure (% of reach area)	Sketch exposed substrate over study reach. Estimate the percentage of reach area with exposed bed and bars.	Survey exposed substrate over study reach. Measure the percentage of reach area with exposed bed and bars.
	Adjacent wetlands	As currently done in phase 2 Field Notes under 4.2, indicate adjacent wetland presence as abundant, some, or none.	Map land use in river corridor and calculate the percentage of river banks with adjacent wetlands.
	Flow alteration	Qualitative assessment of the level of flow alterations on new RHA form. Refer to flow status in Field Notes under 4.3, and where possible refer to local USGS gauge current flow rate.	Map potential flow alterations such as local withdrawals and discharges, and verify with phase 1 and 2 data.
Connectivity	***Density of reach obstructions (# / mi)***	Sketch obstructions on reach, count noting natural or man-made, size, flow when blockage occurs and sum on new tally sheet. If none present on study reach, try to identify proximity to obstructions using phase 1 data and existing local knowledge.	Survey natural and manmade obstructions near project site.
	Density of system obstructions (# / mi)	Where possible, locate all obstructions in the system using phase 1 data and existing local knowledge.	Walk river to locate all natural and manmade obstructions.

	Refuge areas and connections	Sketch refuge areas and connections on study reach. Count and record if the refuge is in- or off-channel, has access during low and bankfull flows, and adds quality habitat. Qualitatively assess refuge area quality and access on new RHA form.	Survey all refuge areas and connections, and evaluate the habitat quality.
River Banks	***Amount of bank erosion (ft)***	Estimate length of left and right bank erosion over reach, as currently done in phase 2. Sum on new tally form. Qualitatively assess the amount of erosion based on percent of banks over the reach that are eroding, and the presence of revetments.	Map and measure all bank erosion.
	Vegetation type and abundance	Determine the percent vegetative coverage within the tree, shrub, and herb layers individually, as well as the percent of invasives that make up the vegetative layer. Also, determine percent coverage of common floral groups for each layer. Data entered on phase 2 Field Notes, and then qualitatively assess cover and root density on new RHA form.	Identify and map vegetation in each layer on banks.
	Bank canopy (% closure)	Measure canopy closure over bank as currently performed in phase 2.	Determine bank canopy closure at each cross section, and note large openings.
	Abundance of mass failures	Sketch mass failures and estimate height of each to determine the rough abundance and average height of failures in reach as currently done in phase 2.	Locate mass failures in system.
	Abundance of undercut banks	Sketch the area of undercut banks. On new tally form indicate the size rank according to maximum depth and length Width relative to bankfull. Note presence or absence of overhanging vegetation and bank stability.	Survey and measure dimensions of all undercut banks.

	Overhanging vegetation (% of reach area)	Sketch the areas of overhanging vegetation, and then estimate percentage of reach area covered.	Survey and measure dimensions of all overhanging vegetation areas.
	Water adjacency	Sketch the location that water meets the banks, and then estimate the percentage of reach length where water touches the bank closest to the thalweg. Enter data on the new tally form.	Calculate water adjacency based on survey data.
Riparian Area	***Vegetated buffer width***	Note dominant buffer width ranges as currently performed in phase 2.	Determine buffer width at each phase 3 survey cross section.
	Vegetation type and abundance	Determine the percent vegetative coverage within the tree, shrub, and herb layers individually, as well as the percent of invasives that make up the vegetative layer. Also, determine percent coverage of common floral groups for each layer. Data entered on phase 2 Field Notes, and then qualitatively assess cover and root density on new RHA form. Canopy closure indicated on new RHA form.	Identify and map vegetation in each layer on banks.
	River corridor development	Qualitatively assess the level of river corridor development and infrastructure. Confirm with existing phase 1 and 2 data.	Identify and map river corridor development.

APPENDIX E: Summary of Current RHA Variable Scoring

8.1 Woody Debris Cover

Variable Ranges for each Condition (Departure) Category

Stream Type	Variables	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
Riffle-Pool (Dune Ripple)	LWD pieces / mile	>100 / mile	100-50	50-25	<25
	LWD size rank 3-6	>50%	50-25	25-10	<10
	Debris jams / mile	>5 / mile	5-3	3-1	none
	Recruitment potential	high	moderate	low	none
	CPOM coverage	channel and margins	limited in channel, present in margins	limited in channel and margins	none
Step-pool (Cascade and Bedrock)	LWD pieces / mile	>200 / mile	200-100	100-50	<50
	LWD size rank 3-6	>75%	75-50	50-25	<25
	Debris jams / mile	>25 / mile	25-15	15-5	<5
	Recruitment potential	high	moderate	low	none
	CPOM coverage	channel and margins	limited in channel, present in margins	limited in channel and margins	none
Plane Bed	LWD pieces / mile	>50 / mile	50-25	25-10	<10
	LWD size rank 3-6	>50%	50-25	25-10	<10
	Debris jams / mile	>5 / mile	5-3	3-1	none
	Recruitment potential	high	moderate	low	none
	CPOM coverage	channel and margins	limited in channel, present in margins	limited in channel and margins	none
Braided	LWD pieces / mile	>100 / mile	100-50	50-25	<25
	LWD size rank 3-6	>50%	50-25	25-10	<10
	Debris jams / mile	>5 / mile	5-3	3-1	none
	Recruitment potential	high	moderate	low	none
	CPOM coverage	channel and margins	limited in channel, present in margins	limited in channel and margins	none

8.2 Bed Substrate Cover

Variable Ranges for each Condition (Departure) Category

Stream Type	Variables	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
Riffle-Pool (Dune Ripple - do not evaluate parameter)	Riffle embeddedness	<20%	20-40	40-75	>75
	Margin embeddedness	<40%	40-60	60-80	>80
	Fining	<10	10-20	20-40	>40
	Riffle stability index	<70%	70-80	80-90	>90
	Sediment mobility and sorting	sediment apparently stable & sorted	some evidence of sediment mobility & lack of sorting	major evidence of sediment mobility & lack of sorting	unstable, unsorted, soft underfoot
	Dense algae	none	small patches	large patches	covering most of bed
Step-pool (Cascade and Bedrock)	Pool embeddedness	<25%	25-50	50-75	>75
	Margin embeddedness	<40%	40-60	60-80	>80
	Fining	<10	10-20	20-40	>40
	Sediment mobility and sorting	sediment apparently stable & sorted	some evidence of sediment mobility & lack of sorting	major evidence of sediment mobility & lack of sorting	unstable, unsorted, soft underfoot
	Dense algae	none	small patches	large patches	covering most of bed
Plane Bed	Run embeddedness	<20%	20-40	40-75	>75
	Margin embeddedness	<40%	40-60	60-80	>80
	Fining	<10	10-20	20-40	>40
	Sediment mobility and sorting	sediment apparently stable & sorted	some evidence of sediment mobility & lack of sorting	major evidence of sediment mobility & lack of sorting	unstable, unsorted, soft underfoot
	Imbrication	limited, short axis aligned with flow	moderate, short axis aligned with flow	moderate, long axis aligned with flow	extensive, long axis aligned with flow
	Dense algae	none	small patches	large patches	covering most of bed
Braided	Riffle embeddedness	<20%	20-40	40-75	>75
	Margin embeddedness	<40%	40-60	60-80	>80
	Fining	<10	10-20	20-40	>40
	Riffle stability index	<70%	70-80	80-90	>90

Braided	Sediment mobility and sorting	sediment apparently stable & sorted	some evidence of sediment mobility & lack of sorting	major evidence of sediment mobility & lack of sorting	unstable, unsorted, soft underfoot
	Dense algae	none	small patches	large patches	covering most of bed

8.3 Scour and Deposition Features

Variable Ranges for each Condition (Departure) Category

Stream Type	Variables	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
Riffle-Pool (Dune Ripple) Dune Ripple - only evaluate pools and ripples)	Pools / mile	>40 / mile	40-20	20-10	<10
	Pool size rank 3-7	>50%	50-25	25-10	<10
	Pool cover	>75% area	75-50	50-25	<25
	Riffle (ripple) coverage and form	>25%, distinct, complete	25-10, moderately formed, complete	25-10, poorly formed, incomplete	<10, indistinct
	Riffle (ripple) spacing	5-7 Wbkf	3-5 or 7-10	1-3 or 10-12	>12
	Hydraulic pattern, distribution	well-defined, 4 depth-velocity combos present	well-defined, 3 depth-velocity combos present	moderately defined, 2 depth-velocity combos present	poorly defined, 2 depth-velocity combos present
	Deposition	finer deposition in slack water below larger debris, and along margins	finer deposition located in slack water below larger substrates/debris, signs of mid-channel accumulation	very large depositional features below larger substrates/debris, abundant mid-channel accumulation	finer deposition throughout channel, even filling pools, larger substrates almost buried OR bed largely incised
Step-Pool (Cascade and Bedrock)	Pools / mile	>70 / mile	70-50	50-30	<30
	Pool size rank 3-7	>50%	50-25	25-10	<10
	Pool cover	>75% area	75-50	50-25	<25
	Step form and stability	distinct, complete, stable	mod. well formed, complete, stable	poorly formed, incomplete, unstable	indistinct or absent, or very unstable
	Step spacing	5-7 Wbkf	3-5 or 7-10	1-3 or 10-15	>15

(Cascade and bedrock stream types: Do not evaluate variables related to step pattern.)	Hydraulic distribution	>2 depth-velocity combos present	2 depth-velocity combos present	1 or 2 depth-velocity combos present	1 depth-velocity combo present
	Deposition	finer deposition in slack water below larger debris, and along margins	finer deposition located in slack water below larger substrates/debris, signs of mid-channel accumulation	very large depositional features below larger substrates/debris, abundant mid-channel accumulation	finer deposition throughout channel, even filling pools, larger substrates almost buried OR bed largely incised
Plane Bed	Pool formation	evident, >50% size rank 3-7	evident, <50% size rank 3-7	limited	absent
	Riffle formation	widespread	moderate	limited	none
	Hydraulic distribution	>2 depth-velocity combos present	2 depth-velocity combos present	1 or 2 depth-velocity combos present	1 depth-velocity combo present
	Thalweg alignment	meandering, side and lateral bar formation evident	moderately meandering, some bar formation evident	barely meandering, minimal bar formation evident	not meandering, no bar formation evident
	Deposition	finer deposition in slack water below larger debris, and along margins	finer deposition located in slack water below larger substrates/debris, signs of mid-channel accumulation	very large depositional features below larger substrates/debris, abundant mid-channel accumulation	finer deposition throughout channel, even filling pools, larger substrates almost buried OR bed largely incised
Braided	Pools / mile	>40 / mile	40-20	20-10	<10
	Pool size rank 3-6	>50%	50-25	25-10	<10
	Pool cover	>75% area	75-50	50-25	<25
	Riffle coverage and form	>25%, distinct, complete	25-10, moderately formed, complete	25-10, poorly formed, incomplete	<10, indistinct
	Riffle spacing	5-7 Wbkf	3-5 or 7-10	1-3 or 10-12	>12
	Hydraulic pattern, distribution	well-defined, 4 depth-velocity combos present	well-defined, 3 depth-velocity combos present	moderately defined, 2 depth-velocity combos present	poorly defined, 2 depth-velocity combos present
	Bar stability and vegetation	stable, >50% coverage	mostly stable, 50-25 coverage	unstable, 25-10 coverage	unstable, <10 coverage

8.4 Channel Morphology

Variable Ranges for each Condition (Departure) Category

Stream Type	Variables	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
Riffle-Pool (Dune Ripple)	width/depth ratio	<15	15-25	25-40	>40
	entrenchment ratio	>1.4	>1.4	>1.4	<1.4
	incision ratio	<1.2	1.2-1.4	1.4-2.0	>2.0
	channel alteration	not evident	minor historic	major historic, or minor recent	extensive historic, or major recent
Step-Pool (Cascade and Bedrock)	width/depth ratio	<12	12-15	15-25	>25
	entrenchment ratio	>1.2	>1.2	>1.2	<1.2
	incision ratio	<1.2	1.2-1.4	1.4-2.0	>2.0
	channel alteration	not evident	minor historic	major historic, or minor recent	extensive historic, or major recent
Plane Bed	width/depth ratio	<15	15-25	25-40	>40
	entrenchment ratio	>1.4	>1.4	>1.4	<1.4
	incision ratio	<1.2	1.2-1.4	1.4-2.0	>2.0
	channel alteration	not evident	minor historic	major historic, or minor recent	extensive historic, or major recent
Braided	width/depth ratio	<30	30-40	40-50	>50
	entrenchment ratio	>2.0	>2.0	>2.0	<2.0
	incision ratio	<1.0	1.0-1.2	1.2-1.4	>1.4
	channel alteration	not evident	minor historic	major historic, or minor recent	extensive historic, or major recent

8.5 Hydrologic Characteristics

Variable Ranges for each Condition (Departure) Category

Stream Type	Variables	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)

Riffle-Pool (Dune Ripple)	wetted width/Wbkf	>0.75	0.75-0.50	0.50-0.25	<0.25
	exposed substrate	<20%	20-40	40-60	>60
	adjacent wetland features	extensive	present	minimal	altered/absent
	flow alteration	no known	minor	major	completely altered
Step-Pool (Cascade and Bedrock)	wetted width/Wbkf	>0.75	0.75-0.50	0.50-0.25	<0.25
	exposed substrate	<10%	10-30	30-50	>50
	adjacent wetland features	extensive	present	minimal	altered/absent
	flow alteration	no known	minor	major	completely altered
Plane Bed	wetted width/Wbkf	>0.75	0.75-0.50	0.50-0.25	<0.25
	exposed substrate	<20%	20-40	40-60	>60
	adjacent wetland features	extensive	present	minimal	altered/absent
	flow alteration	no known	minor	major	completely altered
Braided	wetted width/Wbkf	>0.50	0.50-0.30	0.30-0.10	<0.10
	exposed substrate	<50%	50-60	60-70	>70
	adjacent wetland features	extensive	present	minimal	altered/absent
	flow alteration	no known	minor	major	completely altered

8.6 Connectivity

Variable Ranges for each Condition (Departure) Category

Stream Type	Variables	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
Riffle-Pool (Dune Ripple)	reach obstructions	none	1-2 small at low flow	1-2 small to medium at bankfull flow	>2 at bankfull flow
	system obstructions	absent	limited	present	many
	refuge	abundant low and high flow refuge	abundant refuge, low or high flow limited	limited low and high flow refuge	refuge absent
Step-Pool	reach obstructions	none	1-2 small at low flow	1-2 small to medium at bankfull flow	>2 at bankfull flow

(Cascade and Bedrock)	system obstructions refuge	absent abundant low and high flow refuge	limited abundant refuge, low or high flow limited	present limited low and high flow refuge	many refuge absent
Plane Bed	reach obstructions	none	1-2 small at low flow	1-2 small to medium at bankfull flow	>2 at bankfull flow
	system obstructions refuge	absent abundant low and high flow refuge	limited abundant refuge, low or high flow limited	present limited low and high flow refuge	many refuge absent
Braided	reach obstructions	none	1-2 small at low flow	1-2 small to medium at bankfull flow	>2 at bankfull flow
	system obstructions refuge	absent abundant low and high flow refuge	limited abundant refuge, low or high flow limited	present limited low and high flow refuge	many refuge absent

8.7 River Banks

Variable Ranges for each Condition (Departure) Category

Stream Type	Variables	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
Riffle-Pool (Dune Ripple)	amount of bank erosion	<10%, typical, no revetments	10-30, infrequent, some revetments	30-60, unstable, extensive revetments	>60, unstable, failing revetments
	bank vegetation	>90% in each layer, diverse, good cover and bank stability	90-75 in each layer, diverse, good cover and bank stability	75-50 2 of 3 layers, reduced diversity, little cover and bank stability	<50 in 2 of 3 layers, limited diversity, no cover or bank stability
	bank canopy	>90%	90-75	75-50	<50
	undercut banks / mile	>30 / mile	30-15	15-5	<5
	undercut bank size rank 3-6	>50	50-25	25-10	<10

	undercut stability and overhanging vegetation	stable, abundant overhang, consistent water adjacency	some unstable boundaries or reduced overhang, consistent water adjacency	some unstable boundaries or reduced overhang, reduced water adjacency	mostly unstable boundaries, no overhang, reduced water adjacency
	mass failures	none	1	1-2	>3
Step-Pool (Cascade and Bedrock)	amount of bank erosion	<10%, typical	10-20, infrequent	20-50, unstable	>50, unstable
	bank vegetation	>90% in each layer, diverse, good cover and bank stability	90-75 in each layer, diverse, good cover and bank stability	75-50 2 of 3 layers, reduced diversity, little cover and bank stability	<50 in 2 of 3 layers, limited diversity, no cover or bank stability
	bank canopy	> 90%	90-80	80-60	<60
	undercut banks / mile	>15 / mile	15-10	10-5	<5
	undercut bank size rank 3-6	>50	50-25	25-10	<10
	undercut stability and overhanging vegetation	stable, abundant overhang, consistent water adjacency	some unstable boundaries or reduced overhang, consistent water adjacency	some unstable boundaries or reduced overhang, reduced water adjacency	mostly unstable boundaries, no overhang, reduced water adjacency
	mass failures	none	1	1-2	>3
Plane Bed	amount of bank erosion	<10%, typical	10-30, infrequent	30-60, unstable	>60, unstable
	bank vegetation	>90% in each layer, diverse, good cover and bank stability	90-75 in each layer, diverse, good cover and bank stability	75-50 2 of 3 layers, reduced diversity, little cover and bank stability	<50 in 2 of 3 layers, limited diversity, no cover or bank stability
	bank canopy	>90%	90-75	75-50	<50
	undercut banks / mile	>20 / mile	20-15	15-5	<5
	undercut bank size rank 3-6	>50	50-25	25-10	<10
	undercut stability and overhanging vegetation	stable, abundant overhang, consistent water adjacency	some unstable boundaries or reduced overhang, consistent water adjacency	some unstable boundaries or reduced overhang, reduced water adjacency	mostly unstable boundaries, no overhang, reduced water adjacency
	mass failures	none	1	1-2	>3
	amount of bank erosion	<10%, typical	10-30, infrequent	30-60, unstable	>60, unstable

	bank vegetation	>90% in each layer, diverse, good cover and bank stability	90-75 in each layer, diverse, good cover and bank stability	75-50 2 of 3 layers, reduced diversity, little cover and bank stability	<50 in 2 of 3 layers, limited diversity, no cover or bank stability
Braided	bank canopy	>90%	90-75	75-50	<50
	undercut banks / mile	>30 / mile	30-15	15-5	<5
	undercut bank size rank 3-6	>50	50-25	25-10	<10
	undercut stability and overhanging vegetation	stable, abundant overhang, consistent water adjacency	some unstable boundaries or reduced overhang, consistent water adjacency	some unstable boundaries or reduced overhang, reduced water adjacency	mostly unstable boundaries, no overhang, reduced water adjacency
	mass failures	none	1	1-2	>3

8.8 Riparian Area

Variable Ranges for each Condition (Departure) Category

Stream Type	Variables	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
Riffle-Pool (Dune Ripple)	buffer width	>150 ft	150-100	100-50	<50
	riparian vegetation	>75% in each layer, diverse, no invasives, closed canopy	75-50% in each layer, one type absent, minimal invasives, closed canopy	75-50% in each layer, several types absent, altered, bare or invasives, open canopy	<50% in each layer, several types absent, altered, bare or many invasive open, canopy
	river corridor development	absent	minimal	common	abundant
Step-Pool (Cascade and Bedrock)	buffer width	>200 ft	200-150	150-100	<100
	riparian vegetation	>90% in each layer, diverse, no invasives, closed canopy	90-75% in each layer, one type absent, minimal invasives, closed canopy	75-50% in each layer, several types absent, altered, bare or invasives, open canopy	<50% in each layer, several types absent, altered, bare or many invasive open, canopy
	river corridor development	absent	minimal	common	abundant
	buffer width	>150 ft	150-100	100-50	<50

Plane Bed	riparian vegetation	>75% in each layer, diverse, no invasives, closed canopy	75-50% in each layer, one type absent, minimal invasives, closed canopy	75-50% in each layer, several types absent, altered, bare or invasives, open canopy	<50% in each layer, several types absent, altered, bare or many invasive open, canopy
	river corridor development	absent	minimal	common	abundant
Braided	buffer width	>150 ft	150-100	100-50	<50
	riparian vegetation	>75% in each layer, diverse, no invasives, closed canopy	75-50% in each layer, one type absent, minimal invasives, closed canopy	75-50% in each layer, several types absent, altered, bare or invasives, open canopy	<50% in each layer, several types absent, altered, bare or many invasive open, canopy
	river corridor development	absent	minimal	common	abundant

APPENDIX F: Vermont ANR Reach Habitat Assessment (RHA) Field Forms

1. Riffle-Pool / Dune-Ripple
2. Step-Pool / Bedrock, Cascade
3. Plane Bed
4. Braided / Alluvial Fan
5. RHA Sketch Tally Form

(Visit http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassesspro for additional and updated field forms.)

VTANR REACH HABITAT ASSESSMENT ----- RIFFLE-POOL STREAM TYPE

(Also use this form for dune-ripple stream type.)

Stream Name:_____
Location: _____
_____
Observers: _____
Organization /Agency: _____
USGS Map Name(s):_____
Weather:_____
Flow: base / low / avg. Storm within past 7 days: Y / N

Segment I.D: _____
Date:_____
Town:_____
Elevation: _____ ft.
Latitude (N/S):_____
Longitude (E/W): _____
Drainage Area: _____ sq. mi.
Segment Length: _____ ft.

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	**Good (Minor)**	**Fair (Major)**	**Poor (Severe)**
8.1 Woody Debris Cover LWD size rank variable only used if ≥ 10 pieces	☐ LWD pieces / mile > 100 ☐ LWD size rank 3-6 >50% ☐ debris jams / mile > 5 ☐ high woody debris recruitment potential ☐ CPOM present in channel and margins	☐ 100 ≥ LWD / mile > 50 ☐ 50 ≥ LWD rank 3-6 > 25% ☐ 5 ≥ jams / mile > 3 ☐ moderate woody debris recruitment potential ☐ CPOM limited in channel and present in margins	☐ 50 ≥ LWD / mile > 25 ☐ 25 ≥ LWD rank 3-6 > 10% ☐ 3 ≥ jams / mile > 1 ☐ low woody debris recruitment potential ☐ CPOM limited in both channel and margins	☐ LWD / mile ≤ 25 ☐ LWD size rank 3-6 ≤ 10% ☐ debris jams absent ☐ no woody debris recruitment potential ☐ CPOM absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.2 Bed Substrate Cover *fines: sand if d_{50} ≥ gravel, otherwise silt. (Dune-ripple stream type: Fining only.)	☐ riffle embeddedness < 20% margin embeddedness < 40% ☐ fining* < 10% ☐ Riffle stability index < 70% ☐ sediment apparently stable & sorted ☐ substrate free of dense algae growth	☐ 20 ≤ emb_{riffle} < 40% 40 ≤ emb_{margin} < 60% ☐ 10 ≤ fining* < 20% ☐ 70 ≤ RSI < 80% ☐ some evidence of sediment mobility & lack of sorting ☐ small substrate patches covered by dense algae growth	☐ 40 ≤ emb_{riffle} < 75% 60 ≤ emb_{margin} < 80% ☐ 20 ≤ fining* < 40% ☐ 80 ≤ RSI < 90% ☐ major evidence of sediment mobility & lack of sorting ☐ large substrate patches covered by dense algae growth	☐ riffle embeddedness ≥ 75% margin embeddedness ≥ 80% ☐ fining* ≥ 40% ☐ RSI ≥ 90% ☐ sediments unstable, unsorted, soft underfoot ☐ most of substrate covered by dense algae growth
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.3 Scour and Deposition Features (Dune-ripple stream type: Only evaluate pools and ripples.) *Depth-velocity combinations* *fast-shallow* *fast-deep* *slow-shallow* *slow-deep* *(cutoffs: 1.0 fps, 1.5 ft)* Pool size rank variable only used if ≥ 5 pools	☐ pools / mile > 40 ☐ pool size rank 3-7 >50% ☐ good cover > 75% of total pool surface area ☐ riffle (ripple) coverage > 25% reach area, distinctly formed and complete ☐ 5 ≤ riffle spacing ≤ 7 bankfull channel widths (w_{bkf}) ☐ well-defined riffle-run-pool-glide pattern with all four depth-velocity combinations present ☐ finer deposition located entirely in slack water below larger substrates/debris, and along margins	☐ 40 ≥ pools / mile > 20 ☐ 50 ≥ pool rank 3-7 > 25% ☐ 75 ≥ good cover > 50% of total pool surface area ☐ 25 ≥ riffle coverage > 10% reach area, moderately well formed and complete ☐ 3 ≤ riffle spacing < 5, or 7 < riffle spacing ≤ 10 x w_{bkf} ☐ well-defined riffle-run-pool-glide pattern with three depth-velocity combinations dominant ☐ finer deposition located in slack water below larger substrates/debris, signs of mid-channel accumulation	☐ 20 ≥ pools / mile > 10 ☐ 25 ≥ pool rank 3-7 > 10% ☐ 50 ≥ good cover > 25% of total pool surface area ☐ 25 ≥ riffle coverage > 10% reach area, poorly formed and incomplete ☐ 1 ≤ riffle spacing < 3, or 10 < riffle spacing ≤ 12 x w_{bkf} ☐ moderately defined riffle-run-pool-glide pattern with two depth-velocity combinations dominant ☐ very large depositional features below larger substrates/debris, abundant mid-channel accumulation	☐ pools / mile ≤ 10 ☐ pool size rank 3-7 ≤ 10% ☐ good cover ≤ 25% of total pool surface area ☐ riffle (ripple) coverage ≤ 10% reach area, or mostly indistinct ☐ riffle spacing ≥ 12 bankfull channel widths ☐ poorly defined riffle-run-pool-glide pattern with one depth-velocity combination dominant ☐ finer deposition throughout channel, even filling pools, larger substrates almost buried **or** bed largely incised
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.4 Channel Morphology	☐ width/depth < 15, natural ☐ entrenchment ratio ≥ 1.4, incision ratio < 1.2, good floodplain access ☐ no evidence of channel alteration	☐ 15 ≤ w / d < 25, widening ☐ entrenchment ratio ≥ 1.4, 1.2 ≤ incision ratio < 1.4, reduced floodplain access ☐ evidence of minor historic channel alteration	☐ 25 ≤ w / d < 40, widening ☐ entrenchment ratio ≥ 1.4, 1.4 ≤ incision ratio < 2.0, limited floodplain access ☐ major historic or minor recent channel alteration	☐ w / d > 40, over-widening ☐ entrenchment ratio < 1.4 **or** incision ratio ≥ 2.0, floodplain access unlikely ☐ extensive historic or major recent channel alteration
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	**Good (Minor)**	**Fair (Major)**	**Poor (Severe)**
8.5 Hydrologic Characteristics	☐ wetted width / W_{bkf} > 0.75 ☐ exposed substrate < 20% ☐ adjacent springs, seeps, and wetlands extensive ☐ no known flow alteration	☐ 0.75 ≥ W_{wet} / W_{bkf} > 0.50 ☐ 20 ≤ exp. substrate < 40% ☐ adjacent springs, seeps, and wetlands present ☐ minor flow alteration likely due to flow regulation and/or land use changes	☐ 0.50 ≥ W_{wet} / W_{bkf} > 0.25 ☐ 40 ≤ exp. substrate < 60% ☐ adjacent springs, seeps, and wetlands minimal ☐ major flow alteration likely due to flow regulation and/or land use changes	☐ W_{wet} / W_{bkf} ≤ 0.25 ☐ exposed substrate ≥ 60% ☐ adjacent springs, seeps, and wetlands absent or altered ☐ runoff characteristics completely altered due to flow regulation and storm water influence
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.6 Connectivity Tend towards a higher/lower score for natural/man-made obstructions	☐ no obstructions in reach that block longitudinal movement of aquatic species over all but the lowest flows ☐ system obstructions absent ☐ abundant low **and** high flow refuge	☐ one or two small low flow obstructions present in reach that block movement of aquatic species ☐ limited system obstructions ☐ abundant refuge, with low **or** high flow refuge limited	☐ one or two small to medium bankfull obstructions present in reach that block movement of aquatic species ☐ system obstructions present ☐ limited low **and** high flow refuge	☐ more than two bankfull obstructions present in reach that block movement of aquatic species ☐ many system obstructions ☐ refuge absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.7 River Banks Select different boxes for LB and RB if necessary	☐ bank erosion <10%, typical of natural conditions, little or no bank revetments ☐ bank vegetation > 90% in tree, shrub and herb layers, diverse assemblages, plants create good cover and roots help stabilize bank	☐ 10 ≤ bank erosion < 30%, infrequent small areas, some bank revetments ☐ 90 ≥ bank vegetation > 75% in each layer, diverse assemblages, plants create good cover and roots help stabilize bank	☐ 30 ≤ bank erosion < 60%, mod. unstable banks, and/or extensive bank revetments ☐ 75 ≥ bank vegetation > 50%, in two of three layers, reduced diversity, plants create limited cover and roots do not stabilize bank	☐ bank erosion ≥ 60%, banks unstable, extensive erosion, and failing bank revetments ☐ bank vegetation ≤ 50% in two of three layers, limited diversity, plants create no cover and roots do not stabilize bank
Undercut size rank variable only used if ≥ 5 undercuts	☐ bank canopy > 90% ☐ undercut banks / mile > 30 ☐ undercut bank size rank 3-6 > 50% ☐ undercut banks with mostly stable boundaries, abundant overhanging vegetation, and consistent water adjacency	☐ 90 ≥ bank canopy > 75% ☐ 30 ≥ undercuts / mile > 15 ☐ 50 ≥ undercut bank size rank 3-6 > 25% ☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and consistent water adjacency	☐ 75 ≥ bank canopy > 50% ☐ 15 ≥ undercuts / mile > 5 ☐ 25 ≥ undercut bank size rank 3-6 > 10% ☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and reduced water adjacency	☐ bank canopy ≤ 50% ☐ undercuts / mile ≤ 5 ☐ undercut bank size rank 3-6 ≤ 10% ☐ undercuts with mostly unstable boundaries, no overhanging vegetation, and reduced water adjacency
(score each bank)	☐ no mass failures in valley	☐ 1 mass failure in valley	☐ 1 - 2 mass failures in valley	☐ ≥ 3 mass failures in valley
SCORE _____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1
SCORE _____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1
8.8 Riparian Area Select different boxes for LB and RB if necessary	☐ buffer width > 150 ft ☐ rip. vegetation > 75% in tree, shrub and herb layers, diverse assemblages, no invasives, maximum channel canopy	☐ 150 ≥ buffer width > 100 ft ☐ 75 ≥ rip. veg. > 50% in each layer, one plant type absent, minimal invasives, maximum channel canopy	☐ 100 ≥ buffer width > 50 ft ☐ 75 ≥ rip. veg. > 50% in each layer, several types absent, altered patches, invasives present, reduced canopy	☐ buffer width ≤ 50 ft ☐ rip. veg. ≤ 50% in each layer, several types absent, large altered areas, invasives present, reduced canopy
(score each side of the channel)	☐ river corridor development and infrastructure absent	☐ river corridor development and infrastructure minimal	☐ river corridor development and infrastructure common	☐ river corridor development and infrastructure abundant
SCORE _____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1
SCORE _____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1

8.9 Score: front _____ + back _____ = total _____

Percentage: total score _____ x (100 / 160) = _____

Overall Physical Habitat Condition: _____

SHTD ☐ Existing Stream Habitat Type: _____

Score	*Percentage*	*Condition (Departure)*
136 – 160	**85 – 100**	Reference (None)
104 – 135	**65 – 84**	Good (Minor)
56 – 103	**35 – 64**	Fair (Major)
0 – 55	**0 – 34**	Poor (Severe)

VTANR REACH HABITAT ASSESSMENT ----- STEP-POOL STREAM TYPE

(Also use this form for cascade and bedrock stream types.)

Stream Name:_____
Location: _____
_____
Observers: _____
Organization /Agency: _____
USGS Map Name(s):_____
Weather:_____
Flow: base / low / avg. Storm within past 7 days: Y / N

Segment I.D: _____
Date:_____
Town:_____
Elevation: _____ ft.
Latitude (N/S):_____
Longitude (E/W): _____
Drainage Area: _____ sq. mi.
Segment Length: _____ ft.

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
8.1 Woody Debris Cover LWD size rank variable only used if ≥ 10 pieces	☐ LWD pieces / mile > 200 ☐ LWD size rank 3-6 >75% ☐ debris jams / mile > 25 ☐ high woody debris recruitment potential ☐ CPOM present in channel and margins	☐ 200 ≥ LWD / mile > 100 ☐ 75 ≥ LWD rank 3-6 > 50% ☐ 25 ≥ jams / mile > 15 ☐ moderate woody debris recruitment potential ☐ CPOM limited in channel and present in margins	☐ 100 ≥ LWD / mile > 50 ☐ 50 ≥ LWD rank 3-6 > 25% ☐ 15 ≥ jams / mile > 5 ☐ low woody debris recruitment potential ☐ CPOM limited in both channel and margins	☐ LWD / mile ≤ 50 ☐ LWD size rank 3-6 ≤ 25% ☐ jams / mile ≤ 5 ☐ no woody debris recruitment potential ☐ CPOM absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.2 Bed Substrate Cover *fines: sand if d_{50} ≥ gravel, otherwise silt.	☐ pool embeddedness < 25% margin embeddedness < 40% ☐ fining* < 10% ☐ sediment apparently stable & sorted ☐ substrate free of dense algae growth	☐ 25 ≤ emb_{pool} < 50% 40 ≤ emb_{margin} < 60% ☐ 10 ≤ fining* < 20% ☐ some evidence of sediment mobility & lack of sorting ☐ small substrate patches covered by dense algae growth	☐ 50 ≤ emb_{pool} < 75% 60 ≤ emb_{margin} < 80% ☐ 20 ≤ fining* < 40% ☐ major evidence of sediment mobility & lack of sorting ☐ large substrate patches covered by dense algae growth	☐ pool embeddedness ≥ 75% margin embeddedness ≥ 80% ☐ fining* ≥ 40% ☐ sediments unstable, unsorted, soft underfoot ☐ most of substrate covered by dense algae growth
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.3 Scour and Deposition Features *Depth-velocity combinations* *fast-shallow* *fast-deep* *slow-shallow* *slow-deep* *(cutoffs: 1.0 fps, 1.5 ft)* Pool size rank variable only used if ≥ 5 pools (Cascade and bedrock stream types: Do not evaluate variables related to step pattern.)	☐ pools / mile > 70 ☐ pool size rank 3-7 >50% ☐ good cover > 75% of total pool surface area ☐ steps are distinctly formed, complete and stable ☐ 5 ≤ step spacing ≤ 7 bankfull channel widths (w_{bkf}) ☐ more than two depth-velocity combinations present ☐ finer deposition located entirely in slack water below larger substrates/debris, and along margins	☐ 70 ≥ pools / mile > 50 ☐ 50 ≥ pool rank 3-7 > 25% ☐ 75 ≥ good cover > 50% of total pool surface area ☐ steps are moderately well formed, complete and stable ☐ 3 ≤ step spacing < 5, or 7 < step spacing ≤ 10 x w_{bkf} ☐ two depth-velocity combinations present ☐ finer deposition located in slack water below larger substrates/debris, signs of mid-channel accumulation	☐ 50 ≥ pools / mile > 30 ☐ 25 ≥ pool rank 3-7 > 10% ☐ 50 ≥ good cover > 25% of total pool surface area ☐ steps are poorly formed, incomplete and unstable ☐ 1 ≤ step spacing < 3, or 10 < step spacing ≤ 15 x w_{bkf} ☐ one or two depth-velocity combinations present ☐ very large depositional features below larger substrates/debris, abundant mid-channel accumulation	☐ pools / mile ≤ 30 ☐ pool size rank 3-7 ≤ 10% ☐ good cover over ≤ 25% of total pool surface area ☐ steps are indistinct or absent, or very unstable ☐ step spacing ≥ 15 bankfull channel widths ☐ one depth-velocity combination present ☐ finer deposition throughout channel, even filling pools, larger substrates almost buried **or** bed largely incised
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.4 Channel Morphology	☐ width/depth < 12, natural ☐ entrenchment ratio ≥ 1.2, incision ratio < 1.2, good floodplain access ☐ no evidence of channel alteration	☐ 12 ≤ w / d < 15, widening ☐ entrenchment ratio ≥ 1.2, 1.2 ≤ incision ratio < 1.4, reduced floodplain access ☐ evidence of minor historic channel alteration	☐ 15 ≤ w / d < 25, widening ☐ entrenchment ratio ≥ 1.2, 1.4 ≤ incision ratio < 2.0, limited floodplain access ☐ major historic or minor recent alteration	☐ w / d ≥ 25, over-widening ☐ entrenchment ratio < 1.2 **or** incision ratio ≥ 2.0, floodplain access unlikely ☐ extensive historic or major recent alteration
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	**Good (Minor)**	**Fair (Major)**	**Poor (Severe)**
8.5 Hydrologic Characteristics	☐ wetted width / W_{bkf} > 0.75 ☐ exposed substrate < 10% ☐ adjacent springs, seeps, and wetlands extensive ☐ no known flow alteration	☐ 0.75 ≥ W_{wet} / W_{bkf} > 0.50 ☐ 10 ≤ exp. substrate < 30% ☐ adjacent springs, seeps, and wetlands present ☐ minor flow alteration likely due to flow regulation and/or land use changes	☐ 0.50 ≥ W_{wet} / W_{bkf} > 0.25 ☐ 30 ≤ exp. substrate < 50% ☐ adjacent springs, seeps, and wetlands minimal ☐ major flow alteration likely due to flow regulation and/or land use changes	☐ W_{wet} / W_{bkf} ≤ 0.25 ☐ exposed substrate ≥ 50% ☐ adjacent springs, seeps, and wetlands absent or altered ☐ runoff characteristics completely altered due to flow regulation and storm water influence
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.6 Connectivity Tend towards a higher/lower score for natural/man-made obstructions	☐ no obstructions in reach that block longitudinal movement of aquatic species over all but the lowest flows ☐ system obstructions absent ☐ abundant low **and** high flow refuge	☐ one or two small low flow obstructions present in reach that block movement of aquatic species ☐ limited system obstructions ☐ abundant refuge, with low **or** high flow refuge limited	☐ one or two small to medium bankfull obstructions present in reach that block movement of aquatic species ☐ system obstructions present ☐ limited low **and** high flow refuge	☐ more than two bankfull obstructions present in reach that block movement of aquatic species ☐ many system obstructions ☐ refuge absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.7 River Banks Select different boxes for LB and RB if necessary Undercut size rank variable only used if ≥ 5 undercuts **(score each bank)**	☐ bank erosion <10%, typical of natural conditions, little or no bank revetments ☐ bank vegetation > 90% in tree, shrub and herb layers, diverse assemblages, plants create good cover and roots help stabilize bank ☐ bank canopy > 90% ☐ undercut banks / mile > 15 ☐ undercut bank size rank 3-6 > 50% ☐ undercut banks with mostly stable boundaries, abundant overhanging vegetation, and consistent water adjacency ☐ no mass failures in valley	☐ 10 ≤ bank erosion < 20%, infrequent small areas, some bank revetments ☐ 90 ≥ bank vegetation > 75% in each layer, diverse assemblages, plants create good cover and roots help stabilize bank ☐ 90 > bank canopy > 80% ☐ 15 ≥ undercuts / mile > 10 ☐ 50 ≥ undercut bank size rank 3-6 > 25% ☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and consistent water adjacency ☐ 1 mass failure in valley	☐ 20 ≤ bank erosion < 50%, mod. unstable banks, and/or extensive bank revetments ☐ 75 ≥ bank vegetation > 50%, in two of three layers, reduced diversity, plants create limited cover and roots do not stabilize bank ☐ 80 ≥ bank canopy > 60% ☐ 10 ≥ undercuts / mile > 5 ☐ 25 ≥ undercut bank size rank 3-6 > 10% ☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and reduced water adjacency ☐ 1 - 2 mass failures in valley	☐ bank erosion ≥ 50%, banks unstable, extensive erosion, and failing bank revetments ☐ bank vegetation ≤ 50% in two of three layers, limited diversity, plants create no cover and roots do not stabilize bank ☐ bank canopy ≤ 60% ☐ undercuts / mile ≤ 5 ☐ undercut bank size rank 3-6 ≤ 10% ☐ undercuts with mostly unstable boundaries, no overhanging vegetation, and reduced water adjacency ☐ > 3 mass failures in valley
SCORE _____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1
SCORE _____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1
8.8 Riparian Area Select different boxes for LB and RB if necessary **(score each side of the channel)**	☐ buffer width > 200 ft ☐ rip. vegetation > 90% in tree, shrub and herb layers, diverse assemblages, no invasives, maximum channel canopy ☐ river corridor development and infrastructure absent	☐ 200 ≥ buffer width > 150 ft ☐ 90 ≥ rip. veg. > 75% in each layer, one plant type absent, minimal invasives, maximum channel canopy ☐ river corridor development and infrastructure minimal	☐ 150 ≥ buffer width > 100 ft ☐ 75 ≥ rip. veg. > 50% in each layer, several types absent, altered patches, invasives present, reduced canopy ☐ river corridor development and infrastructure common	☐ buffer width ≤ 100 ft ☐ rip. veg. ≤ 50% in each layer, several types absent, large altered areas, invasives present, reduced canopy ☐ river corridor development and infrastructure abundant
SCORE _____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1
SCORE _____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1

8.9 Score: front _____ + back _____ = total _____

Percentage: total score _____ x (100 / 160) = _____

Overall Physical Habitat Condition: _____

SHTD ☐ Existing Stream Habitat Type: _____

Score	*Percentage*	*Condition (Departure)*
136-160	**85 – 100**	Reference (None)
104 – 135	**65 – 84**	Good (Minor)
56 – 103	**35 – 64**	Fair (Major)
0 – 55	**0 – 34**	Poor (Severe)

VTANR REACH HABITAT ASSESSMENT ----- PLANE BED STREAM TYPE

Stream Name:_____
Location: _____
_____
Observers: _____
Organization /Agency: _____
USGS Map Name(s):_____
Weather:_____
Flow: base / low / avg. Storm within past 7 days: Y / N

Segment I.D: _____
Date:_____
Town:_____
Elevation: _____ ft.
Latitude (N/S):_____
Longitude (E/W): _____
Drainage Area: _____ sq. mi.
Segment Length: _____ ft.

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	**Good (Minor)**	**Fair (Major)**	**Poor (Severe)**
8.1 Woody Debris Cover LWD size rank variable only used if ≥ 10 pieces	☐ LWD pieces / mile > 50 ☐ LWD size rank 3-6 >50% ☐ debris jams / mile > 5 ☐ high woody debris recruitment potential ☐ CPOM present in channel and margins	☐ 50 ≥ LWD / mile > 25 ☐ 50 ≥ LWD rank 3-6 > 25% ☐ 5 ≥ jams / mile > 3 ☐ moderate woody debris recruitment potential ☐ CPOM limited in channel and present in margins	☐ 25 ≥ LWD / mile > 10 ☐ 25 ≥ LWD rank 3-6 > 10% ☐ 3 ≥ jams / mile > 1 ☐ low woody debris recruitment potential ☐ CPOM limited in both channel and margins	☐ LWD / mile ≤ 10 ☐ LWD size rank 3-6 ≤ 10% ☐ debris jams absent ☐ no woody debris recruitment potential ☐ CPOM absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.2 Bed Substrate Cover *fines: sand if d_{50} ≥ gravel, otherwise silt.	☐ run embeddedness < 20% margin embeddedness < 40% ☐ fining* < 10% ☐ sediment apparently stable & sorted ☐ imbrication limited, or mostly with the short axis of particles overlapping in the direction of flow ☐ substrate free of dense algae growth	☐ 20 ≤ emb_{run} < 40% 40 ≤ emb_{margin} < 60% ☐ 10 ≤ fining* < 20% ☐ some evidence of sediment mobility & lack of sorting ☐ imbrication moderate, mostly with the short axis of particles overlapping in the direction of flow ☐ small substrate patches covered by dense algae growth	☐ 40 ≤ emb_{run} < 75% 60 ≤ emb_{margin} < 80% ☐ 20 ≤ fining* < 40% ☐ major evidence of sediment mobility & lack of sorting ☐ imbrication moderate, mostly with the long axis of particles overlapping in the direction of flow ☐ large substrate patches covered by dense algae growth	☐ run embeddedness ≥ 75% margin embeddedness ≥ 80% ☐ fining* ≥ 40% ☐ sediments unstable, unsorted, soft underfoot ☐ imbrication extensive, mostly with the long axis of particles overlapping in the direction of flow ☐ most of substrate covered by dense algae growth
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.3 Scour and Deposition Features *Depth-velocity combinations* *fast-shallow* *fast-deep* *slow-shallow* *slow-deep* *(cutoffs: 1.0 fps, 1.5 ft)* Pool size rank variable only used if ≥ 5 pools	☐ pool formation evident, with ≥50% pool size rank 3-7 ☐ widespread riffle formation ☐ more than two depth-velocity combinations present ☐ meandering thalweg clearly identifiable in cross section, with evidence of side and lateral bar formation ☐ finer deposition located entirely in slack water below larger substrates/debris, and along margins	☐ pool formation evident, with <50% pool size rank 3-7 ☐ moderate riffle formation ☐ two depth-velocity combinations present ☐ meandering thalweg moderately identifiable in cross section, with some evidence of bar formation ☐ finer deposition located in slack water below larger substrates/debris, signs of mid-channel accumulation	☐ limited trace of pool formation ☐ limited riffle formation ☐ one or two depth-velocity combinations present ☐ meandering thalweg barely identifiable in the cross section, with minimal evidence of bar formation ☐ very large depositional features below larger substrates/debris, abundant mid-channel accumulation	☐ pool formation completely absent ☐ no riffle formation ☐ one depth-velocity combination present ☐ meandering thalweg not identifiable in the cross section, with no evidence of bar formation ☐ finer deposition throughout channel, even filling pools, larger substrates almost buried **or** bed largely incised
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.4 Channel Morphology	☐ width/depth < 15, natural ☐ entrenchment ratio ≥ 1.4, incision ratio < 1.2, good floodplain access ☐ no evidence of channel alteration	☐ 15 ≤ w / d < 25, widening ☐ entrenchment ratio ≥ 1.4, 1.2 ≤ incision ratio < 1.4, reduced floodplain access ☐ evidence of minor historic channel alteration	☐ 25 ≤ w /d < 40, widening ☐ entrenchment ratio ≥ 1.4, 1.4 ≤ incision ratio < 2.0, limited floodplain access ☐ major historic or minor recent channel alteration	☐ w /d ≥ 40, over-widening ☐ entrenchment ratio < 1.4 **or** incision ratio ≥ 2.0, floodplain access unlikely ☐ extensive historic or major recent channel alteration
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	**Good (Minor)**	**Fair (Major)**	**Poor (Severe)**
8.5 Hydrologic Characteristics	☐ wetted width / W_{bkf} > 0.75 ☐ exposed substrate < 20% ☐ adjacent springs, seeps, and wetlands extensive ☐ no known flow alteration	☐ 0.75 ≥ W_{wet} / W_{bkf} > 0.50 ☐ 20 ≤ exp. substrate < 40% ☐ adjacent springs, seeps, and wetlands present ☐ minor flow alteration likely due to flow regulation and/or land use changes	☐ 0.50 ≥ W_{wet} / W_{bkf} > 0.25 ☐ 40 ≤ exp. substrate < 60% ☐ adjacent springs, seeps, and wetlands minimal ☐ major flow alteration likely due to flow regulation and/or land use changes	☐ W_{wet} / W_{bkf} ≤ 0.25 ☐ exposed substrate ≥ 60% ☐ adjacent springs, seeps, and wetlands altered or absent ☐ runoff characteristics completely altered due to flow regulation and storm water influence
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.6 Connectivity Tend towards a higher/lower score for natural/man-made obstructions	☐ no obstructions in reach that block longitudinal movement of aquatic species over all but the lowest flows ☐ system obstructions absent ☐ abundant low **and** high flow refuge	☐ one or two small low flow obstructions present in reach that block movement of aquatic species ☐ limited system obstructions ☐ abundant refuge, with low **or** high flow refuge limited	☐ one or two small to medium bankfull obstructions present in reach that block movement of aquatic species ☐ system obstructions present ☐ limited low **and** high flow refuge	☐ more than two bankfull obstructions present in reach that block movement of aquatic species ☐ many system obstructions ☐ refuge absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.7 River Banks Select different boxes for LB and RB if necessary Undercut size rank variable only used if ≥ 5 undercuts **(score each bank)**	☐ bank erosion <10%, typical of natural conditions, little or no bank revetments ☐ bank vegetation > 90% in tree, shrub and herb layers, diverse assemblages, plants create good cover and roots help stabilize bank ☐ bank canopy > 90% ☐ undercut banks / mile > 20 ☐ undercut bank size rank 3-6 > 50% ☐ undercut banks with mostly stable boundaries, abundant overhanging vegetation, and consistent water adjacency ☐ no mass failures in valley	☐ 10 ≤ bank erosion < 30%, infrequent small areas, some bank revetments ☐ 90 ≥ bank vegetation > 75% in each layer, diverse assemblages, plants create good cover and roots help stabilize bank ☐ 90 ≥ bank canopy > 75% ☐ 20 ≥ undercuts / mile > 15 ☐ 50 ≥ undercut bank size rank 3-6 > 25% ☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and consistent water adjacency ☐ 1 mass failure in valley	☐ 30 ≤ bank erosion < 60%, mod. unstable banks, and/or extensive bank revetments ☐ 75 ≥ bank vegetation > 50%, in two of three layers, reduced diversity, plants create limited cover and roots do not stabilize bank ☐ 75 ≥ bank canopy > 50% ☐ 15 ≥ undercuts / mile > 5 ☐ 25 ≥ undercut bank size rank 3-6 > 10% ☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and reduced water adjacency ☐ 1 - 2 mass failures in valley	☐ bank erosion ≥ 60%, banks unstable, extensive erosion, and failing bank revetments ☐ bank vegetation ≤ 50% in two of three layers, limited diversity, plants create no cover and roots do not stabilize bank ☐ bank canopy ≤ 50% ☐ undercuts / mile ≤ 5 ☐ undercut bank size rank 3-6 ≤ 10% ☐ undercuts with mostly unstable boundaries, no overhanging vegetation, and reduced water adjacency ☐ > 3 mass failures in valley
SCORE _____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1
SCORE _____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1
8.8 Riparian Area Select different boxes for LB and RB if necessary **(score each side of the channel)**	☐ buffer width > 150 ft ☐ rip. vegetation > 75% in tree, shrub and herb layers, diverse assemblages, no invasives, maximum channel canopy ☐ river corridor development and infrastructure absent	☐ 150 ≥ buffer width > 100 ft ☐ 75 ≥ rip. veg. > 50% in each layer, one plant type absent, minimal invasives, maximum channel canopy ☐ river corridor development and infrastructure minimal	☐ 100 ≥ buffer width > 50 ft ☐ 75 ≥ rip. veg. > 50% in each layer, several types absent, altered patches, invasives present, reduced canopy ☐ river corridor development and infrastructure common	☐ buffer width ≤ 50 ft ☐ rip. veg. ≤ 50% in each layer, several types absent, large altered areas, invasives present, reduced canopy ☐ river corridor development and infrastructure abundant
SCORE _____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1
SCORE _____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1

8.9 Score: front _____ + back _____ = total _____

Percentage: total score _____ x (100 / 160) = _____

Overall Physical Habitat Condition: _____

SHTD ☐ Existing Stream Habitat Type: _____

Score	*Percentage*	*Condition (Departure)*
136 – 160	**85 – 100**	Reference (None)
104 – 135	**65 – 84**	Good (Minor)
56 – 103	**35 – 64**	Fair (Major)
0 – 55	**0 – 34**	Poor (Severe)

VTANR REACH HABITAT ASSESSMENT ----- BRAIDED STREAM TYPE

(Also use this form for alluvial fans.)

Stream Name:_____
Location: _____
_____
Observers: _____
Organization /Agency: _____
USGS Map Name(s):_____
Weather:_____
Flow: base / low / avg. Storm within past 7 days: Y / N

Segment I.D: _____
Date:_____
Town:_____
Elevation: _____ ft.
Latitude (N/S):_____
Longitude (E/W): _____
Drainage Area: _____ sq. mi.
Segment Length: _____ ft.

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	**Good (Minor)**	**Fair (Major)**	**Poor (Severe)**
8.1 Woody Debris Cover LWD size rank variable only used if ≥ 10 pieces	☐ LWD pieces / mile > 100 ☐ LWD size rank 3-6 >50% ☐ debris jams / mile > 5 ☐ high woody debris recruitment potential ☐ CPOM present in channel and margins	☐ 100 ≥ LWD / mile > 50 ☐ 50 ≥ LWD rank 3-6 > 25% ☐ 5 ≥ jams / mile > 3 ☐ moderate woody debris recruitment potential ☐ CPOM limited in channel and present in margins	☐ 50 ≥ LWD / mile > 25 ☐ 25 ≥ LWD rank 3-6 > 10% ☐ 3 ≥ jams / mile > 1 ☐ low woody debris recruitment potential ☐ CPOM limited in both channel and margins	☐ LWD / mile ≤ 25 ☐ LWD size rank 3-6 ≤ 10% ☐ debris jams absent ☐ no woody debris recruitment potential ☐ CPOM absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.2 Bed Substrate Cover *fines: sand if d_{50} ≥ gravel, otherwise silt.	☐ riffle embeddedness < 20% margin embeddedness < 40% ☐ fining* < 10% ☐ Riffle stability index < 70% ☐ sediment apparently stable & sorted ☐ substrate free of dense algae growth	☐ 20 ≤ emb_{riffle} < 40% 40 ≤ emb_{margin} < 60% ☐ 10 ≤ fining* < 20% ☐ 70 ≤ RSI < 80% ☐ some evidence of sediment mobility & lack of sorting ☐ small substrate patches covered by dense algae growth	☐ 40 ≤ emb_{riffle} < 75% 60 ≤ emb_{margin} < 80% ☐ 20 ≤ fining* < 40% ☐ 80 ≤ RSI < 90% ☐ major evidence of sediment mobility & lack of sorting ☐ large substrate patches covered by dense algae growth	☐ riffle embeddedness ≥ 75% margin embeddedness ≥ 80% ☐ fining* ≥ 40% ☐ RSI ≥ 90% ☐ sediments unstable, unsorted, soft underfoot ☐ most of substrate covered by dense algae growth
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.3 Scour and Deposition Features *Depth-velocity combinations* *fast-shallow* *fast-deep* *slow-shallow* *slow-deep* *(cutoffs: 1.0 fps, 1.5 ft)* Pool size rank variable only used if ≥ 5 pools	☐ pools / mile > 40 ☐ pool size rank 3-7 >50% ☐ good cover > 75% of total pool surface area ☐ riffle coverage > 25% reach area, distinctly formed and complete ☐ 5 ≤ riffle spacing ≤ 7 bankfull channel widths (w_{bkf}) ☐ well-defined riffle-run-pool-glide pattern with all four depth-velocity combinations present ☐ stable bars, vegetative cover on depositional features ≥ 50%, particles well-sorted	☐ 40 ≥ pools / mile > 20 ☐ 50 ≥ pool rank 3-7 > 25% ☐ 75 ≥ good cover > 50% of total pool surface area ☐ 25 ≥ riffle coverage > 10% reach area, moderately well formed and complete ☐ 3 ≤ riffle spacing < 5, or 7 < riffle spacing ≤ 10 x w_{bkf} ☐ well-defined riffle-run-pool-glide pattern with three depth-velocity combinations dominant ☐ mostly stable bars, vegetative cover on depositional features 50-25%, particles moderately sorted	☐ 20 ≥ pools / mile > 10 ☐ 25 ≥ pool rank 3-7 > 10% ☐ 50 ≥ good cover > 25% of total pool surface area ☐ 25 ≥ riffle coverage > 10% reach area, poorly formed and incomplete ☐ 1 ≤ riffle spacing < 3, or 10 < riffle spacing ≤ 12 x w_{bkf} ☐ moderately defined riffle-run-pool-glide pattern with two depth-velocity combinations dominant ☐ unstable bars present, vegetative cover on depositional features 25-10%, particles minimally sorted	☐ pools / mile ≤ 10 ☐ pool size rank 3-7 ≤ 10% ☐ good cover ≤ 25% of total pool surface area ☐ riffle coverage ≤ 10% reach area, or mostly indistinct or absent ☐ riffle spacing ≥ 12 bankfull channel widths ☐ poorly defined riffle-run-pool-glide pattern with one depth-velocity combination dominant ☐ mostly unstable bars, vegetative cover on depositional features < 10%, particles not sorted
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.4 Channel Morphology	☐ width/depth < 30, natural ☐ entrenchment ratio ≥ 2.0, incision ratio < 1.0, good floodplain access ☐ no evidence of channel alteration	☐ 30 ≤ w/ d < 40, widening ☐ entrenchment ratio ≥ 2.0, 1.0 ≤ incision ratio < 1.2, reduced floodplain access ☐ evidence of minor historic channel alteration	☐ 40 ≤ w / d < 50, widening ☐ entrenchment ratio ≥ 2.0, 1.2 ≤ incision ratio < 1.4, limited floodplain access ☐ major historic or minor recent channel alteration	☐ w / d ≥ 50, over-widening ☐ entrenchment ratio < 2.0 **or** incision ratio ≥ 1.4, floodplain access unlikely ☐ extensive historic or major recent channel alteration
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	**Good (Minor)**	**Fair (Major)**	**Poor (Severe)**
8.5 Hydrologic Characteristics	☐ wetted width / W_{bkf} > 0.50 ☐ exposed substrate < 50% ☐ adjacent springs, seeps, and wetlands extensive ☐ no known flow alteration	☐ 0.50 ≥ W_{wet} / W_{bkf} > 0.30 ☐ 50 ≤ exp. substrate < 60% ☐ adjacent springs, seeps, and wetlands present ☐ minor flow alteration likely due to flow regulation and/or land use changes	☐ 0.30 ≥ W_{wet} / W_{bkf} > 0.10 ☐ 60 ≤ exp. substrate < 70% ☐ adjacent springs, seeps, and wetlands minimal ☐ major flow alteration likely due to flow regulation and/or land use changes	☐ W_{wet} / W_{bkf} ≤ 0.10 ☐ exposed substrate ≥ 70% ☐ adjacent springs, seeps, and wetlands absent or altered ☐ runoff characteristics completely altered due to flow regulation and storm water influence
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.6 Connectivity Tend towards a higher/lower score for natural/man-made obstructions	☐ no obstructions in reach that block longitudinal movement of aquatic species over all but the lowest flows ☐ system obstructions absent ☐ abundant low **and** high flow refuge	☐ one or two small low flow obstructions present in reach that block movement of aquatic species ☐ limited system obstructions ☐ abundant refuge, with low **or** high flow refuge limited	☐ one or two small to medium bankfull obstructions present in reach that block movement of aquatic species ☐ system obstructions present ☐ limited low **and** high flow refuge	☐ more than two bankfull obstructions present in reach that block movement of aquatic species ☐ many system obstructions ☐ refuge absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8.7 River Banks Select different boxes for LB and RB if necessary	☐ bank erosion <10%, typical of natural conditions, little or no bank revetments ☐ bank vegetation > 90% in tree, shrub and herb layers, diverse assemblages, plants create good cover and roots help stabilize bank	☐ 10 ≤ bank erosion < 30%, infrequent small areas, some bank revetments ☐ 90 ≥ bank vegetation > 75% in each layer, diverse assemblages, plants create good cover and roots help stabilize bank	☐ 30 ≤ bank erosion < 60%, mod. unstable banks, and/or extensive bank revetments ☐ 75 ≥ bank vegetation > 50%, in two of three layers, reduced diversity, plants create limited cover and roots do not stabilize bank	☐ bank erosion ≥ 60%, banks unstable, extensive erosion, and failing bank revetments ☐ bank vegetation ≤ 50% in two of three layers, limited diversity, plants create no cover and roots do not stabilize bank
Undercut size rank variable only used if ≥ 5 undercuts	☐ bank canopy > 90% ☐ undercut banks / mile > 30 ☐ undercut bank size rank 3-6 > 50% ☐ undercut banks with mostly stable boundaries, abundant overhanging vegetation, and consistent water adjacency	☐ 90 ≥ bank canopy > 75% ☐ 30 ≥ undercuts / mile > 15 ☐ 50 ≥ undercut bank size rank 3-6 > 25% ☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and consistent water adjacency	☐ 75 ≥ bank canopy > 50% ☐ 15 ≥ undercuts / mile > 5 ☐ 25 ≥ undercut bank size rank 3-6 > 10% ☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and reduced water adjacency	☐ bank canopy ≤ 50% ☐ undercuts / mile ≤ 5 ☐ undercut bank size rank 3-6 ≤ 10% ☐ undercuts with mostly unstable boundaries, no overhanging vegetation, and reduced water adjacency
(score each bank)	☐ no mass failures in valley	☐ 1 mass failure in valley	☐ 1 - 2 mass failures in valley	☐ > 3 mass failures in valley
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1
8.8 Riparian Area Select different boxes for LB and RB if necessary	☐ buffer width > 150 ft ☐ rip. vegetation > 75% in tree, shrub and herb layers, diverse assemblages, no invasives, maximum channel canopy	☐ 150 ≥ buffer width > 100 ft ☐ 75 ≥ rip. veg. > 50% in each layer, one plant type absent, minimal invasives, maximum channel canopy	☐ 100 ≥ buffer width > 50 ft ☐ 75 ≥ rip. veg. > 50% in each layer, several types absent, altered patches, invasives present, reduced canopy	☐ buffer width ≤ 50 ft ☐ rip. veg. ≤ 50% in each layer, several types absent, large altered areas, invasives present, reduced canopy
(score each side of the channel)	☐ river corridor development and infrastructure absent	☐ river corridor development and infrastructure minimal	☐ river corridor development and infrastructure common	☐ river corridor development and infrastructure abundant
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1

8.9 Score: front _____ + back _____ = total _____

Percentage: total score _____ x (100 / 160) = _____

Overall Physical Habitat Condition: _____

SHTD ☐ Existing Stream Habitat Type: _____

Score	*Percentage*	*Condition (Departure)*
136 – 160	**85 – 100**	Reference (None)
104 – 135	**65 – 84**	Good (Minor)
56 – 103	**35 – 64**	Fair (Major)
0 – 55	**0 – 34**	Poor (Severe)

Tally Sheet (page 2)

Stream Name:_____ Segment I.D: _____

Location: _____ Date:_____

☐ Sub-Reach

6.1 Large Woody Debris and Jams

Rank	D_{large} (ft)	L (w_{bkf})	Tally	#	%
1	$0.5 \leq D < 1.0$	< 0.5			
2	$0.5 \leq D < 1.0$	≥ 0.5			
3	$1.0 \leq D < 2.0$	< 0.5			
4	$1.0 \leq D < 2.0$	≥ 0.5			
5	$D \geq 2.0$	< 0.5			
6	$D \geq 2.0$	≥ 0.5			
		Total LWDs			
		# LWDs / mile			
		# Debris jams	Full	Part	Total
		# Debris jams / mile	Full	Part	Total

6.2 Pools (note vegetative cover, surface turbulence, fines)

Rank	D (ft)	L,W (w_{bkf})	Tally	#	%
1	$1.0 \leq D < 2.0$	< 0.5			
2	$1.0 \leq D < 2.0$	≥ 0.5			
3	$2.0 \leq D < 3.0$	< 0.5			
4	$2.0 \leq D < 3.0$	≥ 0.5			
5	$D \geq 3.0$	< 0.5			
6	$D \geq 3.0$	≥ 0.5			
7	$D \geq 3.0$	≥ 1.0			
		Total pools			
		# Pools / mile			

6.3 Refuge Areas / Connections

ID	Location	Q_{access}	Notes
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	

6.4 Undercut Banks (note stability, overhanging vegetation)

Rank	D_{max} (ft)	L (ft)	Tally	#	%
1	$0.5 \leq D < 1.0$	< 2.0			
2	$0.5 \leq D < 1.0$	≥ 2.0			
3	$1.0 \leq D < 2.0$	< 2.0			
4	$1.0 \leq D < 2.0$	≥ 2.0			
5	$D \geq 2.0$	< 2.0			
6	$D \geq 2.0$	≥ 2.0			
		Total undercuts			
		# undercut banks / mile			

APPENDIX G: DRAFT Instructions for the Vermont Reach Habitat Assessment (RHA)

Reach Habitat Assessment Introduction

The Vermont Rapid Habitat Assessment (RHA) is typically completed in conjunction with the Phase 2 Stream Geomorphic Assessment (SGA). This document describes the protocols for completing the RHA outside of the Phase 2 Assessment. Instructions reference the Vermont Stream Geomorphic Assessment Phase 2 Handbook (VTANR, 2007).

Materials Needed
To conduct the Rapid Stream Assessments you will need the following materials and equipment:

- Phase 1 data reports and the Phase 1 corridor drawn for reference during the completion of Step 1.6
- Measuring tape (100 ft. or longer – preferably incremented in tenths of feet, **not** inches)
- Range Finder and Hand Level (optional)
- Line level
- Topographic map and ortho-photographs for each reach being assessed
- Pencils and Clipboard
- Camera and film (200 speed film is recommended as it works well at various light levels)
- Measuring rod (A length of 1" to 1 ½" diameter PVC pipe or wooden staff, marked in 1/2 foot increments with a permanent marker, works well. Be sure to plug the ends of PVC pipe with silicon caulking or PVC caps so the rod will not sink or break at the ends.)
- Two long screw drivers or heavy-duty tent stakes to secure the tape measure into the banks when measuring bankfull width.
- Metric ruler or gravelometer
- Waders and/or wading shoes (Old sneakers work well, felt-bottomed boots provide extra traction on slippery rocks; sandals are **not recommended**, in order to prevent foot injuries.)
- High-speed internet access for entering data into the DMS (see Appendix B)
- GPS unit to record field locations

Protocol Steps
The RHA assessment has been organized by parameter number to match the numbering found in the Phase 2 Rapid Stream Assessment handbook. Not all Phase 2 steps will be necessary to complete the RHA. This document will guide the completion of the RHA, but reference to the Phase 2 handbook will be necessary for some steps. The numbers on the Field Notes form correspond to the section numbers in the Phase 2 handbook. For example, if you need more information pertaining to the parameter labeled on the Field Notes form as "2.1: Bankfull Width," then turn to Step 2, Section 2.1, of the Phase 2 handbook.

Data Forms
Paper data forms (Appendix A) and computer data entry forms (Appendix B) are organized by step and parameter number. Information necessary for the RHA has been highlighted. Non-highlighted data would be collected as part of the full Phase 2 protocol and is not used for the RHA. Each of the forms has a heading to record the following information:

- ***Stream Name:*** As printed on the USGS topographic map. It is also helpful to note the name of the receiving water in parentheses.
- ***Segment:*** This is a unique identifier label for segments. It is composed of the reach number in which the segment is located (ex: M07) and a capital letter (ex: A, B, C…) that indicates the segment's location, from downstream to upstream, within the reach. For example, the most downstream segment within the Mainstem reach M07, would be labeled as M07A. The next

segment upstream would be labeled M07B, and so on. If you decide that the reach should not be segmented, do not use the capital letter convention and write "entire reach" in this space.

- ***Location:*** The segment location description should help someone unfamiliar with the area to locate the site. Provide detail in your description. Mark all upstream and downstream boundaries of reaches and segments on a topographic map and label each reach and segment with the appropriate identifiers. *Example:* Off Rt. 100, 2 miles up from Rt.100 / Bridge St. intersection in Granville. Segment begins NE approximately 1/2 mile off Rt.100 just above tributary entering on the east bank.
- ***Date:*** Date or dates during which you conduct the Rapid Stream Assessment for the segment.
- ***Town:*** Town(s) in which segment is located.
- ***Elevation:*** Record the elevation of the *upstream* end of the segment from the topographic map.
- ***Observers:*** Name of observer(s).
- ***Organization/Agency:*** Several-letter acronym(s) of the organizations, groups, and agencies represented in the assessment crew.
- ***Latitude and Longitude:*** If you are using a GPS fill this section out. Make sure to note the datum used, which should be the NAD 83 State Plane Coordinates (in meters).
- ***U.S.G.S. Map Name:*** USGS map name(s) on which the watershed is located. Map names are usually located in the bottom right hand corner of the maps.
- ***Drainage Area:*** If the drainage area has not already been determined from a Phase 1 survey, or from a published source, calculate drainage area as described in the Phase 1 Watershed Assessment, Step 1. Record the drainage area in square miles.
- ***Segment (or reach) Length:*** If the segment is < 500 ft. long, measure the length of the segment with a measuring tape (100 ft. tape or greater). Record the segment length in feet. Have one person hold the tape at one end of the segment and have the second person stretch the tape out as they walk to the other end of the segment. Follow the thalweg (deepest part of the channel) as much as possible when walking with the tape. If the segment is longer than your tape, leapfrog each other along the channel until you have measured the total distance of the segment. If the segment is > 500 ft. long, or is very difficult or unsafe to walk in the channel, measure the length of the segment off the orthophotos. Draw on the photo any areas where the channel has moved from the location shown on the photo, and make sure to adjust your segment length measurement to capture these channel changes. Circle on the Field Notes form whether your segment measurement is a ground or an orthophoto measurement.
- ***Weather:*** Air temperature and precipitation conditions. (Examples: Temperature is approx. 70^0 F with overcast sky // Temperature is approx. 75^0, sunny, no clouds)
- ***Flow Status:*** Answer "base, "low" or "avg." based on knowledge of river and recent storm events.
- ***Rain Storm within past 7 days:*** Answer "yes" or "no" based on whether the river has carried flows from a large rainstorm on any of the seven days prior to your field assessment.
- ***Flood history:*** Indicate (yes or no) whether you are familiar with the last occurrence(s) of major flood(s) in your assessment reach (recurrence interval > 10 yrs). Appendix L contains long-term flood history graphs for 33 U.S.G.S. Gage Stations around Vermont. Refer to the station data nearest to the reach you are assessing and/or use additional local sources and recent knowledge where possible. This may be important because the small stream being assessed may have experienced a major flood, while the larger river reach downstream where the gage located did not flood during the same storm or runoff event. Record additional flood history sources in the comments section of the Field Notes form

Starting the Reach Habitat Assessment – Defining Segments and Making Sketches

To start the Reach Habitat assessment you must first do the following:

1. Create sub-reaches and reach segments where appropriate to define stream units within the Phase 1 reaches which have different reference and existing conditions.
2. Complete field sketches of the segments and reaches for which Phase 2 assessments will be completed.

1. Creating Sub-reaches and Reach Segments

Study reaches are typically determined and typed in the Phase 1 assessment based on confinement, valley slope and other parameters using remote sensing. If Phase 1 data is available field verification is completed. In doing so, if you determine that valley setting and reference stream type conditions change within a reach such that there is more than one reference stream type within the reach, you may decide to subdivide the reach into two or more reaches, which are termed "**sub-reaches.**" In addition, to capture the variation in the observed physical channel and habitat conditions within a given reach, it may be necessary to break the reach into **segments** that correspond with substantial changes in the channel condition. The distinctions between the uses of reach, sub-reach, and segment designations are explained in the Phase 2 handbook "Starting the Phase 2 Assessment – Defining Segments and Making Sketches" Section.

When using this protocol as a stand alone assessment, a Phase 1 Assessment may not have been completed. The study reach may be defined by specific project means. A reference stream type must be assigned following instructions in the Phase 1 handbook Step 2.

2. Completing Segment Sketches

Making a sketch of your segment (or reach) is an essential part of conducting in stream assessments. Use your own paper to draw a planform (bird's eye) view of the stream and surrounding corridor. Using the topographic map(s) to help get oriented, draw a North arrow on the sketch. A complete set of Sketch and Map codes are provided in Appendix A to help you label features on the sketch and topographic maps.

The plan form sketch provides an opportunity to see both the vertical and lateral constraints on the stream system, in addition to habitat features that have resulted from the physical processes taking place over the study reach or segment. The constraints may modify channel adjustments (i.e., natural grade control provide vertical stability) or they may substantially increase the stream's erosion hazard potential. Take special note of planform alignments on the sketch (e.g., the stream entering a culvert or bridge at an acute or right angle, or a house located on the outside and downstream end of a meander bend). You may find it helpful to use the topographic map, a copy of the orthophoto, or an outline of the channel traced from the orthophoto to begin your sketch. Make sure to include a scale on your sketch (e.g., 1 inch = 500 ft).

The same sketch codes can be used to note the location of features, developments, and infrastructure on topographic maps and orthophotos. Map coding can be especially useful in examining the location of features within the length of your reach and within the watershed as a whole. For instance, marking grade controls on the topographic map may help you evaluate the distance over which a bed degradation process will migrate upstream or the amount of stream habitat affected by grade controls that are fish migration barriers.

All Phase 2 parameters are evaluated as you walk the entire segment (or reach); however, you will be choosing a representative section within the segment (or reach) to do more detailed measurements of

cross-sections, sediment, and streambank and riparian condition and to complete the Rapid Assessment forms.

The Segment/Reach Sketch Tally Form provides a location to record certain findings while walking the assessment area and making the site sketch. The heights of bankfull features above the water surface and channel width are recorded at the top of the page. Observed channel and planform changes are summarized on the tally sheet. The form also has columns for recording **lengths** and **heights** of eroding banks, lengths of bank revetments, corridor encroachments and beaver influenced segments. In addition, habitat features are accounted for on the Sketch Tally. Large woody debris, pools, refuge areas, and undercut banks are tracked on the Sketch Tally and sketch map as you walk the reach to help you recall details about these parameters when you complete the Field Notes form at the representative section you have selected, and perform the RHA.

The following items should be included in the plan view sketch for use in the habitat assessment:
(Of the 15 sketch items desired for the RHA, 10 are new, 3 need expansions, and two are already done in the Phase 2 sketch.)

Location of LWD pieces	(new)
Location of debris jams	(already done)
Area covered by CPOM	(new)
Area covered by riffles	(already done but want estimation of surface area)
Area covered by pools	(already done but want estimation of surface area)
Area of exposed substrate	(already done as bars but want estimation of surface area)
Obstructions	(already done as grade control)
Refuge areas	(new)
Refuge connections	(new)
Mass failures	(new)
Undercut banks	(new)
Overhanging vegetation	(new)
Water adjacency	(new)
Area of fine sediment accumulation	(new)
Patches of Dense Algae Growth	(new)

Note that in addition to the required sketch items, it is also useful to take notes on the sketch about absences of expected features or peculiar circumstances.

Field Form: Rapid Stream Assessment Field Notes

A rapid stream assessment should begin with a walk through the entire reach in order to familiarize yourself with the stream channel and corridor. Many parameters on the Field Notes form require measuring or estimating stream features along the entire segment (or reach). If you are unsure how to evaluate a parameter or unable to measure a parameter due to unsafe conditions, choose **"unknown"** or **"not evaluated,"** respectively, from the parameter menus (where available) and record this on the Field Notes form. As noted previously, only highlighted areas of the Field Notes form need to be completed for the RHA. Variables measured in the field are noted below.

Step 1: Valley and River Corridor

1.3 RIVER CORRIDOR ENCROACHMENTS (FIT)

Refer to Phase 2 Handbook Step 1.3 for river corridor encroachment measurement details. Record on Sketch Tally form.

1.6 GRADE CONTROLS (FIT)

Refer to Phase 2 Handbook Step 1.6 for grade control measurement details. Record on field notes form.

Step 2: Stream Channel

Streams in different physical settings have predictable flow and sediment discharge patterns determined by the climatic, geographic, and geologic characteristics of the valley in which they occur. Different physical settings result in different fluvial processes and different stream types, which are identified by their channel form and sediment transport characteristics. Step 2 involves measuring the dimensions of the channel and its sediments in order to identify the stream type and to determine whether the existing stream type of the present channel is consistent with its setting. For example, a relatively straight channel with little or no access to a floodplain during annual high water, is a stream type found in nature, but not typically in an unconfined valley where gravel is the dominant sediment size in the stream bed and banks. This landscape setting would commonly support a meandering, low gradient channel with floodplain access. Finding such an inconsistency at your site may explain observed channel adjustments and reach condition.

Where to Conduct Step 2 Assessments: Measurements of channel dimensions, such as bankfull width, maximum depth and flood prone width (Figure 2.1), are conducted at the channel "cross-over" locations (Figure 2.2). In a meandering stream, a cross-over is the area where the main current or flow in the channel crosses over from one side of the channel to the other. Riffles are usually located at cross-over locations. In steep gradient channels that run relatively straight, the main flow of the channel does not usually move from side to side across the channel, but rather cascades over cobble and boulder steps or runs straight over a uniform channel bottom. In these stream types, channel dimensions should be measured at these cascades, steps, or uniform runs. In a very low gradient stream where distinct riffles may not form, you should still perform channel measurements at cross-over locations, which may resemble shallow runs. **Do not take channel measurements at pools or you will over-estimate the channel width and maximum depth. Be sure to mark on your sketch where you take cross section measurements.**

2.1 BANKFULL WIDTH

Refer to Phase 2 Handbook Step 2.1 for Bankfull Width measurement details. Record on Field Notes form.

2.1a WETTED WIDTH

Background
The wetted width, the distance between the left edge of water and the right edge of water, indicates how much of the channel bottom is full of water during the time of the assessment.

Evaluation
Locate the edges of water during the cross section measurements, and record and determine the wetted width on the Cross Section worksheet and Field Notes Form.

2.1b W_{wetted} / $W_{bankfull}$ RATIO

Background
The ratio between the wetted width and bankfull width gives a snapshot of how full the channel is relative to the bankfull level, which is indicative of current system hydrology. A ratio of <1 is most common where the bankfull width is larger than the current wetted width. Typically, if this ratio is equal to 1, bankfull flows are taking place (and an assessment should not be taking place). In an extremely entrenched channel the wetted width could equal the bankfull width due to vertical channel walls, resulting in a ratio equal to 1 at non-bankfull flow.

Evaluation
Divide the wetted width (2.1a) by the bankfull width (2.1) and record on the Field Notes form. Example: If the stream has a wetted width of 15 ft. and a bankfull width of 30 ft., the W_{wetted} / $W_{bankfull}$ ratio is 15 ÷ 30 = 0.5.

2.2 MAXIMUM BANKFULL DEPTH

Refer to Phase 2 Handbook Step 2.2 for maximum bankfull depth measurement details. Record on Field Notes form.

2.3 MEAN BANKFULL DEPTH

Refer to Phase 2 Handbook Step 2.3 for mean bankfull depth measurement details. Record on Field Notes form.

2.4 FLOODPRONE WIDTH

Refer to Phase 2 Handbook Step 2.4 for Floodprone Width measurement details. Record on Field Notes form.

2.5 RECENTLY ABANDONED FLOODPLAIN (RAF)

Refer to Phase 2 Handbook Step 2.5 for Recently Abandoned Floodplain measurement details. Record on Field Notes form.

2.6 WIDTH / DEPTH RATIO

Refer to Phase 2 Handbook Step 2.6 for Width/Depth Ratio measurement details. Record on Field Notes form.

2.7 ENTRENCHMENT RATIO

Refer to Phase 2 Handbook Step 2.7 for Entrenchment measurement details. Record on Field Notes form.

2.8 INCISION RATIO

Refer to Phase 2 Handbook Step 2.8 for Incision Ratio measurement details. Record on Field Notes form.

2.9 SINUOSITY

Refer to Phase 2 Handbook Step 2.9 for Sinuosity measurement details. Record on Field Notes form.

2.10 RIFFLE / STEPS

Refer to Phase 2 Handbook Step 2.10 for riffle / step condition measurement details. Record on Field Notes form.

2.11 RIFFLE / STEP SPACING

Distance between riffles is measured for ***Riffle-Pool and Braided*** stream types and steps for ***Step-Pool*** stream types. Refer to Phase 2 Handbook Step 2.11 for riffle and step spacing measurement details. This may be estimated using the scale on the stream sketch. Record on Field Notes form.

2.12 BED SUBSTRATE COMPOSITION

Background
Bed substrate composition represents the particle size distribution of bed sediments and the presence of silt/clay. These factors are significant from a fluvial process and aquatic habitat standpoint, in addition to

the non-living organic matter that occurs on the bed including large woody debris, debris jams and CPOM (6.1).

Measurements of the bed material are conducted to help characterize the stream's ability to carry different size sediments. The type of material found in the bed and bars of the stream reflects the depth and slope of the bankfull flow. In the upper reaches of a watershed the bed material tends to be coarser cobbles and boulders. This is because the stream can easily move the smaller materials. As you go further down in the watershed the bed material generally becomes finer, moving towards sands and gravels near the mouth of the rivers. The presence of silt and clay indicate near lake-like flows, which may be ongoing (in the case of silts), but are typically associated with Vermont's glacial and post-glacial history. Substrate size and abundance are important features of aquatic habitat. Different organisms thrive on different size substrates, and will often use bed sediments for cover (fish, aquatic insects, salamanders) and colonization (algae, aquatic insects).

Embeddedness, or the degree the coarser materials that make up the stream bed (i.e., cobbles, boulders, snags and other stream bottom structures) are surrounded and covered by finer particles (i.e., sand and silt), is an important habitat consideration of the bed substrate. Embeddedness is most commonly measured as the percentage that the full height of the coarse material is covered by surrounding finer sediments. An embedded streambed may be packed hard with sand and silt such that rocks in the stream bottom are difficult or impossible to pick up. When the spaces between the rocks are filled with fine sediments, little room is available for fish, amphibians, and macroinvertebrates to use the substrate for cover, resting, spawning, and feeding. A streambed that is not embedded has many voids for organisms to occupy and has loose rocks that are easily removed from the stream bottom. Fining is an alternative measure of fine sediment deposition included in the assessment.

Evaluation

Bed Sediment Composition: Bed sediment composition is measured for use in calculating the Riffle Stability Index (RSI). For the RHA this is necessary only for ***Riffle-Pool and Braided reference stream types.*** Using a pebble count methodology, measure particle size distribution in a typical riffle as described in detail in Phase 2 handbook section 2.12. Largest mobile particle size will be measured on an adjoining bar as described in the following section. Space is provided on the Cross Section worksheet in the Bed Substrate Composition table to count particle sizes, determine the percentage that each is present, and record embeddedness. Percentages are then transferred to the Field Notes form.

Embeddedness: Embeddedness varies depending on where the observations are taken in the stream. To evaluate the large-scale sediment movement and deposition in the channel of riffle-pool, plane bed, and braided stream types, make observations of embeddedness in the upstream and central portions of riffles or runs in areas containing cobble substrates. For step-pool stream types, observe the in-channel level of embeddedness in the downstream part of the small pools preferably in relatively high velocity areas, to determine if the periodic flushing flows are frequent enough to maintain clean sediments that create good aquatic habitat. Also evaluate embeddedness in the margins of the channel outside of the main flow to investigate the degree of sediment deposition in these locations.

The mean embeddedness is determined from observations of 3 to 5 typical particles from both the in-channel bed feature of interest and the margin area encountered during the pebble count transect. Space is provided on the Cross Section worksheet in the Bed Substrate Composition table to enter the individual embeddedness measurements in the channel (Ch) and margins (Ma), and record the means on the Field Notes form.

Place your wading staff next to a selected rock of at least softball size, up to volleyball size, and note the approximate distance between the top of the rock down to the surrounding fine particles. This is the

portion of the rock that **is not** embedded. Next, lift the rock from the surrounding fine sediment and rest it on the stream bottom as close as possible to its original orientation. Once the rock is freed from the surrounding fine sediment, measure the total height of the rock. Embeddedness of this rock is equal to ((total height – the not embedded height) / total height) * 100.

In some cases, a line may be visible on the removed rock where the border between the free water and surrounding fine sediment once was located. The upper surface that was exposed to the flowing water is often slimy and dark in color due to a covering of algae, whereas the surface of the rock that was in contact with the stream bottom will appear relatively "clean." To check the embeddedness measurement, see if the height of the bottom of the rock to the line, or the portion of the rock that **is** embedded, is equal to the (total height – the not embedded height).

It does not matter what units are used for the measurements as long as measurements are consistent. When lifting the rock from stream bottom watch the size of the plume of fine sediment that is released from around the rock for additional insight on embeddedness. In fast flowing water it may be difficult to see through the water to observe the sediment plume. If the rock is difficult to extract from the stream bottom, it is likely embedded.

Fining: Fining provides another estimate of fine deposits, important because lower fining generally translates to higher quality habitat. The measurement of the fining variable begins with defining fines for the assessment segment (or reach). Fines are considered to be sand if the median particle size (d_{50}) is gravel or larger (most cases in Vermont), while silt is used to define the fine fraction for channel beds having sand or smaller particles as the d_{50} (USEPA, 2006). Select a 1 m^2 (~11 ft^2) observation plot that is located in the main current in the feature most commonly associated with each stream type (e.g., a riffle in a riffle-pool, a ripple in a dune-ripple, etc…). Estimate the percentage of the area in the observation plot that is covered with fines. A minimum of two additional determinations of fining is recommended in the same bed feature to check and refine the initial estimate. Fining is measured for all stream types, and recorded on the cross-section form in the Bed Substrate Composition table.

2.13 AVERAGE LARGEST PARTICLE

If reference stream type is Riffle-Pool or Braided this measurement is needed for calculation of RSI. The average largest mobile particle size on an exposed bar is measured. This is measured on a bar adjacent to where the riffle pebble count was performed. Refer to Phase 2 Handbook Step 2.8 for Average Largest Particle measurement details. Space is provided on the Cross Section worksheet for the individual particle measurements on the bed (Bd) and bar (Br), and record the average size on the Field Notes form. Only measurement on the bar is necessary for calculation of RSI.

2.13a EXPOSED SUBSTRATE

Background

Exposed substrate is the cumulative amount of bars (i.e., point, mid-channel, diagonal, delta, and side) that is not covered by water. Exposed substrate is a surface hydrology indicator that directly represents the amount of useable aquatic habitat in the channel at the time of observation. If excessive sediment deposition leads to large areas of exposed substrate over long periods of time, fish and other mobile aquatic organisms will likely move to other areas and more stationary animals and plants outside of the wetted channel will no longer exist in that location.

Evaluation
Refer to the site sketch, which includes exposed bars, to estimate the percentage of the bankfull channel surface area over the assessed reach or segment that is not covered by water at the time of observation. Round estimates to the nearest 10%, and consider rounding down if observations are made during periods of extreme low flows. Record % exposed substrate on the Field Notes form.

2.14 STREAM TYPE

The current stream type is determined using data previously collected in Step 2. Refer to Phase 2 Handbook Step 2.14 Stream Type for details. Record all stream type information on the Field Notes form. This may indicate a departure from the reference stream type.

Step 3: Stream Banks, Buffers and Corridors

3.1 STREAM BANKS

Bank Erosion (FIT): Note the length and average height of the actively eroding banks on both right and left banks. Measure the height of erosion from the toe of the slope (the streambed) to the top of the bank. There is space on the Sketch Tally Form to tally bank erosion as you walk the segment (or reach).

Bank erosion is an area of raw and barren soil where the vegetation does not have the ability to hold the soil and/or the soil has slumped or fallen into the channel (Figure 3.5). Phase 2 bank erosion assessment should attempt to quantify active and accelerated erosion, and not the background erosion that occurs at a more natural (slower) rate. For example, you may assess a channel where both banks show exposed soil throughout the reach, which may indicate minor erosion typical of natural stream processes. This minor bank erosion should not be considered in your assessment, especially if the following are true:
• vegetative roots are exposed but the vegetation is holding the bank;
• there are no apparent human-related changes to bank erodibility and/or hydraulic forces (i.e. changes in velocity and direction of flow); and large geo-technical "slump" failures are not observed. Slumps are areas where changes in the moisture content of the bank soils increase the potential for material to slide down (Fischenich, 2000).

Use the Feature Indexing Tool (FIT) in SGAT to document the location of erosion on the right bank or the left bank as well as the height of the erosion. When the FIT data is uploaded into the DMS the data will automatically be populated for each reach where erosion is noted.

Bank Revetments (FIT): Bank revetments are structures installed in an attempt to stop stream bank erosion. Revetments may be "hard", such as gabions and riprap, or "soft", such as conifer tree-tops (Figure 3.6). Note the type of revetment and the length of each bank in the segment (or reach) that is artificially stabilized on the Sketch Tally Sheet. Typically in Vermont hard bank treatments are used to armor the bank against scour and undercutting; but, in streams that are going through adjustment, rip-rap may become undermined by the stream and contribute to the instability of the channel.

Use the Feature Indexing Tool (FIT) in SGAT to document the location of revetments on the right bank and left bank. When the FIT data is uploaded into the DMS the data will automatically be populated for each reach where revetments are noted.

Bank and Near Bank Vegetation Type: At a representative cross section, visually estimate the percent of the area covered in the tree, shrub (and sapling), and herb layers as in full leaf conditions in the bank and in the "near-bank" area for both the left and right stream banks (determined facing downstream). *Evaluate only the area from bankfull to the top of bank plus 5 feet back from the top of the bank.* Trees, shrubs, and herbs are defined as follows:

- Trees – Woody with diameter at breast height (DBH) $\geq$ 3 inches and any height;
- Shrubs / Saplings – Woody with DBH < 3 inches and height $\geq$ 3 ft; and
- Herbs – All non-woody plants and woody plants with height < 3 ft.

Each layer is assessed individually. For example, a given site may have complete tree coverage (100%), half coverage in the shrub / sapling layer (50%), and no herbs (0%). Shrubs and herbs are mostly responsible for covering the ground surface on the bank and near-bank areas so this implies that 50% of the ground is bare. If climbing woody vines are present on half or more of the trees or shrubs make a note of the percent coverage in the comment box.

The next step is to visually determine the percent composition of general plant groups within each layer. The groups include:

Trees, Shrubs / Saplings and Herbs	**Invasive**	Non-native plant species: Trees – Black locust, Norway maple, Tree of heaven Shrubs – Honeysuckle (hollow stems are invasive), Japanese barberry Herbs – Japanese knotweed, Phragmites, Purple loosestrife, Garlic Mustard Vines – Oriental bittersweet
Trees	**Coniferous**	Trees that keep their needles year round such as pine, cedar, and hemlock
Trees	**Deciduous**	Trees that lose their broad leaves in fall such as maple, elm, butternut, and oak
Shrubs / Saps.	**WADs**	Willows, alders, dogwoods – Common native stream bank shrubs
Shrubs / Saps.	**Saplings**	Various shrubs or enter an abundant species
Herbs	**Grasses**	Native grasses, rushes and sedges
Herbs	**Forbs**	Native non-woody flowering plant other than grasses

Each layer is assessed individually, and the sum of the percent composition should equal 100% within each layer. For example, a shrub layer with 50% coverage may be composed of 25% invasive species, 65% WADs, and 10% other species.

The purpose of considering vegetation immediately beyond the bankfull elevation in the near-bank area is to document the presence and type of plant roots that are binding the soil and providing resistance to bank erosion within the channel boundaries. Bank vegetation is also important in shading the channel edge and providing overhanging vegetation which can be used as cover by aquatic animals and is a source of organic matter for the stream. If you are familiar with any species of invasive plants present in the nearbank area, write the names in the comments section of the Field Notes form.

Bank Canopy: For both right and left banks estimate the average percent canopy over the margin of the channel, upstream to downstream along the nearbank area. To do this stand in the channel facing the bank and look straight up into the tree and shrub canopy. From this viewpoint, estimate the percent of the sky within your field of vision that is blocked by foliage and branches. This is the percent canopy. If there is no vegetation above your head when you view the sky then the percent canopy is zero. Do this at the

locations within the segment where cross-sections were completed (at least 3 locations) and record the average percent canopy along each bank. You are striving for an estimate that is the typical condition along the majority of the segment (or reach).

***Across Channel Canopy*:** Stand in the middle of the channel and evaluate whether the trees that are over the channel have an open or closed canopy (Figures 3.7A and 3.7B). Trees that meet over the channel create a closed canopy. Areas where streamside trees on opposite banks do not meet, or touch, over the channel are considered to have an open canopy. This parameter evaluates complete channel shading and is important in distinguishing canopy cover of small streams from large streams, the latter of which may not form a closed canopy due to the channel width being too great. Record the condition that best represents the majority of the segment (or reach).

3.2 RIPARIAN BUFFER

Buffer Width: Record the dominant and sub-dominant buffer width categories in the segment (or reach), for both the left and right sides of the channel. This parameter does **not** determine an average buffer width, but rather the most dominant buffer condition of the segment. Remember that the buffer is a portion of the river corridor, adjacent to the channel, which is naturally vegetated and largely undisturbed. Do not count areas that are being pastured, or are recently fallow as buffer. Fallow fields should only be counted as buffer if there is evidence of shrubs/saplings beginning to propagate in the fields. Circle the dominant and sub-dominant categories on the Field Notes form, and indicate dominant with "dom" and subdominant with "sub-dom."

Buffer Vegetation Type: Visually estimate the percent of the area covered in the tree, shrub (and sapling), and herb layers as in full leaf conditions in the riparian buffer for both the left and right side of the channel. Trees, shrubs, and herbs are defined in 3.1 above. Each layer is assessed individually.

Changes in buffer conditions may warrant segment breaks. If the there is wide variability in the buffer vegetation type and width within a reach, you may consider establishing segments based on these buffer condition differences. These differences should be pronounced and extensive. For example, you would not break out a segment of brush-dominated buffer for a 200 ft. length of channel that is largely conifer tree dominated. On the other hand, you might consider breaking out a 2000 ft. long section of the reach that has no buffer as its own segment, if the majority of the one mile reach has a 50 ft. wide forested buffer.

Visually determine the percent composition of general plant groups within each layer. The groups included are defined in Section 3.1 above. Each layer is assessed individually, and the sum of the percent composition should equal 100% within each layer.

Step 4: Flow Modifiers

Step 4 evaluates the natural processes and human impacts that affect the amount of water in the channel. River systems are affected by *decreases* in flow, such as water withdrawals, or *increases* in flow, such as stormwater runoff, as well as natural features in the system that affect the flow, such as wetlands, springs and seeps. *This section does not evaluate the typical seasonal fluctuations of stream flow.*

4.1 SPRINGS, SEEPS AND SMALL TRIBUTARIES

Background
The prevalence of springs, seeps, and small tributaries may indicate the water storage characteristics of the watershed. Streams with greater surface and sub-surface water storage tend to be less flashy. The extended duration of runoff events in high storage watersheds, may result in streams with relatively smaller dimensions which are less sensitive to the adjustment processes brought on by storm events.

Ground water influence in streams and rivers is especially important during periods of drought or low-flow. The water that enters a stream from springs, seeps or small tributaries is often cooler in the summer than surface water temperatures. Fish seek out these cooler areas during the summer. Similarly, in the winter these areas contain relatively warm water, due to the groundwater origin, compared to the near freezing temperatures of surface water exposed to the cold winter air, and again are beneficial to fish and other aquatic biota.

Evaluation
Note the relative abundance of springs, seeps or small tributaries entering the channel. Natural features such as springs and seeps or tributaries *contribute groundwater* to the channel.

Menu

Extensive	Numerous small tributaries, springs and/or seeps entering the stream site.
Present	Small tributaries, springs, and/or seeps enter the stream occasionally.
Minimal	Infrequent small tributaries, springs and/or seeps do not enter the stream site
Absent	No small tributaries, springs and/or seeps observed entering the segment (reach)
Altered	Small tributaries, springs, and/or seeps present, but natural functions have been altered.

4.2 ADJACENT WETLANDS

Background
Similar to the watershed characteristics evaluated as part of Step 4.1, wetlands serve both water storage and habitat functions.

Evaluation
Note the relative abundance of wetlands adjacent to the channel. For the purposes of this assessment, wetlands can be identified by the presence of vegetation that usually requires wetted soils, such as cattails, sedges and rushes, willows and alders. Wetland information can be obtained from the ANR Division of Water Quality, which houses the National Wetlands Inventory (NWI) maps and the Vermont Significant Wetland Inventory (VSWI) maps, as well as from the NRCS Soil Surveys.

Menu

Extensive	Extensive wetlands present along stream segment (reach)
Present	Wetlands present but too small to extent along stream segment (reach)
Minimal	Wetlands present but very small percentage of stream segment (reach) length
Absent	No wetlands observed along stream segment (reach)
Altered	Wetlands present, but natural functions have been altered.

4.3 FLOW STATUS

Background

Many measurements included in this phase of assessment are dependent upon river stage at the time of assessment (i.e., measures of pool depth). Knowledge of river stage is important for correct interpretation of assessment data. This qualitative measure will allow the data user a general sense of river conditions without having to look at local gage data. The flow status at time of assessment is therefore included in the assessment and recorded not only on the Field Notes Form, but also the top section of Reach Habitat and Reach Geomorphic Assessment Forms.

Evaluation
Assess this variable based on prior knowledge of stream flow conditions or a review of regional gage flow data. Indicate whether the amount of flow in the channel at the time of the assessment is **Low** due to drought conditions, **Base** (typical summer flows), or **Average**. Average flow is higher than the typical base flow, but not specifically influenced by a storm event. These flows may occur a few days after a storm event and would be shown on a regional hydraulic gage around the annual median flow.
A High flow designation is not included as is highly recommended that you avoid surveying during high flow periods. Not only can stream conditions be dangerous, but stream features may be obscured and difficult to accurately assess due to turbid water.

4.6 UPSTREAM / DOWNSTREAM FLOW REGULATIONS

Note any upstream or downstream flow regulations on the Field Notes form, as described in Step 4.6 of the Phase 2 handbook.

Step 5: Channel Bed and Planform Changes

5.5 CHANNEL ALTERATIONS

Note any channel alterations, including length of straightening, on the Field Notes form, as described in Step 5.5 of the Phase 2 handbook.

Step 6: Measurements and observations

6.1 LARGE WOODY DEBRIS, DEBRIS JAMS AND CPOM

Background
LWD is wood material that is located at least partially within the bankfull channel and meets the following size criteria:

- Minimum length of 6 feet;
- Minimum diameter at the larger end of 0.5 feet; and
- Minimum diameter of 0.5 feet at a distance of 6 feet from the larger end.

The target diameter of the larger end of a piece of LWD is ≥ 0.5 foot to provide good cover. Half of the bankfull channel width is set as a divide between smaller and larger LWD lengths. LWD diversifies local hydraulics and substrate, and creates small pockets of habitat for fish, invertebrates, and amphibians to carry out a range of life-cycle functions. In addition, LWD has some influence over sediment deposition and scour in local stream bed and bank environments. The size of large woody debris is factored on those pieces which are not very transient in most size streams.

Debris jams are numerous pieces of LWD, as defined above, and associated CPOM that are channel spanning or nearly so. The decision to call a non-spanning cluster of woody debris a jam hinges on whether the structure is influencing processes such as sediment transport and forming hydraulic features that serve as habitat. Note that debris jams can span only a portion of the bankfull channel and still have a significant influence on habitat. When tallying debris jams space is available to record both full channel spanning and partial non-channel spanning jams. These groupings of wood create important habitat complexes due to their size and many diverse habitat pockets. A single debris jam can create feeding locations and refuge for many individuals of different species at a given time.

All visible pieces of wood that are smaller than LWD are and other vegetable matter are considered detritus or coarse particulate organic matter (CPOM). CPOM can include twigs, leaves, cones and dead plant matter that collects on the stream bed. It may occur in clumps, such as leaf packs at the bottom of a pool or piles of branches and twigs, or as single pieces, such as a fallen tree branch. Though each piece of CPOM may be fairly transient in a stream segment (or reach), in that it continually moves downstream over time, the load of CPOM in a segment (or reach) should be fairly constant over time if watershed and river corridor characteristics do not change substantially. There are notable seasonal fluctuations in CPOM load, however, such as the increase in leaf matter associated with deciduous trees dropping their leaves in the autumn.

Evaluation

LWD pieces are drawn on the sketch and recorded on the Sketch Tally according to the diameter at the larger end (ft) and the length (/W_{bkf}) rank. A wading staff marked with half-foot intervals is ample for determining diameters. Bankfull width can be approximated from initial observations of bankfull indicators, and then confirmed during cross section measurements. While observing LWD, consider the LWD recruitment potential from the surrounding river corridor and upstream. All debris jams, as defined above, are tallied. A **full** debris jam indicates that it spans the entire channel. A **part** debris jam indicates a non-spanning jam determined to have a significant impact on available habitat.

Once all of the LWD in the study reach or segment is observed and tallied, add the counts in each rank to determine the total number of LWD pieces. Divide number of LWD less than 1 foot (ranks 1-2) and greater than 1 foot in diameter (ranks 3-6)

6.1 Large Woody Debris and Jams

Rank	D_{large} (ft)	L (w_{bkf})	Tally	#	%
1	0.5 ≤ D < 1.0	< 0.5			
2	0.5 ≤ D < 1.0	≥ 0.5			
3	1.0 ≤ D < 2.0	< 0.5			
4	1.0 ≤ D < 2.0	≥ 0.5			
5	D ≥ 2.0	< 0.5			
6	D ≥ 2.0	≥ 0.5			

Total LWDs			
# LWDs / mile			
# Debris jams	Full	Part	Total
# Debris jams / mile	Full	Part	Total

by the total to get the percentage of smaller and larger LWD present. Divide the total number of LWD pieces by the assessment length (miles) to get the density of LWD.

Sketch debris jam locations and tally them in the large woody debris and jams table. Divide the total number of jams by the assessment length (miles) to get the density of debris jams.

While walking the study reach or segment, sketch patches that are mostly covered by CPOM. Once the sketch is complete, visually estimate the amount of surface area covered by CPOM. A visual estimate of CPOM will be most meaningful to compare between segments (or reaches) or to compare a particular segment over time if field assessments are done at relatively the same time in the calendar year, preferably late summer before leaf drop. CPOM is naturally lower in riffles due to high water velocities, so be sure that the spatial relationship between CPOM patches and riffles is clear in the sketch. CPOM is also naturally more abundant in the margins, clearly note CPOM in channel.

6.2 POOLS

Background
Pools are the deepest locations of a stream reach. Water surface slope of pools at below bankfull flows is typically near zero. Pools are often located on the outside of meander bends, downstream of contractions or behind large features that cause plunging flow. Minimum pool depth is set at 1 foot, and the target pool depth is > 2 feet for cover. Half of the bankfull channel width is set as a divide between smaller and larger pools by surface area.

Evaluation
Draw pool locations and approximate extent on the sketch and record on the Sketch Tally according to maximum depth (ft) and largest dimension in relation to bankfull width (length or width/W_{bkf}) rank. A homemade wading staff marked with half-foot intervals is ample for determining the water depth. Bankfull width can be approximated from initial observations of bankfull indicators, and then confirmed during the cross section measurements. While observing and sketching each pool, take note of the amount of vegetative and debris cover over and in the pool, the degree to which the pool volume is reduced due to accumulation of fine sediment particles, and any water surface turbulence associated with the pool. These factors largely determine the quality of the cover produced by a pool.

6.2 Pools (note vegetative cover, surface turbulence, fines)

Rank	D (ft)	L,W (w_{bkf})	Tally	#	%
1	$1.0 \leq D < 2.0$	< 0.5			
2	$1.0 \leq D < 2.0$	≥ 0.5			
3	$2.0 \leq D < 3.0$	< 0.5			
4	$2.0 \leq D < 3.0$	≥ 0.5			
5	$D \geq 3.0$	< 0.5			
6	$D \geq 3.0$	≥ 0.5			
7	$D \geq 3.0$	≥ 1.0			
		Total pools			
		# Pools / mile			

Once all of the pools in the study reach or segment are observed, add the counts in each rank to determine the total number of pools. Divide number of pools less than 2 feet (ranks 1-2) and greater than 2 feet deep (ranks 3-6) by the

total to get the percentage of shallow and deeper pools present. Divide the total number of pools by the assessment length (miles) to get the pool density.

6.3 REFUGE AREAS / CONNECTIONS

Refuge areas are retreats for mobile organisms during stressful conditions such as floods, droughts, heat waves, or deep freeze. Channel refuge can include side channels, downstream of islands, large stable debris jams, boulder clusters, eddies in the channel margins, and protruding rocks or debris near the channel margins. Refuge features outside of the main channel that require access channels include oxbows, near-channel depressions, and small tributaries.

6.3 Refuge Areas / Connections

ID	Location	Q_{access}	Notes
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	
	in / out	low / bkf	

Sketch potential refuge locations and include a letter identifier. Record the letter identifier on the Sketch Tally and indicate if the refuge area is in the main channel or outside of it. Determine if the refuge area is accessible during low flows and/or bankfull flows. In addition, make a qualitative assessment (consider cover, substrate heterogeneity, and stability) whether or not the refuge area expands high quality habitat. The purpose of this assessment is to identify useful refuge areas that are both accessible over a range of flows and provide good habitat.

6.4 UNDERCUT BANKS

Undercut banks are pockets under the bank that are at least 0.5 feet horizontal and 0.5 feet deep. Deeper undercuts are generally better aquatic habitat, with those > 1.0 feet preferred.

6.4 Undercut Banks (note stability, overhanging vegetation)

Rank	D_{max} (ft)	L (ft)	Tally	#	%
1	$0.5 \leq D < 1.0$	< 2.0			
2	$0.5 \leq D < 1.0$	≥ 2.0			
3	$1.0 \leq D < 2.0$	< 2.0			
4	$1.0 \leq D < 2.0$	≥ 2.0			
5	$D \geq 2.0$	< 2.0			
6	$D \geq 2.0$	≥ 2.0			
		Total undercuts			
		# undercut banks / mile			

Sketch the location of undercut banks on the sketch and count by maximum water depth (ft) and length in the direction of flow rank on the Sketch Tally. A homemade wading staff marked with half-foot intervals is ample for determining the water depth and undercut bank length. While observing and sketching each undercut bank, note if the feature appears stable and likely to be able to persist for approximately six months to a

year, or if the feature appears to be more temporary and shows sign of on-going erosion and collapse that could be washed away in the next flood.

After observing all of the undercut banks in the study reach or segment, add the counts in each rank to determine the total number of undercuts. Divide number of undercuts less than 1 foot (ranks 1-2) and greater than 1 foot deep (ranks 3-6) by the total to get the percentage of shallow and deeper undercuts present. Divide the total number of undercut banks by the assessment length (miles) to get the density of undercut banks.

Overhanging vegetation is an important component of the cover associated with an undercut bank. Sketch the areas where vegetation overhangs the stream channel and banks. Pay attention to whether the overhanging vegetation is within one foot of the water surface that is the most important for local cover, or beyond one foot from the water surface that is important for shading and larger scale overhead cover. Once the sketch is complete, estimate the percentage of the assessment surface area that is covered by overhanging vegetation. Also, use the sketch to estimate the degree overhaning vegetation is associated with undercut banks.

Undercut banks are only useful for aquatic habitat if the feature is wet, water is adjacent to the bank, and water is moving at a velocity that is tolerable for aquatic organisms. For wider channel types with a defined thalweg and bed features (riffle-pool, dune-ripple, braided), indicate the length that water is adjacent to the bank closest to the thalweg. For narrower channel types (step-pool, cascade, bedrock) mark the length that water is adjacent to both banks. Once the sketch is complete, estimate the percentage of the length of the bank(s) over the assessment area that are adjacent to water. Also, use the sketch to estimate the amount of water adjacency to undercut banks. Note any undercut banks where flow velocities appear to be high relative to the main channel flow, and possibly could limit habitat use.

Step 8: Reach **Habitat Assessment (RHA)**

Background

Physical processes form habitat in a stream channel. Importation of woody debris, movement of sediment over a range of flows, formation of scour and depositional features due to channel morphology and flow variability, and changes on dynamic river banks all establish important habitat features. Combined with chemical constituents and biological interactions, physical habitat determines biological productivity and diversity; and drives the aquatic ecosystem. By taking a detailed look at the habitat resulting from the physical processes taking place in a stream it is possible to understand how fluvial processes impact aquatic communities.

It is important to note that habitat assessment such as the RHA does not replace the need for monitoring biological communities. Metrics that describe biological populations are the ultimate response variables when determining biological integrity because species integrate conditions and their assemblage represents overall health of an ecosystem. Physical habitat quality is an indication of a stressor on the biological community, and thus is an effective tool to explain results of biomonitoring, guide future sampling, and develop restoration strategies to promote biological recovery.

Several federal and state agencies have existing rapid habitat assessment protocols of varying levels of detail. The U.S. Environmental Protection Agency (EPA) has developed and published Rapid Bioassessment Protocols (RBPs) (Barbour et al., 1999) which contain Rapid Habitat Assessment (RHA) protocols to:

• Determine if a stream is supporting or not supporting aquatic life;
• Characterize the existence and severity of habitat degradation;
• Help to identify sources and causes of habitat degradation; and
• Evaluate the effectiveness of control actions and restoration activities.

A modified version of the RBP assessment was used as the previous phase 2 rapid habitat assessment in previous versions of these protocols, and although the variables have largely changed, the general construct and scoring system is modeled after this work.

Evaluation Overview

The parameters in the RHA evaluate the physical components of a stream (the channel bed, banks, and adjacent riparian area), and in turn how the physical condition of the stream affects aquatic life. The eight parameters used in the RHA are:

- Woody debris cover (8.1);
- Bed substrate cover (8.2);
- Scour and depositional features (8.3);
- Channel morphology (8.4);
- Hydrologic characteristics (8.5);
- Connectivity (8.6);
- River banks (8.7); and
- Riparian area (8.8).

Several variables describing each parameter are evaluated by the assessor and the appropriate boxes on the form are checked. Some of variables are directly determined from data on the field notes and sketch tally forms, while others require more qualitative information based on observations. The assessor then reviews the location of the check marks and decides how to score the parameter on a scale of 0 to 20. Variables and the range of scores for each parameter are placed into four condition/departure categories to guide the scoring.

Score	Condition	Departure from reference
20-16	Reference	None
15-11	Good	Minor
10-6	Fair	Major
5-1	Poor	Severe

Note that the River Banks and Riparian Area parameters are scored individually for each side of the channel, and thus are scored differently using a 0 to 10 range so that their sum is 0 to 20 like all of the other parameters. In the end, scores from the eight parameters are added to obtain a total score, which is then compared to a reference condition score of 160. The reference score is obtained from perfect scores of 20 for each parameter (8 * 20 = 160).

If abundant habitat information exists at a healthy reference that is determined to be suitably close (i.e., in the same stream, watershed, or region) to the study stream, the reference score of 160 can be fine-tuned to better reflect local reference conditions. The state river scientist working in the region of the assessment will decide if such an adjustment should be made.

It is important to study these protocols and practice them in the field before collecting data. This will improve your ability to gather data consistently. Guidance on selecting the appropriate RHA field form and how to score variables and parameters follows. In addition, each parameter is described in detail below.

Selecting the RHA Field Form

Because physical habitat is a function of stream channel type, four different RHA field forms are available for the assessment that cover the most common reference channel types present in Vermont.

Form #	Primary use		Secondary use	
1	Riffle-pool	B, C	Dune-ripple	E, F
2	Step-pool	A, B	Cascade and bedrock	A
3	Plan bed	B, C, other	None	None
4	Braided	D	Alluvial fan	B, C, D

Each of the four RHA field forms is unique due to differences in the variables and/or their ranges expected for each stream type. In addition, some of the forms that can be used for multiple stream types contain instructions in gray in the “habitat parameter” column on how to adjust the

analysis for the secondary use. For example, on the riffle-pool form the bed substrate cover and scour and depositional features parameters are altered when assessing dune-ripple streams types.

Be sure to use the RHA field form that is appropriate for the reference stream type of the segment (or reach), as determined in Phase 1 and verified in Phase 2 Step 2.

General Scoring Guidance

For each parameter, begin with the top variable and work your way down. Look across the variable row to explore the values, ranges, and descriptive text within each condition/departure category to guide the variable scoring. Be sure that exactly one box in each row of variables is checked, unless that variable is different on the different banks. Then make a note of which bank each check refers to.

After each variable has been checked in the appropriate condition/departure category, a parameter score is assigned. Review the location of variable check marks reflecting the observations of the stream segment or reach, keeping in mind that variables at the top of the list tend to be based on collected data and carry more weight in the analysis and those at the bottom of the list tend to be more qualitative. Circle the selected parameter score, and write the number in the space provided under the parameter name. Note that it is very unlikely that all of the checks will fall in the same condition/departure category so the assessor will have to integrate the scores and observations to decide the best parameter score. The top variables can be used to guide the general scoring, while the bottom variables are best used to nudge the score one way or the other.

Do not skip parameters as this will cause an error in the total score. If you are unsure about how to score a variable or parameter, note the question or problem in the comments section on the Field Notes form.

8.1 WOODY DEBRIS COVER

Refer to the following locations in the SGA for additional information and required data.

- *Segment (or reach) sketch*
- *6.1 Large Woody Debris, Debris Jams and CPOM*
- *3.1 Near Bank Vegetation, Bank Canopy, Channel Canopy*
- *3.2 Buffer Vegetation*

Background

Variables	*Linking physical processes, habitat, and life-cycle functions*
Large woody debris (LWD pieces / mile) (LWD size rank 3-6) [All stream types]	Input from riparian forests or longitudinal input from upstream locations due to the processes associated with in-channel sediment storage and the lateral migration of a stream within its valley. Large wood creates substrate for macroinvertebrate colonization, stores fine sediments, and leads to hydraulic diversity offering shelter, feeding locations, and rearing grounds for adult, young-of year (YOY), and juvenile fish.

Debris jams density (debris jams / mile) [All stream types]	Accumulated from wood input to the channel from upstream locations at locations of limited (sediment and wood) transport capacity. Debris jams create substrate for macroinvertebrate colonization and diversify local hydraulics offering shelter and feeding locations for adult, YOY, and juvenile fish. Deep scour associated with debris jams creates important refuge locations.
Woody debris recruitment potential [All stream types]	Input from riparian forests or longitudinal input from upstream locations due to the processes associated with in-channel sediment storage and the lateral migration of a stream within its valley. Large wood, debris jams, and smaller organic material creates substrate for macroinvertebrate colonization, fine sediment storage, and leads to hydraulic diversity offering shelter, feeding locations, and rearing grounds for adult, YOY, and juvenile fish.
CPOM presence [All stream types]	Allochthonous and autochthonous inputs of organics and their retention in low velocity areas create the heterotrophic base of the aquatic food web for detritovourous invertebrates, shelter for macroinvertebrates, and concentration of food sources for fish.

Woody materials of different sizes create important habitat features. Smaller pieces and shreds of wood are a source of food and cover, or a safe refuge, for small organisms such as some macroinvertebrates and juvenile fish. All visible pieces of wood that are smaller than LWD and other vegetable matter are considered coarse particulate organic matter (CPOM). Larger pieces of wood as defined in Step 6.1 are called large woody debris (LWD) and provide essential cover for fish, reptiles and amphibians. LWD and the small scour pool that is common downstream of larger pieces offers refuge from high flows and predation.

Woody debris is an important habitat feature in all channel types. Wood material is often abundant in small step-pool stream types in forested watersheds. Relatively less woody debris cover is expected in larger channel types due to a smaller proportion of the channel width being covered by the tree canopy and increased flows to continually transport wood downstream. Woody debris cover is expected to be lowest for a plane bed reference stream type. With limited heterogeneity on the river bed and uniform hydraulics across the channel width, plane bed channels typically retain limited amounts of wood debris. The lack of woody debris cover is a noteworthy habitat deficiency associated with plane bed channels.

Reduction in woody debris cover can take place if the source of material is cut off from the channel or if the channel cannot retain the wood that enters the channel. Land use change away from forest cover is a common way that the source of woody debris is reduced. Geomorphic changes such as channel incision can disconnect a channel from its floodplain that once supplied wood to the stream during floods and wind storms.

Even if a channel does receive wood from the canopy and floodplain, useful cover is only established if the channel has ample heterogeneity to retain the material under the given hydrology and hydraulics of the system. For example, streams that are channelized and experience frequent high flows are not likely to retain wood long enough to form useful cover. On the other hand, a healthy naturally meandering stream will have low-velocity locations throughout the channel where wood can accumulate, persist, and form useable cover even during small floods.

Evaluation

Riffle-Pool (Dune-Ripple) Stream Type

Habitat Parameter	Condition (Departure) Category																			
	Reference (None)					Good (Minor)					Fair (Major)					Poor (Severe)				
8.1 Woody Debris Cover LWD size rank variable only used if ≥ 10 pieces	☐ LWD pieces / mile > 100 ☐ LWD size rank 3-6 >50% ☐ debris jams / mile > 5 ☐ high woody debris recruitment potential ☐ CPOM present in channel and margins					☐ 100 ≥ LWD / mile > 50 ☐ 50 ≥ LWD rank 3-6 > 25% ☐ 5 ≥ jams / mile > 3 ☐ moderate woody debris recruitment potential ☐ CPOM limited in channel and present in margins					☐ 50 ≥ LWD / mile > 25 ☐ 25 ≥ LWD rank 3-6 > 10% ☐ 3 ≥ jams / mile > 1 ☐ low woody debris recruitment potential ☐ CPOM limited in both channel and margins					☐ LWD / mile ≤ 25 ☐ LWD size rank 3-6 ≤ 10% ☐ debris jams absent ☐ no woody debris recruitment potential ☐ CPOM absent				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Large woody debris density (LWD pieces / mile) is calculated in *Step 6.1* on the Sketch Tally Form. The more LWD, the more woody debris cover and better the habitat. The LWD density variable is measured for all stream types, with the ranges adjusted based on differences in expected reference conditions as described above.

Percentage of larger LWD (LWD size rank 3-6) is calculated from data collected during *Step 6.1* on the Sketch Tally Form. Dividing the sum of the count totals of size ranks 3, 4, 5, and 6 by the total count will give the percentage of larger LWD. In general, the larger the piece of LWD the more cover provided by that feature. The percentage of larger LWD variable is measured for all stream types, with the ranges consistent for all but step-pool systems where larger LWD is anticipated due to the typical greater abundance of larger trees in steeper headwater locations.

Debris jams density (debris jams / mile) is calculated in *Step 6.1* on the Sketch Tally Form. As with LWD, the more jams the more cover and better the habitat. The debris jams density variable is measured for all stream types, with the ranges adjusted based on differences in expected reference conditions as described above.

Woody debris recruitment potential is an important variable to investigate the presence of source material in the assessment location that could contribute trees to form woody debris cover in the future. Observations for this qualitative assessment (scored as high, moderate, low or no potential recruitment) include looking at the extent of source material in the near bank and riparian areas, as well as considering lateral connectivity to those source areas. Also, refer to *Steps 3.1* and *3.2* on the Field Notes Form for additional information on the tree cover near the channel. A check would be placed in the high recruitment potential box (reference condition category) for a channel with vegetated banks containing many trees and a large forested floodplain that appears to be frequently inundated and contributing wood to the system. On the other hand, a channel with no trees on the banks or in the riparian area would warrant a check in the no recruitment potential box (poor condition category). Some wood will likely get transported into this area from upstream locations; however, the potential recruitment at the assessment location is poor, or severely departed from reference conditions. The woody debris recruitment potential variable is measured in the same way for all stream types.

CPOM coverage is determined from the sketch map and assessed in relationship to the stream type reference condition for both the channel and margin. CPOM is an important source of food and cover for macroinvertebrates, and thus more CPOM generally results in better habitat. Smaller streams under a canopy of trees will likely have more CPOM than larger streams. As with LWD, both the abundance of source material and its retention influence CPOM coverage. Because CPOM can vary widely over seasons due to leaf drop, it is important to note in the Comments Section on the Field Notes Form if leaf drop happened recently and if it appears to be having a strong influence on the assessment. The CPOM coverage variable is measured for all stream types, with the ranges adjusted based on differences in expected reference conditions as described above.

8.2 BED SUBSTRATE COVER

Refer to the following locations in the SGA for additional information and required data.

- *2.12 Bed Substrate Composition*
- *2.13 Average Size of Largest Bed and Bar Particles*

Background

Variables	*Linking physical processes, habitat, and life-cycle functions*
Mean embeddedness (% Embeddedness in Main Hydraulic Feature) (% Embeddedness in Margin) [All stream types]	Suspended fine sediment inputs throughout the watershed exceed the stream's transport capacity during low flow periods, including the flood recession periods, and then settle and clog the voids between coarse sediment impairing gravel spawning fish, young-of-year (YOY) shelter, and macroinvertebrate habitat. Embedded sediments are more resistant to entrainment and may lead to sediment discontinuity and erosion processes downstream.
Fining (%) [All stream types]	Substrate size is a function of watershed characteristics, primarily geologic materials, discharge, channel slope and confinement that all influence sediment transport rate, distribution, sorting, bed roughness, and hydraulic patterns. Plants and macroinvertebrates are closely linked to sediment size, as is fish shelter and reproduction.
Riffle stability index (RSI) (%) [Riffle-pool and braided stream types]	Consolidation of particles and the amount of substrate movement due to hydrology (timing and intensity of runoff) and local hydraulics (stream power relative to boundary resistance) in riffles influences the permanence of habitat, which determines the periodicity of riffle habitat features influencing aquatic plants, macroinvertebrates, and fish.
Sediment stability [All stream types]	Consolidation of particles and the amount of substrate movement due to hydrology (timing and intensity of runoff) and local hydraulics (stream power relative to boundary resistance) influences the permanence of habitat, which determines the periodicity of habitat features influencing aquatic plants, macroinvertebrates, and fish.
Dense Algae Growth [All stream types]	Dense patches of algae growth indicate an imbalance in nutrient or sunlight levels. Algae will clog the voids between coarse sediment impairing gravel spawning fish, young-of-year (YOY) shelter, and macroinvertebrate habitat.
Imbrication [Plane Bed stream type]	Consolidation of particles, the amount of substrate movement due to hydrology (timing and intensity of runoff), local hydraulics (stream power relative to boundary resistance), and particle layering and sorting that takes place following floods influences the permanence of habitat, which determines the periodicity of habitat features influencing aquatic plants, macroinvertebrates, and fish.

The channel bed constitutes essential habitat in streams and rivers where varying degrees of roughness form cavities and spaces that are used as cover. Benthic, or bottom-dwelling, macroinvertebrates and juvenile fish rely on the void spaces between gravels and cobbles for habitat. If these spaces become embedded with finer sediments or dense algae, this critical habitat component can be lost resulting in diminished biological populations. Fining, the percentage of an area covered by fine particles, is a similar variable to embeddedness that several scientists (e.g., McHugh and Budy, 2005; USEPA, 2006) suggest may be a more accurate indicator of biological impairment.

Some studies focusing on fish populations measure embeddedness and fining in spawning habitat where eggs are deposited or habitat commonly used by par (i.e., head of riffles and runs). These areas may require different ranges of reference conditions given the requirements for the associated life cycle functions. Such detailed analysis is typically not used in this rapid assessment and reserved for more in-depth habitat studies.

Both embeddedness and fining are a function of upstream inputs of fine sediment from the watershed as well as the amount of sediment transport taking place at the assessment site under the current flow regime. The percentages of embeddedness and fining are not expected to differ substantially with stream type, with the possible exception being slightly increased values in low-velocity locations in step-pool channels that can retain a lot of fine material between floods. Activities such as logging in the headwaters without preserving adequate buffer widths can increase fine sediment input from the watershed that can work its way downstream smothering aquatic habitat along the way. Geomorphic change initiated from a range of activities such as altering watershed hydrology or channelization can lead to excessive erosion and increased fine sediment that can impair aquatic habitat.

The stability of bed features is an important habitat consideration as some level of permanence is required for colonization and persistence of aquatic plants and macroinvertebrates. Frequent large disturbances make even the best looking habitat uninhabitable due to its on-going instability. Too little disturbance will allow for excessive fine sediment to build up and smother aquatic habitat on the stream bed. An intermediate level of disturbance has been found to create habitat that is both maintained long enough for colonization and has fine sediments cleaned out periodically (Townsend et al., 1997).

The riffle stability index (RSI) (Kappesser, 2002) is a useful way to estimate the permanence of riffles, as a percent of the riffle that is mobile. It is the percent of particles in a riffle finer than the largest mobile particle measured on an exposed bar, as determined from the cumulative distribution generated from a pebble count centered on the nearest riffle. A lower RSI is preferred so that only a portion of a riffle mobilizes during small- and moderate-sized floods. If RSI is too large, the instability of the riffle may not allow colonization and persistence of biological communities. RSI is not expected to vary between stream types where riffles exist (i.e., riffle-pool and braided).

Imbrication, the shingle-like deposit in which the upstream particle partially overlaps its downstream neighbor (Bunte and Abt, 2001), is a useful qualitative measure of bed structure.

Both the level if imbrication and the general orientation of particle axes can help identify the amount of bed movement. This variable is only used for the assessment of plane bed reference stream types, where bed instability often limits habitat. In this case, less imbrication is preferred.

Evaluation

Riffle-Pool (Dune-Ripple) Stream Type

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
8.2 Bed Substrate Cover *fines: sand if $d_{50} \geq$ gravel, otherwise silt. (Dune-ripple stream type: Fining only.)	☐ riffle embeddedness < 20% margin embeddedness < 40% ☐ fining* < 10% ☐ Riffle stability index < 70% ☐ sediment apparently stable & sorted ☐ substrate free of dense algae growth	☐ $20 \leq emb_{riffle} < 40\%$ $40 \leq emb_{margin} < 60\%$ ☐ $10 \leq$ fining* < 20% ☐ $70 \leq RSI < 80\%$ ☐ some evidence of sediment mobility & lack of sorting ☐ small substrate patches covered by dense algae growth	☐ $40 \leq emb_{riffle} < 75\%$ $60 \leq emb_{margin} < 80\%$ ☐ $20 \leq$ fining* < 40% ☐ $80 \leq RSI < 90\%$ ☐ major evidence of sediment mobility & lack of sorting ☐ large substrate patches covered by dense algae growth	☐ riffle embeddedness $\geq$ 75% margin embeddedness $\geq$ 80% ☐ fining* $\geq$ 40% ☐ RSI $\geq$ 90% ☐ sediments unstable, unsorted, soft underfoot ☐ most of substrate covered by dense algae growth
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

Mean embeddedness (%) for both the in-channel feature of interest and the margin area is calculated in *Step 2.12* on the Field Notes Form. Lower embeddedness generally indicates better habitat. Embeddedness is measured for all stream types, with the in-channel measurement located in the feature most commonly associated with each stream type. For example, in a step-pool channel embeddedness is measured at both the downstream part of a pool in the main current where water velocity is highest and in the margin where velocity is lower. The range of expected embeddedness levels is consistent for all stream types except for the step-pool channel where pool embeddedness in reference conditions is likely higher. Embeddedness is omitted from the RHA assessment for dune-ripple stream types due to the expected lack of larger particle sizes against which to measure embeddedness.

Fining (%) is a variable that is calculated during *Step 2.12* and recorded on the cross-section worksheet. Lower fining generally translates to higher quality habitat. The measurement of the fining variable begins with defining fines for the assessment segment (or reach). Fines are considered to be sand if the median particle size (d_{50}) is gravel or larger (most cases in Vermont), while silt is used to define the fine fraction for channel beds having sand or smaller particles as the d_{50} (USEPA, 2006). Select a 1 m^2 (~11 ft^2) observation plot that is located in the main current in the feature most commonly associated with each stream type (e.g., a riffle in a riffle-pool, a ripple in a dune-ripple, etc…). Estimate the percentage of the area in the observation plot that is covered with fines. A minimum of two additional determinations of fining is recommended in the same bed feature to check and refine the initial estimate. Fining is measured for all stream types, and a consistent range of values is used.

The riffle stability index (RSI) (%) is calculated from data located in *Steps 2.12* and *2.13* on the Field Notes Form. Lower RSI values indicate better habitat quality. RSI is the percent finer, based on the pebble count centered on a riffle, of the largest mobile particle on the nearest exposed bar. A rough estimate of RSI can be made in the field, but this determination should be refined in the office once a more detailed cumulative distribution plot can be assembled. RSI is

only measured at riffles, with braided channels likely having more mobile riffles under reference conditions due to the presence of abundant sediment and varied flows paths.

Example: The largest mobile particle on bar was calculated in Step 2.12 to be 113 mm. Using pebble count data seen below, this particle is considered to be a medium cobble. Use an interpolation method to determine percent of particles finer than 113 mm.
By linear interpolation: (128-90)/(84.6-79.2) = (128-113)/(84.6-RSI), where RSI = 82.8 mm

Sample Particle Size Distribution Data as Measured using Pebble Count Methodology:

	Size Limits (mm)				Percent	Cumulative
Particle Name	lower	upper	Tally	Count	Passing	% Finer
silt/clay	0	**0.063**			0.0	0.0
very fine sand	0.063	**0.125**			0.0	0.0
fine sand	0.125	**0.250**		3	2.7	2.7
medium sand	0.250	**0.500**		3	2.7	5.4
coarse sand	0.500	**1**		3	2.7	8.1
very coarse sand	1	**2**		0	0.0	8.1
very fine gravel	2	**4**		4	3.6	11.7
fine gravel	4	**5.7**		5.7	5.1	16.9
fine gravel	5.7	**8**		8	7.2	24.1
medium gravel	8	**11.3**		12	10.8	35.0
medium gravel	11.3	**16**		13	11.7	46.7
coarse gravel	16	**22.6**		6	5.4	52.1
coarse gravel	22.6	**32**		10	9.0	61.2
very coarse gravel	32	**45**		6	5.4	66.6
very coarse gravel	45	**64**		6	5.4	72.0
small cobble	64	**90**		8	7.2	79.2
medium cobble	90	**128**		6	5.4	84.6
large cobble	128	**180**		7	6.3	91.0
very large cobble	180	**256**		7	6.3	97.3
small boulder	256	**362**		3	2.7	100.0
small boulder	362	**512**			0.0	100.0
medium boulder	512	**1024**			0.0	100.0
large boulder	1024	**2048**			0.0	100.0
very large boulder	2048	**4096**			0.0	100.0
bedrock	4096	**-**			0.0	100.0

A qualitative interpretation of bed mobility and sediment sorting is made for all stream types based on field observations. Sediment that is stable under foot and generally sorted by grain size is indicative of a stable bed that is good for habitat. Stable particles tend to appear darker than mobile ones as algae and slimes can colonize the stationary particle without frequent abrasion. On the other hand, sediment that seems soft when walked on and unsorted creates a bed that is too mobile, which leads to poor habitat. Particles that are more mobile or less stable tend to be cleaner and brighter than similar types of particles that are stationary due to repeated physical abrasion.

Dense algae blooms, such as green algae or diatoms, covering patches of the stream bottom can reduce access to clean substrate and decrease available dissolved oxygen. A healthy stream may have a thin film of periphyton covering rocks, a basic food source for aquatic organisms not

considered during this assessment. Patches of dense algae are assessed for all stream types and are noted on the sketch map during the segment walk. The relative coverage of algae patches is recorded as substrate free of algae or small substrate patches, large substrate patches, or most of the substrate is covered with dense algae growth.

Imbrication of particles and orientation is assessed to indicate bed stability in channels that have a plane bed reference type. When the a-axis (longest axis) is oriented parallel to the flow direction (i.e., a-axis imbricated) high intensity sediment transport is taking place such as debris flows. B-axis imbrication, when the b-axis is parallel to the direction of flow, indicates particle movement in fluid flows in low to moderate sediment transport rates (Bunte and Abt, 2001). Assess the qualitative nature of the imbrication in the channel, and also explore the imbrication on nearby exposed bars to confirm the observation. Limited short-axis imbrication could be considered to be better for habitat since fewer high sediment transport events are likely than if long-axis imbrication was dominant.

8.3 Scour and Depositional Features

Refer to the following locations in the SGA for additional information and required data.

- *Segment (or reach) sketch*
- *6.2 Pools*
- *2.10 Riffles / Steps*
- *2.11 Riffle / Step Spacing*
- *2.12 Bed Substrate Composition*
- *2.9 Sinuosity*

Background

Variables	*Linking physical processes, habitat, and life-cycle functions*
Pools (pools / mile) (pool size rank 3-7) [Riffle-pool, step-pool, and braided stream types]	The differential resistance of bed and bank materials creates opportunity for plunging, convergent and bending flows that differentiate bed features along the longitudinal channel profile creating deep pools that serve as thermal refugia for fish during low flows, locations of visual isolation from overhead predation, low-velocity flow refugia, and winter habitat.
Pool cover (%) [Riffle-pool, step-pool, and braided stream types]	Bank resistance and the presence of over-hanging vegetation, coupled with debris accumulation, provide cover in pools that expands diversified refuge for macroinvertebrates and fish, and provide visual isolation from predators.
Riffle (ripple) cover (%) [Riffle-pool (dune-ripple) and braided stream types]	Longitudinal distribution and lateral sorting of sediments leads to bed feature differentiation in the channel profile and creates riffles and plunging flows that are well-oxygenated and beneficial to macroinvertebrates and fish. Turbulence creates fish cover with visual isolation, clean gravel-spawning sites, and interstitial refuge for macroinvertebrates and young of the year (YOY) fish.
Riffle/step spacing (bankfull widths) [Riffle-pool and step-pool stream types]	Longitudinal distribution and lateral sorting of sediments leads to bed feature differentiation in the channel profile and creates riffles and plunging flows that are well-oxygenated and beneficial to macroinvertebrates and fish. Turbulence creates fish cover with visual isolation, clean gravel-spawning sites, and interstitial refuge for macroinvertebrates and young of the year (YOY) fish.

Bed feature pattern [Riffle-pool, step-pool, and braided stream types]	Turbulence and secondary lateral currents cause the selective entrainment, transport and deposition of bed and bank materials producing systematic sorting of grain sizes between erosion and depositional features. Watershed, corridor, and channel characteristics influence the size, frequency, and distribution of bed features with a range of water depth-velocity combinations, substrate sizes, and local hydraulics necessary for cover, refuge, and reproduction of plants and animals.
Diversity of hydraulic units [All stream types]	Sorting and distribution of sediment and organic materials create micro- and meso-bed forms resulting in hydraulic (depth-velocity) conditions favorable for creating macroinvertebrate or YOY fish habitat.
Fine deposition location [All stream types]	Although fine sediment can typically build up near the channel margin away from the main flow velocity, periodic flushing should move these particles through a river. In the main channel, suspended fine sediment inputs throughout the watershed exceed the stream's transport capacity during low flow periods, including the flood recession periods, and then settle and clog the voids between coarse sediments impairing gravel spawning fish, YOY shelter, and macroinvertebrate habitat.
Pool & riffle formation [Plane bed stream type]	Turbulence and secondary lateral currents cause the selective entrainment, transport and deposition of bed and bank materials producing systematic sorting of grain sizes between scour/step pools and riffle bars. These features are naturally absent in a plane bed reference stream type, and may evolve towards bed feature formation based on watershed, corridor, and channel characteristics influence.
Thalweg alignment [Plane bed stream type]	Turbulence and secondary lateral currents cause the selective entrainment, transport and deposition of bed and bank materials producing systematic thalweg meandering in most channel types. Plane beds tend to have uniform flow and often lack the hydraulics to initiate meandering. By tracking thalweg alignment one investigates how watershed, corridor, and channel characteristics influence the size, frequency, and distribution of bed features with a range of water depth-velocity combinations, substrate sizes, and local hydraulics necessary for cover, refuge, and reproduction of plants and animals.
Bar stability [Braided stream type]	Turbulence and secondary lateral currents cause the selective entrainment, transport and deposition of bed and bank materials, which create significant deposits and active channel widths for braided stream types. The frequency of the range of flows over the large exposed bars dictates bar stability based on sediment sorting and establishment of vegetation. If bar stabilization takes place for suitable periods of time to form useable habitat, the multiple channels of a braided stream type can contain good habitat for all aquatic organisms.

Scour and depositional features constitute essential structure of aquatic habitat. As a healthy stream or river moves water and sediment down its course in a dynamic equilibrium (Lane, 1955), patterns of bed features and associated hydraulic units are formed that diversify the bed and create different types of habitat for many different species and stages of aquatic plants, macroinvertebrates, and fish. In addition to physical structure, scour and depositional features produce a range of depth-velocity combinations that are closely linked to life-cycle functions.

Pools offer important cover for macroinvertebrates and fish, with larger pools having better fish cover suitable for establishing hydraulic and thermal refuge locations. Pools are important habitat features in all stream types. Pools are abundant in step-pool and riffle-pool stream types under reference conditions. In plane bed channels, pools are typically present in much lower

numbers or even absent, with sporadic presence of a deepening bed that could form into a pool. Target pool depth is 2 feet, and the presence of associated cover such as LWD and overhanging vegetation improve the habitat quality of the pool.

Riffles and ripples also provide for cover in terms of visual isolation and high dissolved oxygen due to constant mixing with the air. These locations are of particular importance for macroinvertebrates and fish as the fast velocity and high dissolved oxygen is used for reproductive life-cycle functions. Riffles are expected in riffle-pool and braided stream types, with some evidence of riffle formation possible in plane bed streams as they form bars and a meandering thalweg.

In step-pool stream types, the regular distribution and abundance of steps is analogous to riffles. The plunging flow over a step, often a large tree crossing the channel or an accumulation of large particles such as boulders, creates a local deep spot and an associated downstream pool that macroinvertebrate and fish use for cover. The diverse hydraulics and habitat of each step-pool complex is important as habitat features in this stream type are more prone to fragmentation during periods of low flows.

Bed patterns and hydraulic features are integrally linked to stream types, and in fact are used to characterize channels in several classification systems (e.g., Montgomery and Buffington, 1993). The patterns of bed features and associated hydraulic features that are a product of the physical processes and their natural variability are a primary determinant of the organisms that inhabit a stream type. Deviations from expected patterns can take place when natural processes are changed such as alteration of hydrology and sediment regime, or when channel morphology is constrained due to channelization and other related activities. Subtle habitat change due to shifting of bed features and hydraulics away from reference conditions can render a location uninhabitable for some organisms that require specific living conditions. Distinct and regular changes in expected bed patterns indicate reference habitat. For example, clear patterns of riffle, run, pool and glide suggest a healthy riffle-pool channel. For hydraulic features, the presence of the expected number of depth-velocity combinations (fast-shallow, fast-deep, slow-shallow, and slow-deep with cutoffs at 1.0 fps, 1.5 ft) for a given stream type is indicative of healthy habitat. All four depth-velocity combinations are expected in riffle-pool and braided streams, while two hydraulic types are presumed reference in step-pool and plane bed stream types.

In a healthy stream or river, erosion and deposition are constantly taking place along the channel in moderation over the natural range of flows. At a given cross section, more deposition is expected in the low flow locations along one or both banks, depending on the stream type. For example, deposition on a riffle-pool stream type is expected on the inside of meander bends where velocity is lowest. In step-pool streams, increased fines may accumulate periodically on the margins of the widest portion of the pools. The abundance and location of fine sediment deposition is a useful clue about the temporal aspects of flushing flows that clean out bottom habitat. The reference condition for all stream types is fines are solely located in slack water behind debris and along margins. If fine sediment builds up in the mid-channel and fills in pools than it is likely that excessive deposition is taking place due to increased sediment supply and/or reduced transport.

The uniform hydraulics and homogenous bed of a plane bed channel limit species diversity. Habitat improvement is likely if some heterogeneity takes place in this channel type either through natural channel evolution towards a new equilibrium or through an active approach to enhancing habitat heterogeneity if conditions are appropriate. In both cases, habitat can be improved if a meandering thalweg is produced to diversify bed features and hydraulic patterns.

Braided reference type streams are very wide, have multiple flow paths, large exposed bars and often are unstable. The lack of stability in the bed and bars is an important limiting factor of the habitat in braided channel types. Sorting, stability, and amount of vegetation are all explored on the large deposition features in a channel that has a braided reference stream type. The more stable, sorted and vegetated the sediment, the less likely it is to adjust each flood allowing for colonization by aquatic plants and macroinvertebrates.

Evaluation

Riffle-Pool (Dune-Ripple) Stream Type

Habitat Parameter	Condition (Departure) Category			
	Reference (None)	Good (Minor)	Fair (Major)	Poor (Severe)
8.3 Scour and Deposition Features (Dune-ripple stream type: Only evaluate pools and ripples.) *Depth-velocity combinations* *fast-shallow* *fast-deep* *slow-shallow* *slow-deep* *(cutoffs: 1.0 fps, 1.5 ft)* Pool size rank variable only used if ≥ 5 pools	☐ pools / mile > 40 ☐ pool size rank 3-7 >50% ☐ good cover > 75% of total pool surface area ☐ riffle (ripple) coverage > 25% reach area, distinctly formed and complete ☐ 5 ≤ riffle spacing ≤ 7 bankfull channel widths (w_{bkf}) ☐ well-defined riffle-run-pool-glide pattern with all four depth-velocity combinations present ☐ finer deposition located entirely in slack water below larger substrates/debris, and along margins	☐ 40 ≥ pools / mile > 20 ☐ 50 ≥ pool rank 3-7 > 25% ☐ 75 ≥ good cover > 50% of total pool surface area ☐ 25 ≥ riffle coverage > 10% reach area, moderately well formed and complete ☐ 3 ≤ riffle spacing < 5, or 7 < riffle spacing ≤ 10 x w_{bkf} ☐ well-defined riffle-run-pool-glide pattern with three depth-velocity combinations dominant ☐ finer deposition located in slack water below larger substrates/debris, signs of mid-channel accumulation	☐ 20 ≥ pools / mile > 10 ☐ 25 ≥ pool rank 3-7 > 10% ☐ 50 ≥ good cover > 25% of total pool surface area ☐ 25 ≥ riffle coverage > 10% reach area, poorly formed and incomplete ☐ 1 ≤ riffle spacing < 3, or 10 < riffle spacing ≤ 12 x w_{bkf} ☐ moderately defined riffle-run-pool-glide pattern with two depth-velocity combinations dominant ☐ very large depositional features below larger substrates/debris, abundant mid-channel accumulation	☐ pools / mile ≤ 10 ☐ pool size rank 3-7 ≤ 10% ☐ good cover ≤ 25% of total pool surface area ☐ riffle (ripple) coverage ≤ 10% reach area, or mostly indistinct ☐ riffle spacing ≥ 12 bankfull channel widths ☐ poorly defined riffle-run-pool-glide pattern with one depth-velocity combination dominant ☐ finer deposition throughout channel, even filling pools, larger substrates almost buried **or** bed largely incised
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

Pool density (pools / mile) is calculated in *Step 6.2* on the Sketch Tally Form. Habitat generally improves with more pools. Pool density is determined for riffle-pool, step-pool, and braided stream types, with the values being higher for step-pool streams. A qualitative assessment of pool formation is made for plane bed streams where pools are not likely to be abundant.

Percentage of larger pools (pool size rank 3-7) is calculated from data in *Step 6.2* on the Sketch Tally Form. Sum the counts in size ranks 3, 4, 5, 6, and 7, and divide by the total number of pools. A higher percentage of larger pools is better habitat. The percentage of larger pools is determined for riffle-pool, step-pool, and braided stream types, with consistent ranges across the condition categories between each type.

In addition to pool density and size, pool cover is qualitatively assessed for riffle-pool, step-pool, and braided stream types. Reference cover would indicate the presence of LWD, overhanging

vegetation, detritus, and surface turbulence cover at least 75% of the surface area of the pools over the assessment reach that all enhance the cover function of a pool. Pools without cover would be relatively shallow and lack the cover components described above.

Riffle coverage (%) is estimated from the segment (or reach) sketch. Compare the surface area covered by riffle with the total surface area of the assessment and make an educated guess on the percent that is riffle. More riffle tends to be better habitat. Riffle coverage is measured for riffle-pool and braided stream types, with ripple coverage being measured in the same way for the dune-ripple stream type. Observation of how distinct and complete each riffle is over the transition into other bed features is determined in *Step 2.10* in the Field Notes Form. Use this information and additional observations during the RHA to gain information on the stability of the riffles and, whether they will likely remain for some time or be washed away during the next flood. For plane bed stream types, a qualitative estimate of riffle formation is made.

Step form and stability is measured in *Step 2.10* in the Field Notes Form, and with additional visual observations during the RHA. As with riffles, distinct breaks between adjacent bed features and stable, well-formed steps indicate better habitat over a time frame that could be effectively used by macroinvertebrates and fish. An abundance of unstable step-pools would lead to poor habitat that is difficult for most organisms to survive in.

Riffle and step spacing (number of bankfull widths) is determined in *Step 2.11* in the Field Notes Form, and from the segment (or reach) sketch for the appropriate stream types. While walking the reach and looking at bankfull level indicators, also note the approximate bankfull width on the sketch and use this measure as a scale when determining spacing between bed features. This width estimate may need to be refined during the subsequent cross section measurements, yet given the variables ranges of 5 bankfull channel widths for each condition category on the RHA forms it is likely that the initial check mark will remain valid. Expected riffle spacing for a reference riffle-pool stream type is between 5 and 7 bankfull widths, and the expected step spacing is about 5 bankfull widths.

Hydraulic patterns are estimated from the segment (or reach) sketch and direct field observations during the RHA. Look for the appropriate number of depth-velocity combinations for each stream type as described above.

The qualitative assessment of fine particle deposition is made during the site walk and during the RHA analysis. If many in-channel accumulations of fines are encountered the site receives a poor score, while if fines are only observed on the margins of channel and behind large debris than a good score would be checked. Check *Step 2.12* on the Field Notes Form for additional information on the abundance of fine particles.

For braided stream types, the stability of large sediment deposition is qualitatively assessed. Determine if the particles are well-sorted indicating expected hydraulics and better habitat, or if the particles are scattered suggesting unnatural flood flows and recession, and likely less stable habitat. If bars appear stable, or firm under foot, and have more than half of their surface areas covered by vegetation, they may be stabilizing and will help form more permanent aquatic

habitat. Bars that are soft under foot and have little vegetation are likely highly mobile causing an unstable bed and excessive sedimentation that makes for poor habitat.

8.4 Channel Morphology

Refer to the following locations in the SGA for additional information and required data.

- *2.6 W/d_{mean} Ratio*
- *2.7 Entrenchment Ratio*
- *2.8 Incision Ratio*
- *5.5 Channel Alterations*

Background

Variables	*Linking physical processes, habitat, and life-cycle functions*
Width/depth ratio [All stream types]	Watershed and valley characteristics, channel boundary resistance, and location within the longitudinal profile set the geomorphic context for a given channel, of which the width/depth ratio is a fundamental measure. Width/depth ratio is indicative of mean channel depth and thereby the hydraulic efficiency of the stream to move the sediments supplied to the channel which influences instream habitat due to creation of hydraulic patterns locally and over the length of a river reach.
Entrenchment and incision ratios [All stream types]	Watershed and valley characteristics determine where a channel sits vertically relative to its floodplain. Changes in floodplain connection have a profound affect on stream power and sediment transport characteristics influencing the development and distribution of habitat-related bed forms. Increased sediment transport as a result of incision results in deposition and embeddedness in downstream locations. Lateral connectivity and the periodicity of floodplain inundation define organism access to slow water locations important for fish rearing and retreat during high water.
Channel alteration [All stream types]	Channelization, bank armoring, gravel excavation, and fixed grade control all influence channel morphology, hydraulics, sediment transport and cover types. Altered macro-, meso- and micro-habitats influence all aquatic flora and fauna.

Channel morphology is integrally linked to aquatic habitat, which in turn influences the biological communities in stream or river. As channel width and depth increase moving from headwaters to watershed outlet, predictable changes in all trophic levels take place along a continuum (Vannote et al., 1980). These expected natural patterns, however, can be altered by discontinuities associated with dams, confluence with impaired tributaries, and strong deviations from natural channel morphology. The width/depth ratio is measured for all stream types, with the ranges for each condition category adjusted based on expected channel dimensions. For reference conditions, width/depth ratio is expected to be less than 30 for braided stream types, less than 15 for riffle-pool, dune-ripple, and plane bed stream types, and less than 12 for step-pool, bedrock, and cascade stream types.

Connectivity between a channel and its floodplain is a critical consideration for habitat quality over long time periods because floodplains that are accessible provide hydraulic refuge areas during floods, important nursery grounds for some types of juvenile fish during spring flows, and

inputs of non-living organic matter such as large woody debris. In addition, floodplains have very large flow areas relative to stream channels, and thus water velocity is relatively slow. This flood attenuation regulates stream power and reduces the chances of excessive erosion or deposition to alter habitat. Floodplain connectivity, or ER and IR, is an important consideration because it dictates the nature and frequency of continued habitat maintenance that takes place during each and every flood.

Both entrenchment and incision ratios (ER and IR) indicate the lateral connectivity between a channel and its floodplain. Flows are contained within the channel alone in highly entrenched streams (ER < 1.4, IR $\geq$ 2) that can cause frequent changes to habitat and make it difficult for organisms to survive. On the other hand, streams exhibiting little or no entrenchment (ER $\geq$ 1.4, IR < 1.2) can readily access their floodplain at bankfull flows, thus habitat is continually safeguarded from excessive erosion and deposition except for extreme events. ER and IR are measured for all stream types, with slight adjustment of the ranges for condition categories based on stream type.

Recent and historic channel alteration by humans typically set in motion a host of changes to channel, banks, and floodplain that impair aquatic habitat. Recent alterations such as application of riprap and other reinforcements to protect infrastructure alter natural channel morphology and can collectively increase stream power and impair habitat over large areas. Other common alterations include gravel mining, dredging or cleaning out fine sediments, straightening, and damming. Although often harder to see, large scale historic alterations such as deforestation, straightening for locating transportation corridors, gravel mining, and dredging can still be having a negative impact on habitat.

Evaluation

Riffle-Pool (Dune-Ripple) Stream Type

Habitat Parameter	Condition (Departure) Category																			
	Reference (None)					Good (Minor)					Fair (Major)					Poor (Severe)				
8.4 Channel Morphology	☐ width/depth < 15, natural ☐ entrenchment ratio $\geq$ 1.4, incision ratio < 1.2, good floodplain access ☐ no evidence of channel alteration					☐ 15 $\leq$ w / d < 25, widening ☐ entrenchment ratio $\geq$ 1.4, 1.2 $\leq$ incision ratio < 1.4, reduced floodplain access ☐ evidence of minor historic channel alteration					☐ 25 $\leq$ w / d < 40, widening ☐ entrenchment ratio $\geq$ 1.4, 1.4 $\leq$ incision ratio < 2.0, limited floodplain access ☐ major historic or minor recent channel alteration					☐ w / d > 40, over-widening ☐ entrenchment ratio < 1.4 **or** incision ratio $\geq$ 2.0, floodplain access unlikely ☐ extensive historic or major recent channel alteration				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Width/depth ratio is calculated in *Step 2.6* on the Field Notes Form. Width/depth ratio is used in the RHA for all stream types, and reference conditions are directly correlated to each type. Increased width/depth ratio indicates channel widening which tends to degrade habitat.

Entrenchment ratio is calculated in *Step 2.7* on the Field Notes Form, and is used in the RHA for all stream types. The entrenchment ratio ranges for each condition category are adjusted based on stream type. Lower entrenchment ratio indicates less access to the floodplain, while higher values indicate that the floodprone area is relatively wide as compared to the channel width.

Incision ratio is measured in *Step 2.8* on the Field Notes Form. Larger incision ratios indicate more channel incision and lower quality habitat or the potential for frequent disturbance due to limited floodplain access. Incision ratio is measured for all stream types, with slightly lower condition category range for braided stream types.

Channel alteration is determined in *Step 5.5* on the Field Notes Form. More channel alteration impairs the physical processes that form aquatic habitat. Channel alteration is determined for all stream types.

8.5 Hydrologic Characteristics

Refer to the following locations in the SGA for additional information and required data.

- *2.1b W_{wetted} / W_{bkf} Ratio*
- *Segment (or reach) sketch*
- *2.13a % Exposed Substrate*
- *4.1 Springs or Seeps*
- *4.2 Adjacent Wetlands*
- *4.3 Flow status*
- *4.6 Stormwater Inputs*
- *4.7 Flow Regulation*
- *3.3 Riparian Corridor*

Background

Variables	*Linking physical processes, habitat, and life-cycle functions*
Wet width/bankfull width [All stream types]	Watershed hydrology and channel morphology determine the amount of wetted useable habitat available for all trophic levels, as well as channel stability and the temperature regime present.
Exposed substrate (%) [All stream types]	Watershed hydrology, substrate composition, and channel morphology determine the amount of wetted useable substrate habitat available for all trophic levels, as well as channel stability and the temperature regime present.
Adjacent springs, seeps, and wetlands [All stream types]	Watershed hydrology, fine sediment storage and lack of drainage infrastructure in the valley bottom allow riparian wetland formation that buffers the river channel, protects bank integrity, mediates inflow via storage, and creates sources of organic inputs all of which are important for invertebrates and fish.
Flow alterations [All stream types]	Adjustment of natural flow magnitude and frequency initiates geomorphic change altering the channel morphology and sediment regime, which in turn influences reach and local hydraulics that influence habitat.

Hydrology is a master variable for rivers and streams as it fundamentally drives every physical process. The amount of water in the channel is representative of watershed hydrology during the

season of observation, and an indicator of the amount of area that may potentially serve as aquatic habitat for plants, macroinvertebrates and fish. The amount of water in the channel and the amount of exposed substrate are measured in all stream types as indicators of current hydrology.

It is important to note that hydrology and instream flows naturally vary, and that this variability is important to drive a range of key physical processes that form habitat. Alteration of watershed hydrology can not only increase or decrease flow magnitudes, but can also disturb the natural flow regime that creates the appropriate range of variability of flows (Richter et al., 1996; Poff et al., 1997). Deviations from natural flow lead to repeated stress to habitat. Frequent excessively large floods or long periods of drought impair habitat by altering sediment transport, channel morphology, and water quality.

Springs, seeps, and other wetlands that are adjacent to a channel can reduce the impacts of altered hydrology, and help establish thermal refuge. In addition, riparian wetlands also perform important functions such as flood attenuation, fine sediment capture, nutrient processing, and local ground water recharge. The result is more suitable habitat in the channels and along the banks. Without adjacent wetlands, a channel and its habitat is more vulnerable to impairment due to watershed alteration. The presence of riparian wetlands is important to all channel types.

Evaluation

Riffle-Pool (Dune-Ripple) Stream Type

Habitat Parameter	Condition (Departure) Category																			
	Reference (None)					Good (Minor)					Fair (Major)					Poor (Severe)				
8.5 Hydrologic Characteristics	☐ wetted width / W_{bkf} > 0.75 ☐ exposed substrate < 20% ☐ adjacent springs, seeps, and wetlands extensive ☐ no known flow alteration					☐ 0.75 ≥ W_{wet} / W_{bkf} > 0.50 ☐ 20 ≤ exp. substrate < 40% ☐ adjacent springs, seeps, and wetlands present ☐ minor flow alteration likely due to flow regulation and/or land use changes					☐ 0.50 ≥ W_{wet} / W_{bkf} > 0.25 ☐ 40 ≤ exp. substrate < 60% ☐ adjacent springs, seeps, and wetlands minimal ☐ major flow alteration likely due to flow regulation and/or land use changes					☐ W_{wet} / W_{bkf} ≤ 0.25 ☐ exposed substrate ≥ 60% ☐ adjacent springs, seeps, and wetlands absent or altered ☐ runoff characteristics completely altered due to flow regulation and storm water influence				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Wetted width / bankfull width ratio is calculated in *Step 2.1b* on the Field Notes Form. Also, refer to the flow status observation in *Step 4.3* on the Field Notes Form for additional information. Wetted width / bankfull width ratio is used in the RHA for all stream types, and reference conditions are consistent (>0.75) except for braided stream types (>0.5) that have less wetted area due to exposed bars.

Exposed substrate, or bars, is drawn on the segment (or reach) sketch, and calculated in *Step 2.13a* on the Field Notes Form. While in the field, review the sketch and estimate how much of the assessment area is covered by exposed bars. Additional field observations may be useful to check the initial determination of percent exposed bar area. The exposed substrate variable is measured for all stream types, with the range for condition categories adjusted based on expected values. For reference conditions, step-pool (<10%), riffle-pool (20%) and plane bed (<20%)

have the lowest amount of exposed bars, while braided channel should have more (<50%) due to multiple flow paths and exposed bars.

The presence of springs and seeps is rated in *Step 4.1* and the presence of adjacent wetlands is determined in *Step 4.2* on the Field Notes Form. With additional observations during the RHA analysis to confirm these data, adjacent springs, seeps, and wetlands is observed for all stream types.

Flow statues (*Step 4.3*), stormwater inputs (*Step 4.6*), flow regulation (*Step 4.7*), and land use in the riparian corridor (*Step 3.3*) are all measured on the Field Notes Form and are useful for investigating flow alterations for all stream types. Flow alteration increases with the amount of flow regulation, land use change away from natural vegetation, and stormwater inputs.

8.6 Connectivity

Refer to the following locations in the SGA for additional information and required data.

- *1.6 Grade Controls*
- *Segment (or reach) sketch*
- *6.3 Refuge Areas / Connections*

Background

Variables	*Linking physical processes, habitat, and life-cycle functions*
Presence of reach obstructions [All stream types]	The presence of dams and natural obstructions limit animal movement and population dispersal of most fish. Plant, macroinvertebrate and fish habitat change takes place due to altered hydrology and sediment transport with more obstructions influencing reach hydraulic patterns. Obstructions alter temperature regime, dominant food type, sediment transport, hydrology, and hydraulics, with more significant deviations form typical habitat the closer to an obstruction.
Presence of system obstructions [All stream types]	The presence of dams and natural obstructions limit animal movement and population dispersal of most fish. Plant, macroinvertebrate and fish habitat change takes place due to altered hydrology and sediment transport with more obstructions leading to more fragmented habitat and disrupted processes.
Presence of refuge areas and connections [All stream types]	Channel slope, hydraulics, sediment supply, and floodplain forming processes create slow water areas in abandoned channels and other features formed and accessed during various flood stages providing refuge to macroinvertebrates and fish during floods, some low flow conditions, and hiding locations from predators.

Connectivity is an important habitat consideration in streams and rivers, with many processes being influenced by the degree of both longitudinal and lateral connectivity. Lateral connectivity

between a channel and its floodplain is described in the channel morphology RHA parameter (8.4) by both entrenchment and incision ratios. The emphasis here is the longitudinal connectivity, which directly influences the movements of both resident and migratory fish and downstream drift of macroinvertebrates. Several barriers across a river system can limit important life cycle functions and populations of a specific species. Barriers such as dams and culverts alter hydrology and sediment transport initiating a range of channel and habitat changes downstream. Barriers introduce discontinuities to the normal continuum of processes, habitat and biological communities along a river channel (Ward and Stanford, 1995b). Longitudinal connectivity is investigated in the reach and system via the presence of barriers for all channel types.

The presence of refuge areas, and connectivity to these locations, is an important habitat consideration that is often overlooked. With the dynamic nature of the river environment, places to move during stressful conditions (e.g., floods, droughts, extreme heat) or to avoid predation can improve the overall quality of habitat in a location. Refuge areas can be located in the channel or in features that lie outside of the main channel. The presence of refuge areas, when they are accessible, and the quality of habitat in the location are important habitat considerations for all channel types.

Evaluation

Riffle-Pool (Dune-Ripple) Stream Type

Habitat Parameter	Condition (Departure) Category																			
	Reference (None)					Good (Minor)					Fair (Major)					Poor (Severe)				
8.6 Connectivity Tend towards a higher/lower score for natural/man-made obstructions	☐ no obstructions in reach that block longitudinal movement of aquatic species over all but the lowest flows ☐ system obstructions absent ☐ abundant low and high flow refuge					☐ one or two small low flow obstructions present in reach that block movement of aquatic species ☐ limited system obstructions ☐ abundant refuge, with low **or** high flow refuge limited					☐ one or two small to medium bankfull obstructions present in reach that block movement of aquatic species ☐ system obstructions present ☐ limited low **and** high flow refuge					☐ more than two bankfull obstructions present in reach that block movement of aquatic species ☐ many system obstructions ☐ refuge absent				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

The presence of reach obstructions is reported in *Step 1.6* on the Field Notes Form. Obstructions over the observation area are important for all stream types. As the number and size of obstructions increase, habitat is more fragmented over a wider range of flows. The absence of obstructions is the reference condition. Obstruction can be natural or introduced by humans, both of which fragment habitat. After scoring all variables for this parameter and deciding on the score for the parameter, tend towards a higher score for natural obstructions and a lower score for man-made obstructions.

Obstruction throughout the watershed are evaluated by looking at maps and gathering local knowledge about dams, falls, undersized culverts and any other obstruction that may be present. Data for this variable may be available in assessments on other river in the watershed. The amount of watershed obstructions is assessed for all stream types.

Refuge areas and their connections are recorded on the segment (or reach) sketch and recorded in *Step 6.3* on the Sketch Tally Form for all stream types. Abundant refuge with good habitat accessible over a range of low and high flows is the reference condition.

8.7 River Banks

Refer to the following locations in the SGA for additional information and required data.

- *3.1 Bank Erosion*
- *3.1 Bank Revetment Type*
- *3.1 Near Bank Vegetation*
- *3.1 Bank Canopy*
- *6.4 Undercut Banks*
- *3.1 Mass Failures*

Background

Variables	*Linking physical processes, habitat, and life-cycle functions*
Amount of erosion (%) [All stream types]	Increased bank erosion rates reduce habitat quality by increasing disturbance regime and adding fines to habitat features. The result is a reduction in productive aquatic habitat.
Vegetation type and abundance (%) [All stream types]	Roots of trees, shrubs and herbaceous species increase bank stability (via bank and floodplain roughness and channel boundary resistance), allowing formation of better near-bank habitat consisting of undercuts and overhanging vegetative cover. Bank vegetation provides shade that is important for macroinvertebrates and fish in warmer seasons.
Bank canopy [All stream types]	Bank vegetation forms near-bank and canopy cover that is important for fish cover, setting up thermal refuge, and winged-adult invertebrate habitat. Bank canopy also supplies the channel with organics inputs to the food web and beneficial channel roughness.
undercut banks (undercut banks / mile) (undercut bank size rank 3-6) (stability and overhanging vegetation) [All stream types]	The combination of stable banks, suitable near-bank hydraulics, and system hydrology collectively produce deep, cool undercut banks. Stable banks and ample riparian and bank vegetation create overhanging vegetation that is important for macroinvertebrate reproduction and fish cover in bank habitat. Overhanging vegetation shades the river channel and also is a source of organics to support the lower part of the food web.
Presence of mass failures [All stream types]	Through large inputs of sediment, mass failures degrade plant, macroinvertebrate, and fish habitat. Gravel-spawning success is reduced with more mass failures. Such events can introduce very large amounts of colluvium into the system leading to widespread channel adjustment and habitat degradation.

River banks are dynamic boundaries that help form important habitat for macroinvertebrates and fish. Some erosion and deposition is expected along the banks, but excessive erosion beyond typical scour of the toe, or bottom, of the bank impairs habitat. Unnatural amounts of erosion can take place when water impinges directly on the bank due to altered channel alignment, the stream power is unusually large due to upstream channelization and/or disconnection from the floodplain, bank resistance is low due to the textures of the bank particles, and banks have been weakened due to removal of vegetation. Bank erosion can impair habitat on all stream types.

Important habitat features produced by the river banks include bank canopy, undercut banks, and overhanging vegetation. Habitat quality improves with increasing amounts of each of these features for all stream types. Good bank canopy helps shade the channel in warmer seasons. Undercut banks provide important refuge areas for macroinvertebrates and fish to avoid predation, floods, and warm water temperatures due to low flows in summer.

Mass failures, or large erosion events in the landscape, can take place near a stream and impair instream and near-bank habitat. Mass failures contribute excessive amounts of erosion to the channel network which can smother habitat as it is transported downstream. If mass failures take place adjacent to a river, the bank is typically damaged and lacks the structural integrity to prevent excessive erosion. More mass failures tend to result in more excessive bank erosion that is generally bad for habitat on all stream types.

Evaluation

Riffle-Pool (Dune-Ripple) Stream Type

Habitat Parameter	Condition (Departure) Category										
	Reference (None)			Good (Minor)			Fair (Major)			Poor (Severe)	
8.7 River Banks	☐ bank erosion <10%, typical of natural conditions, little or no bank revetments			☐ 10 ≤ bank erosion < 30%, infrequent small areas, some bank revetments			☐ 30 ≤ bank erosion < 60%, mod. unstable banks, and/or extensive bank revetments			☐ bank erosion ≥ 60%, banks unstable, extensive erosion, and failing bank revetments	
Select different boxes for LB and RB if necessary	☐ bank vegetation > 90% in tree, shrub and herb layers, diverse assemblages, plants create good cover and roots help stabilize bank			☐ 90 ≥ bank vegetation > 75% in each layer, diverse assemblages, plants create good cover and roots help stabilize bank			☐ 75 ≥ bank vegetation > 50%, in two of three layers, reduced diversity, plants create limited cover and roots do not stabilize bank			☐ bank vegetation ≤ 50% in two of three layers, limited diversity, plants create no cover and roots do not stabilize bank	
Undercut size rank variable only used if ≥ 5 undercuts	☐ bank canopy > 90%			☐ 90 ≥ bank canopy > 75%			☐ 75 ≥ bank canopy > 50%			☐ bank canopy ≤ 50%	
	☐ undercut banks / mile > 30			☐ 30 ≥ undercuts / mile > 15			☐ 15 ≥ undercuts / mile > 5			☐ undercuts / mile ≤ 5	
	☐ undercut bank size rank 3-6 > 50%			☐ 50 ≥ undercut bank size rank 3-6 > 25%			☐ 25 ≥ undercut bank size rank 3-6 > 10%			☐ undercut bank size rank 3-6 ≤ 10%	
	☐ undercut banks with mostly stable boundaries, abundant overhanging vegetation, and consistent water adjacency			☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and consistent water adjacency			☐ undercuts with some unstable boundaries or reduced overhanging vegetation, and reduced water adjacency			☐ undercuts with mostly unstable boundaries, no overhanging vegetation, and reduced water adjacency	
(score each bank)	☐ no mass failures in valley			☐ 1 mass failure in valley			☐ 1 - 2 mass failures in valley			☐ ≥ 3 mass failures in valley	
SCORE _____ (LB)	Left Bank	10	9	8	7	6	5	4	3	2	1
SCORE _____ (RB)	Right Bank	10	9	8	7	6	5	4	3	2	1

Bank erosion (%) is determined in *Step 3.1* on the Field Notes Form, and is evaluated in the RHA for all stream types. Less bank erosion results in more stable banks and near-bank habitat. Although they limit erosion by increasing bank resistance, artificial bank revetments such as riprap limit natural bank processes and tend to reduce the quality of habitat primarily through limiting vegetation coverage. Reference conditions are less than 10% of the bank length actively

eroding and the absence of revetments. Variable ranges are lowered slightly for step-pool stream types as less bank erosion is expected.

Bank vegetation (type and % coverage) is evaluated in *Step 3.1* on the Field Notes Form, and is evaluated in the RHA for all stream types. In addition, observations are needed to qualitatively investigate the amount of vegetative cover and the degree to which roots help stabilize the banks. The presence of trees, shrubs, and herbs is important as each plays a role in bank stabilization and associated habitats. Reference conditions include more than 90% coverage by diverse assemblages in each vegetation layer, vegetation creates good cover, and roots help stabilize bank.

Bank canopy (% coverage) is evaluated in *Step 3.1* on the Field Notes Form, and is evaluated in the RHA for all stream types. Coverage of 90% is the reference for all stream types except for step-pool channels where complete bank coverage is likely in natural conditions.

Undercut bank density (undercuts / mile) is calculated in *Step 6.4* on the Sketch Tally Form. The more undercuts, the more refugia near the bank and better the habitat. The undercut bank density variable is measured for all stream types, with the ranges adjusted based on differences in expected reference conditions.

The percentage of larger undercut banks (undercuts with size rank 3-6) is calculated in *Step 6.4* on the Sketch Tally Form. Dividing the sum of the count totals of size ranks 3, 4, 5, and 6 by the total count will give the percentage of larger undercut banks. In general, the larger the undercut the more cover provided by that feature. The percentage of larger undercut banks is measured for all stream types with consistent ranges for the condition categories.

During the RHA, the stability of and approximate amount of overhanging vegetation associated with each undercut bank is determined. This information is best used to confirm the decision to check a box in one of the condition categories based on the percentage of larger undercut banks. Reference condition is mostly stable undercut banks that are covered by vegetation, while poor condition is if undercut banks are actively slumping, have raw erosion faces, and lack overhanging vegetation.

The presence of mass failures is calculated in *Step 3.1* on the Field Notes Form, and used in the RHA for all stream types. More mass failures tend to result in more impacted habitat.

8.8 Riparian Area

Refer to the following locations in the SGA for additional information and required data.

- *3.2 Buffer Width*
- *3.2 Buffer Vegetation*
- *3.3 Riparian Corridor*

Background

Variables	*Linking physical processes, habitat, and life-cycle functions*
Vegetated buffer width [All stream types]	Preservation of natural vegetation in the river corridor improves habitat via shading the channel, supplying organics, attenuating fine sediment and high flows, and taking up excess nutrients. The result is improved habitat for macroinvertebrates and fish with larger buffer widths.
Vegetation type, abundance and canopy condition [All stream types]	The diversity of vegetation in riparian buffers increases various types of root structure, ground surface roughness, and the general stability of the riparian zone. Each of these improves near bank habitat and the attenuation functions of vegetated buffers that influence all physical regimes and habitat components.
River corridor development [All stream types]	Through influencing watershed hydrology and sediment load, land cover can manifest itself as habitat change. Altered flow rate and sediment regime influences meso-habitats that ultimately affect small scale habitats for plants, macroinvertebrates and fish.

Riparian areas are an important transition zone between a river and its watershed. Important processes such as flood attenuation, sediment capture, nutrient uptake, transfer of organic material, and shading of water all take place in naturally vegetated buffers. Once cleared or altered, buffers no longer perform many of the functions to support healthy aquatic habitat. The width of the naturally vegetated buffer, the abundance and type of buffer vegetation present, the closure of the channel by the tree canopy, and the amount of development, or land use change, in the river corridor characterizes the riparian area.

Although the focus of this assessment is aquatic habitat, it is important to note the many important functions that riparian buffers play to terrestrial species. Many amphibians, birds, and small mammals utilize riparian areas for movement, foraging, and shelter.

Naturally vegetated buffers are essential for aquatic habitat as they regulate the disturbance regime in the channel by reducing the size of floods, sediment loads, nutrient loads, and incident solar radiation. The fundamental relationship between a stream and its river corridor influences virtually every natural process, which in turn creates habitat. This influence on the biological communities in a river or stream is beyond the more direct influence associated with importation of organic material, the reproduction of some winged adult macroinvertebrate species in buffer vegetation, and the use of buffer areas as refuge during floods. Vegetated buffers are important for all stream types.

The amount and type of vegetation in the buffer is another important consideration for both the aquatic and terrestrial communities inhabiting the valley floor. Focusing on the aquatic habitat, densely vegetated buffers are more effective at insulating channels from disturbances. A mix of root types is more effective at creating stable soils in the buffer, which can influence the stability of the nearby river bank.

Development in the river corridor alters the processes that shape habitat, and also typically creates physical limitations as human infrastructure is protected with a range of management activities. Once a channel's ability to move laterally is limited, cascading effects leads to impaired habitat that begins with alteration of hydrology, hydraulics, and sediment transport. Rehabilitation projects may control the level of impairment; however, true restoration that includes long-term sustainable amounts of habitat can only be achieved if the river has ample room to move and carry out natural processes and attain a desired shape.

Evaluation

Riffle-Pool (Dune-Ripple) Stream Type

Habitat Parameter	Condition (Departure) Category										
	Reference (None)			Good (Minor)			Fair (Major)			Poor (Severe)	
8.8 Riparian Area Select different boxes for LB and RB if necessary **(score each side of the channel)**	☐ buffer width > 150 ft ☐ rip. vegetation > 75% in tree, shrub and herb layers, diverse assemblages, no invasives, maximum channel canopy ☐ river corridor development and infrastructure absent			☐ 150 ≥ buffer width > 100 ft ☐ 75 ≥ rip. veg. > 50% in each layer, one plant type absent, minimal invasives, maximum channel canopy ☐ river corridor development and infrastructure minimal			☐ 100 ≥ buffer width > 50 ft ☐ 75 ≥ rip. veg. > 50% in each layer, several types absent, altered patches, invasives present, reduced canopy ☐ river corridor development and infrastructure common			☐ buffer width ≤ 50 ft ☐ rip. veg. ≤ 50% in each layer, several types absent, large altered areas, invasives present, reduced canopy ☐ river corridor development and infrastructure abundant	
SCORE _____ (LB)	Left Bank	10	9	8	7	6	5	4	3	2	1
SCORE _____ (RB)	Right Bank	10	9	8	7	6	5	4	3	2	1

Buffer width (ft) is determined in *Step 3.2* on the Field Notes Form. Larger widths are better for habitat. The reference condition for most stream types is a buffer width larger than 150 feet, with the exception of step-pool channels where a 200-foot buffer is the reference condition due typical forest cover in headwaters and the desire to protect streams in steeper terrain that are often more sensitive to disturbance.

Buffer vegetation (type and % coverage) is evaluated in *Step 3.2* on the Field Notes Form, and is evaluated in the RHA for all stream types. In addition, observations are needed to qualitatively investigate the amount of vegetative cover and the abundance of invasive species. Reference conditions include more than 75% coverage (90% for step-pool stream types) by diverse assemblages in each vegetation layer and no invasive species.

Invasive species are aggressive and can typically out-compete native species so a situation may arise where an assessment location meets the coverage criteria for reference condition, yet a large part of the vegetation in one of the layers is a monoculture of an invasive species. In this case, the assessor should prioritize the role of the vegetation towards aquatic habitat, and give more weight to the amount of coverage than the species assemblage. If, however, the stand of invasives is not serving the functions that a natural diverse vegetated buffer would for bank stabilization and habitat then a lower condition category would be checked.

Channel canopy is evaluated in *Step 3.1* on the Field Notes Form, and is evaluated in the RHA for all stream types. A closed channel canopy is the reference condition; however, this may not be true for larger channels where trees can not lean from a bank to the center of the channel. For larger channels, consider the expected bankfull channel width, the size of trees that should be and currently are present, and the bank canopy previously scored in the river bank parameter. Use channel canopy as a secondary variable to confirm condition or break ties between two condition categories.

River corridor development is evaluated in *Step 3.3* on the Field Notes Form, and is evaluated in the RHA for all stream types. The reference condition is the absence of river corridor development and infrastructure, with the threat of impaired habitat as development increases.

APPENDIX H: Pilot Study Sites

Browns River, Jericho/Underhill

Segment	Location	Length (ft)	Stream Type (ref)	Notes
M16-A	Downstream of Mill Side Park, under roadway	1,115	Plane bed? (riffle-pool)	wbkf=54 ft, almost fully armored.
M16-B	Mill Side Park to M16-C	12,261	Braided (riffle-pool)	Riprap present, RHA=64%, degradation, widening, aggradation & planform, CEMIII, poor geomorphic condition, wbkf=117 ft
M16-C	M16-B to Underhill Center	5,202	Step-pool (riffle-pool)	RHA=90%, CEMII, reference geomorphic condition, wbkf=53 ft

Selected to study adjacent transport and deposition dominated segments
Existing biomonitoring data and in 2007 BASS Lab study basin

Batten Kill, Dorset

Segment	Location	Length (ft)	Stream Type (ref)	Notes
M12-A	Downstream of Route 7 to Little Mad Tom Brook	2,476	Riffle-pool (riffle-pool)	wbkf=31 ft, Marshy area - largely unaltered meandering channel, RHA=84%, CEMI, reference geomorphic condition
M12-B	From Mad Tom Brook to second Rt 7 crossing	4,290	Plane-bed (riffle-pool)	wbkf=31 ft, widened and incised after straightening. Some aggradation occurring in straightened segment, may be obscuring historic incision. RHA=57%, CEMIV

Suggested by Ken Cox, fishery population sampling end of August and early September, good historic data set, ~reference conditions for macroinvertebrates
Selected to study CEM I versus IV, and large geomorphic differences

Poultney River, Poultney (adjacent to GMC)

Segment	Location	Length (ft)	Stream Type (ref)	Notes
M-09A	GMC land past wastewater treatment facility in village of Poultney	7,704	Riffle-pool (riffle-pool)	wbkf=43 ft, riprap present, sedimented riffles, glacial lake clay at base of banks and possible post European sediment deposition and artificial fill in upper bank, very active depositional area. Minor bedrock constraints throughout including at bridge at downstream end so no channel adjustments observed at bridge, Planform changes and widening resulting from aggradation on flat valley floor.RHA=60%, CEMIII
M-09B	Downstream of bridge	3,058	Riffle-pool (riffle-pool)	wbkf=42 ft, riprap present, Bermed and straightened-armored and widened channel but too much armoring to work on banks and complete widening and planform changes. Railroad grade on left bank armored with large slate slabs. Also berming on right bank. Straightened channel that has been unable to fully adjust with aggradation and planform changes as in Segment A because of bank armoring. RHA=48%, CEMIII

Selected to study varying degrees of lateral confinement
Existing biomonitoring data and in 2007 study basin

Wanzer Brook –Fairfield

Segment	Location	Length (ft)	Stream Type (ref)	Notes
T3.05-A	?	2,410	Riffle-pool (?)	wbkf=22 ft, Beaver dam has been breached and water dropped 2 to 3 ft in height by bank evidence. Segment may have been straightened historically when area was broadly deforested. Trib. rejuvenation is localized to beaver dam breach, and does not suggest systemic channel degradation. RHA=71%, CEMI, Min adjust occurring. Aggrad from u/s sediment sources is notable. Stability w/in segm prob afforded by extens woody buffers, lack of encroachments or undersized crossings, and pres of wetland areas which may be offering sediment/flow attenuation.
T3.05-B	Callan, Riley, Gaudette properties	3,160	Riffle-pool (?)	wbkf=11 ft, Likely straightened u/s of Pumpkin Village Road. Heavily impacted by cows in stream d/s of Pump Vill Rd. Phase 1 reach elevations incorrect. Corrected elevation gives steeper slope (1.1%) but no change in ref stream type. RHA=47%, CEMII, Aggrad, wid, & PF (Meander Migr) in resp to past straightening, direct pasturing , and lack of woody riparian buffers. Incis is minor to mod, despite stressors. Cohesive soils & Culvert crossings may be offering eros resistence & grade control.

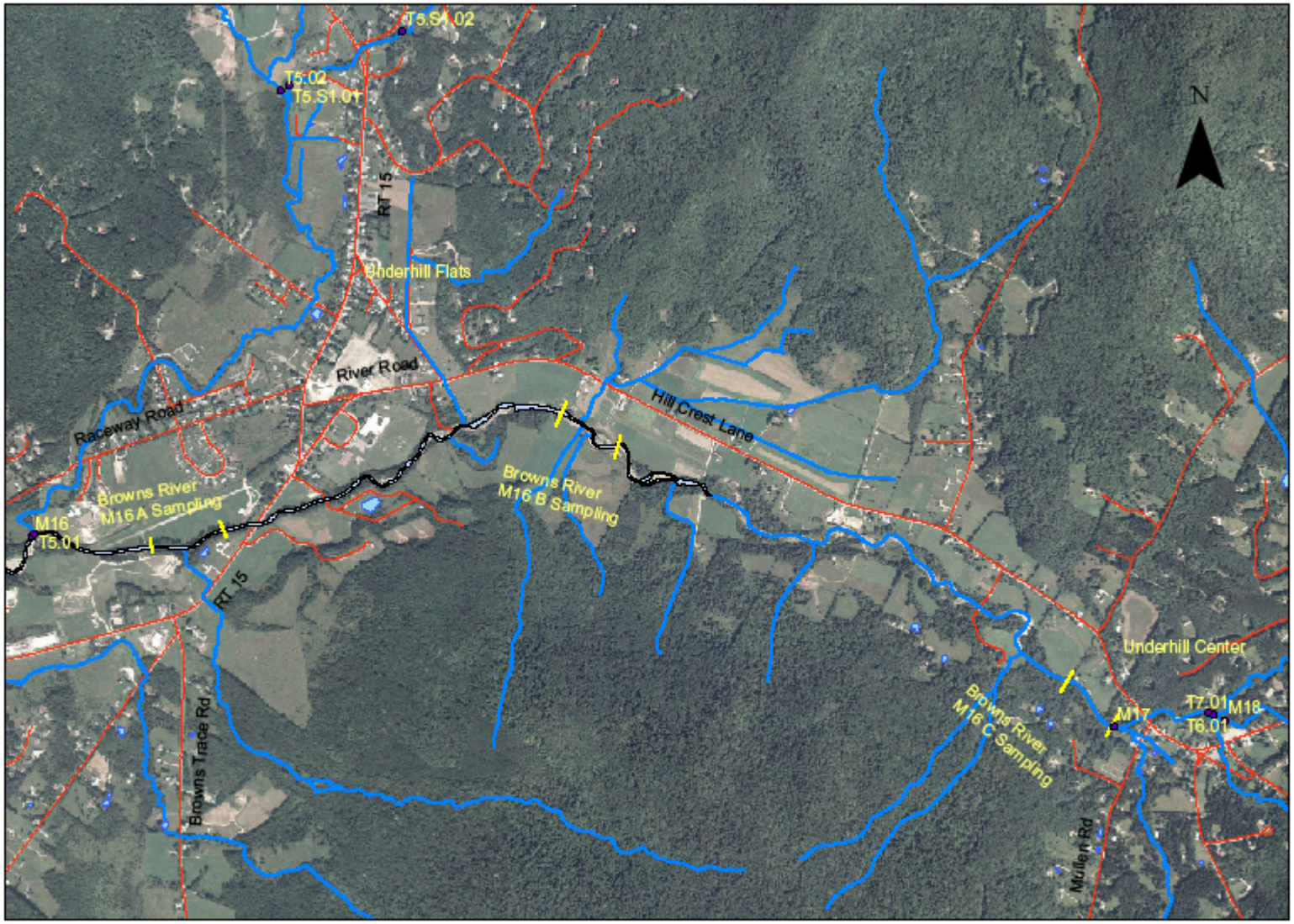
Selected to study influence of buffers and wetland presence
Existing biomonitoring data and DEC sampling this year
BASS Lab uses nearby Chester Brook as reference site
Floodplain restoration in September

Tweed River – Pittsfield

Segment	Location	Length (ft)	Stream Type (ref)	Notes
T6.04-A	Townsend Brook confluence up to the downstream end of Stonewood Crossing road bridge.	4,500	Riffle-pool (riffle-pool)	wbkf=50 ft, dredging, RHA=56%, CEMIII, Widening, aggradation, and planform adjustment from historic incision
T6.04-B	From downstream end of Stonewood Crossing road bridge up to the Johnson Brook confluence.	1,600	Plane Bed (riffle-pool)	wbkf=56 ft, dredging, RHA=52%, CEMII, Degradation from straightening

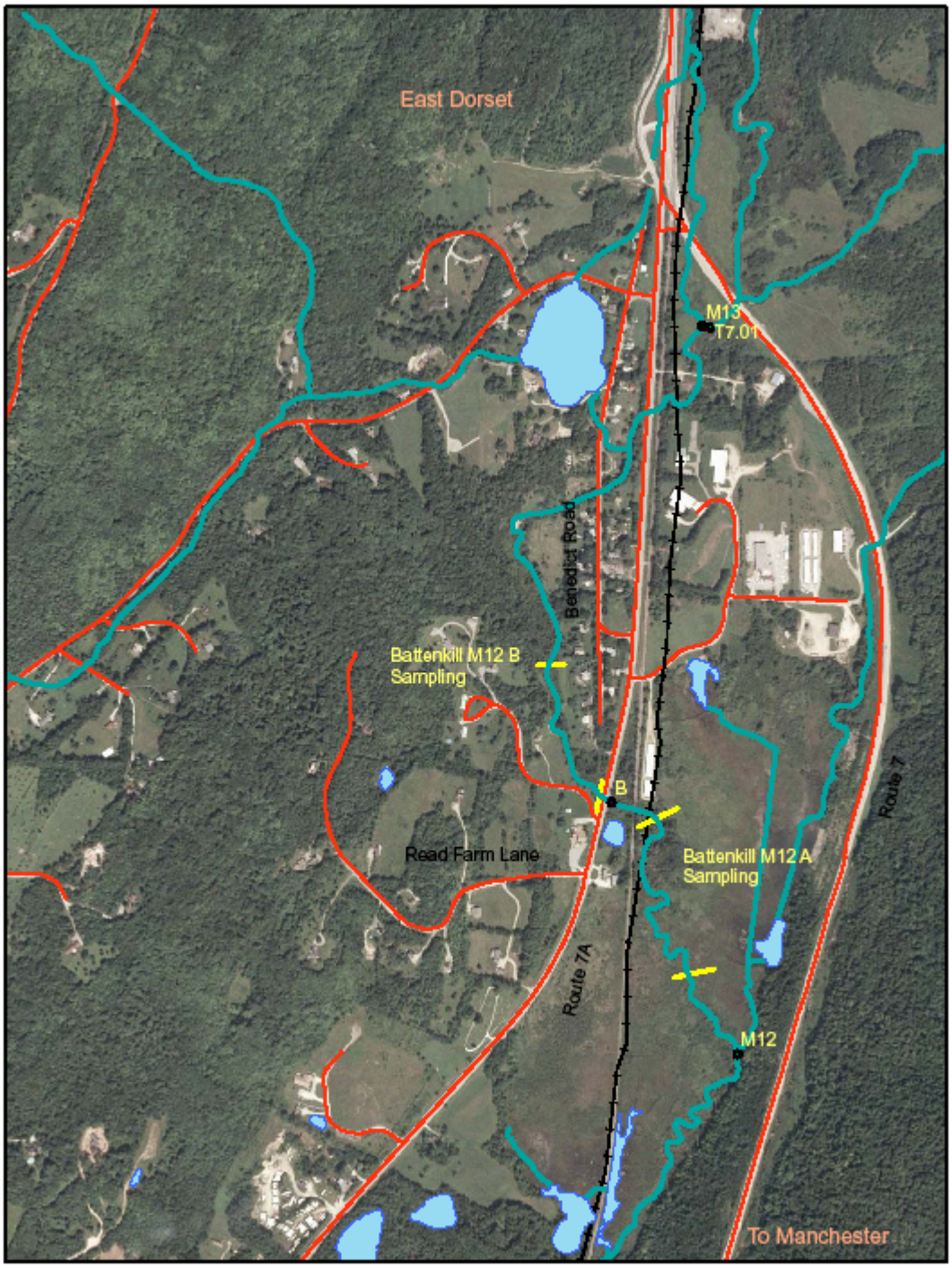
Selected to study differences between aggradational and degradational segments
Long-term fisheries data on Tweed, and lower abundance than expected

2007



0 375 750 1,500 Feet

Browns River M 16 A, B, & C

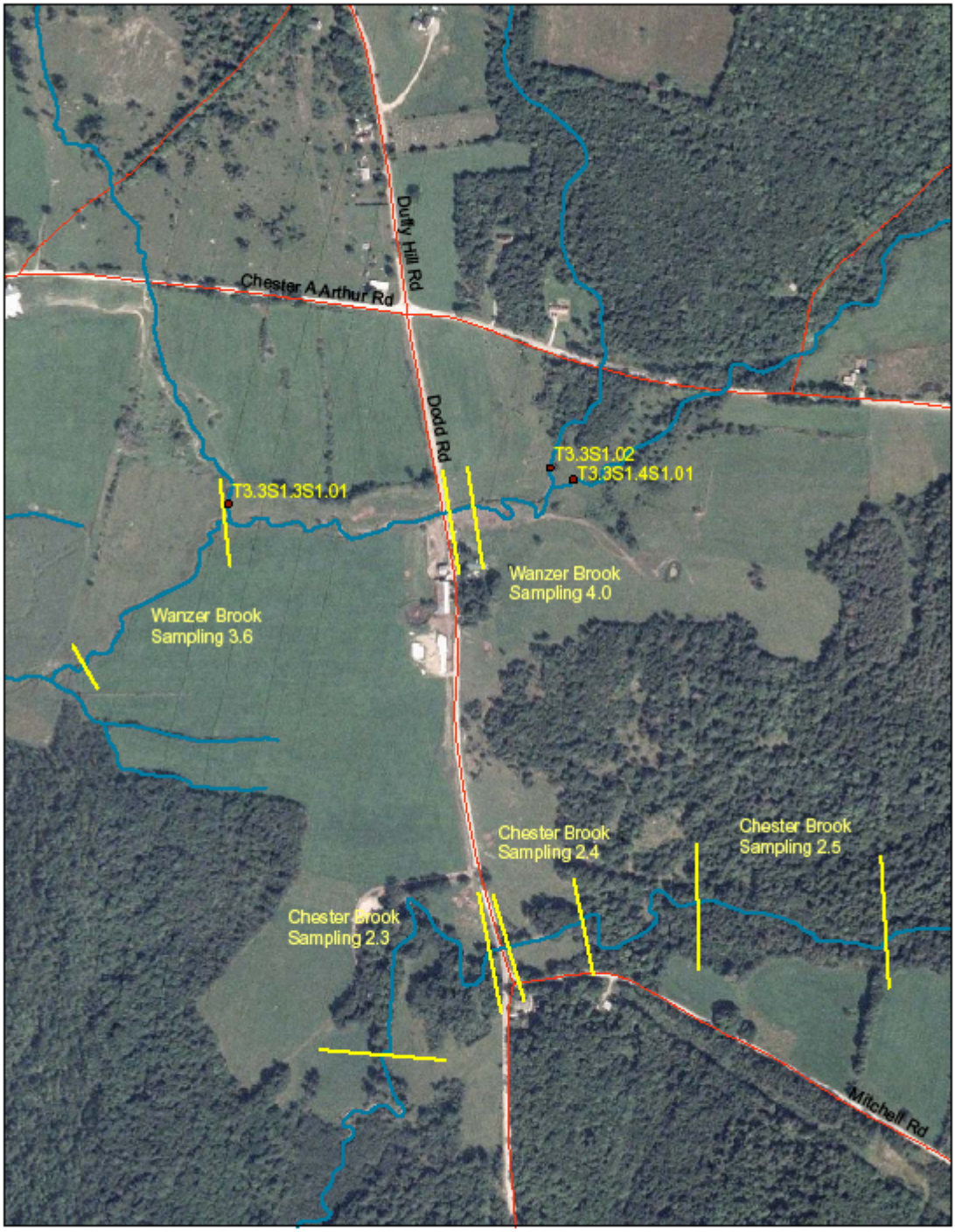


0 175 350 700 Feet

Battenkill M12 A & B

N

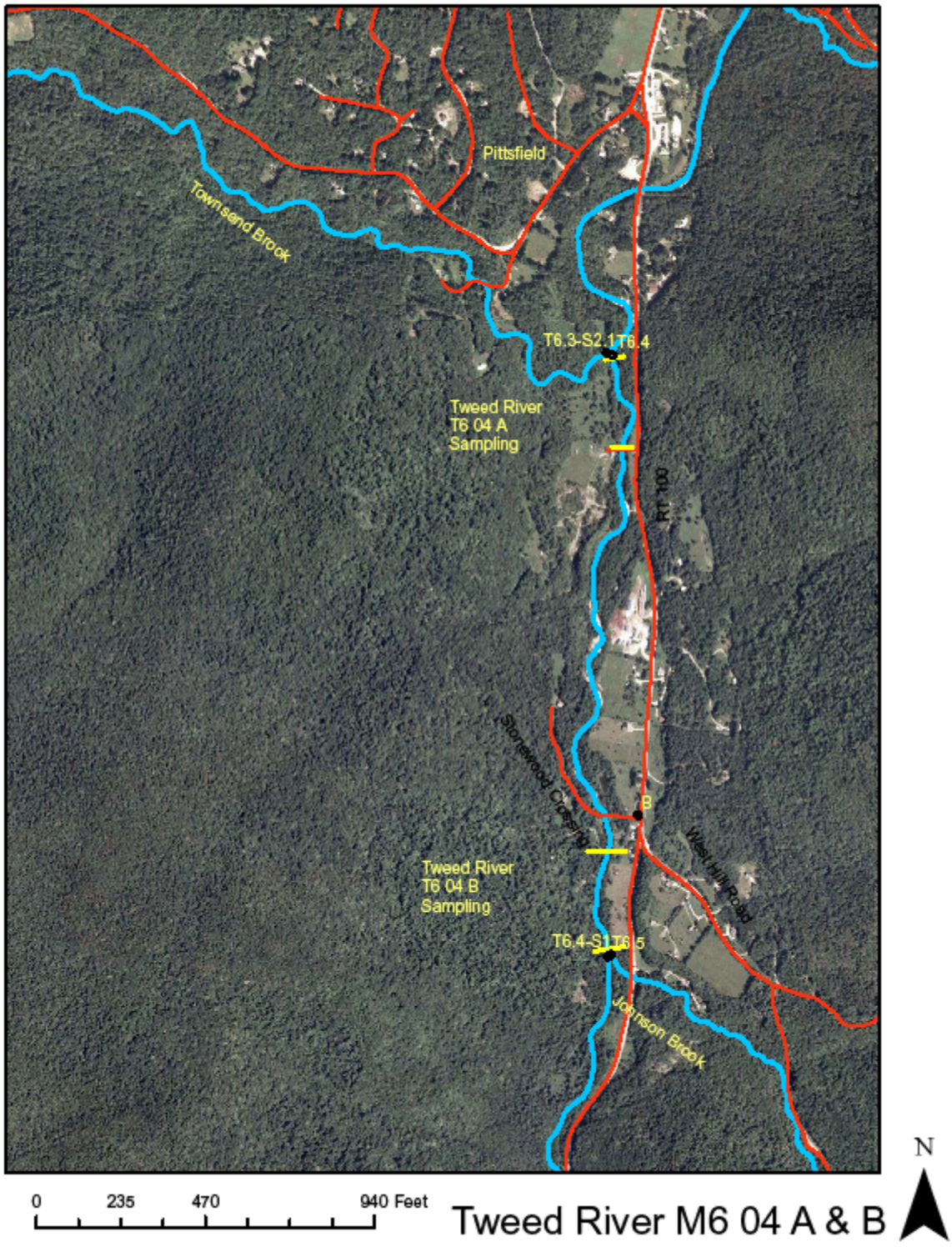
Poultney River M9 A & B



0 335 670 1,340 Feet

Wanzer and Chester Brooks

N



Tweed River M6 04 A & B

APPENDIX I: Summary of Initial Testing

RHA Ease of Use

Ten sites were selected to test the RHA on multiple stream types with different conditions. All sites selected had existing Phase 2 Stream Assessments (VTANR, 2007), and this information guided the choice of reaches and segments. In addition to the assessments completed by Milone & MacBroom, Fitzgerald Environmental Associates was sub-contracted to provide an independent check on the learning curve and usability of the new RHA. A day of field training was provided and then the sub-consultant assessed six streams of varied geomorphic conditions using the new RHA. Feedback was gathered from our initial testing, the sub-consultant trials, and all other members of the project team who joined us at various stages of the overall RHA study. Findings on ease of use and assessment time are summarized here.

The RHA has been integrated with the existing Phase 2 assessment protocols. RHA data are collected during the assessment segment/reach walk and at a representative cross section as is currently performed for the RGA. Experienced assessors will notice a good deal of overlap between the current observations made for the RGA and those required for the new RHA – a testament to the strong relationship between channel and habitat condition.

During the segment/reach walk habitat features are sketched on blank paper along with the channel features, and a tally of large woody debris (LWD) and jams, pools, undercut banks, and refuge areas are recorded on a new Sketch Tally Sheet. Fourteen habitat features are assessed during the segment/reach sketch in addition to the information currently sketched for the RGA.

#	Variable	Status
1	Location of LWD pieces	New
2	Location of debris jams	Already sketched
3	Area covered by CPOM	New
4	Area covered by riffles	Already sketched, expand to be able to estimate surface area
5	Area covered by pools	Already sketched, expand to be able to estimate surface area
6	Area of exposed substrate (bars)	Already sketched, expand to be able to estimate surface area
7	Obstructions	Already sketched as grade controls
8	Refuge areas	New
9	Refuge connections	New
10	Mass failures	New
11	Undercut banks	New
12	Overhanging vegetation	New
13	Water adjacency	New
14	Location of fine sediment accumulation	New

Feature size tallies are based on half-foot measurement intervals to facilitate rapid measurement. A simple wading rod marked with half-foot increments is used to measure pool depth, LWD width, undercut length and adjacent water depth, and verify that an undercut is more than 0.5 feet into the bank. Once all of the data are collected, simple calculations are used to obtain the total number of features and their densities over the assessment reach. We have found that a two-person field crew can divide tasks to rapidly complete the RHA after the segment/reach walk, with one person performing calculations with a field calculator while the other person starts the assessment at the designated representative cross section. Although a two-person field crew is ideal for both efficiency and safety, the RHA is readily completed by one assessor.

The segment/reach walk and sketch now allows for a fully integrated channel-habitat assessment in an efficient way. For example, assessors recording grade control are now simultaneously investigating longitudinal connectivity. The amount of exposed substrate is related to useable wetted habitat in the stream. Channel measurements influence expected habitat features. An effort was made to integrate the channel and habitat measures into a seamless system as exists in nature. This may take experienced assessors time to adjust to, yet in the end this approach is both more accurate and efficient.

Bankfull channel width is used for reference in the RHA. As assessors determine bankfull width, they will then relate LWD length and pool length or width to this measure as a general size indicator. Larger size rankings are associated with features that are greater than half of bankfull width.

If an assessor is already experienced with the SGA protocols, it is estimated that within one or two days new procedures associated with the updated RHA will become familiar due to similarities with the RGA protocols. Practice with identifying habitat features such as hydraulic patterns, suitable refuge areas, and undercut bank characteristics will evolve over time as assessors gain experience with the integrated physical and habitat field observations.

The RHA has primarily been developed as a component of the phase 2 assessment, yet throughout the protocol development future users of the RHA requested that the procedure also be available in a stand-alone format. An RHA data collection field form is available to facilitate extra-phase 2 assessments.

Assessment Time

Assessments during this project were completed on streams where Phase 2 assessments had been previously completed, yet as a stand-alone RHA. A two-person field crew was used with one person sketching and another measuring features and recording the tally. For all sites and as a stand-alone assessment procedure the RHA took between 1 and 11 hours per mile, with a mean assessment time of approximately 6 hours per mile. This estimate is artificially high due to our field discussions about refinements to the assessment protocols, and some questionable observation lengths used in the rate calculation. A more accurate measure of the true assessment rate is taken from the pilot study sites alone, where protocol refinement was not made and we had existing experience with the assessment methods. The RHA took an average of approximately 4 hours per mile. This estimate makes sense as 2 to 3 miles were often assessed in a field day. This rate is also similar to that often cited in the Phase 2 Assessment, of which the RHA is a similar assessment.

It is estimated that when completing the Phase 2 Stream Geomorphic Assessment that an extra 1 to 2 hours should be allotted per segment/reach while becoming familiar with the new RHA. After getting familiar with the RHA procedures the time addition to the Phase 2 Assessment would be negligible. After their initial testing, Fitzgerald Environmental Associates indicated that new RHA should not add significantly to the effort or cost per assessment reach for consultants and that after some initial time allocation for learning the new protocols a little more detail on the sketch, tallying features, and some number crunching on the RHA form should not add much time to the overall Phase 2 Assessment.

APPENDIX J: Comparing Old and New Versions of the Vermont RHA

Introduction

Of the thirty-five sites assessed with the new RHA during this study, twenty-five have old Vermont RHA data associated with previous stream geomorphic assessments (VTANR, 2007). A comparison between the new and old VT RHA data was performed to explore changes in the overall, parameter, and variable scoring.

Overall Score

In summary, the general overall RHA score was consistent between the new and old protocol. Trends are explored based on a percentage of total score to avoid confusion since the new score total maximum is 160 while the old score is out of a possible 200. Most data points fall around the line with a slope of one along which the new and old RHA score are the same. Moving away from this line is coincident with changes in the overall condition category assigned with the RHA score. For example, points on the line with the same old and new RHA score have condition categories of fair (F), while those that are above the line indicative of a higher new RHA score show better condition categories of good (G). The analysis of the overall RHA score suggests that the scoring system for the new RHA adequately represents stream conditions.

It is worth mentioning that throughout the development of this protocol the extended project team expressed concerns with the limited utility in summary scoring that frequently is too vague for detailed site comparisons. This feature is left in the RHA for consistency with the rapid geomorphic assessment score (RGA), comparability to previous rapid habitat assessment protocols (e.g., USDA, 1998; Barbour et al., 1999; VTANR, 2007), and to facilitate coarse site comparisons. The strength of the new RHA truly lies in the more detailed analysis of parameters and specific variables. This combination of general and detailed data will support a wide range of management objectives related to instream habitat protection and restoration.

Some overall condition categories changed between the new and old RHA. Five sites improved from fair to good and one site changed from poor (P) to good. Three sites classified as good under the old RHA declined to fair status for the new RHA. In addition, two of the three reference (R) sites changed to good while one changed to fair. The mean overall RHA score increases continuously from poor to reference as expected, with each category being statistically distinct. The scores for the fair and good categories between the old and new RHA are statistically similar.

The comparison of the overall condition category illustrates concerns with basing site comparisons on single aggregate scoring that can mask what is taking place at each site. All of the sites were determined to be fair or good using the new RHA, while one site was called poor and three sites were called reference under the old RHA. The variables were explored for sites where the condition category changed between new and old RHA, and the logic behind the change always made sense. For example, Johnnie Brook was previously scored as a reference (87.5%) with the old RHA and is now fair (63%) with the new RHA. The change is due to poor connectivity and bed substrate cover variables, several of which were not previously assessed. Although the changes between old and new RHA condition category are logical, the chance that the overall RHA condition category ranges may need adjustment exists. This task is reserved for the future once the more data are collected.

Parameter Scores

Comparison of RHA parameter scores is not straight forward because the old RHA parameters typically identify only one or two variables, while the new RHA parameters represent consideration of between three and eight different variables assessed during the new protocols. Nonetheless, the relationships between the parameters were explored to investigate patterns in the data.

Comparisons of the old epifaunal substrate cover parameter to the new woody debris cover, bed substrate cover, and scour and depositional features parameters shows a loose relationship with old and new parameters appearing to increase together. However, the data are mostly

characterized by variability that is likely a function of parameters representing different variables, true differences between the time of assessments due to both change in conditions and natural variation, and differences between the assessors.

The old frequency of riffles or pools parameter tracks the new scour and depositional features parameter. The new scour and depositional feature parameter appears to regularly score lower values than the old parameter (i.e., data points often fall below the line where the two would be equal). This offset is most likely associated with the new parameter representing pool density, size distribution, and quality of cover; riffle coverage and spacing; the level of hydraulic diversity; and the characterization of fine sediment deposition versus the old parameter solely measuring riffle or pool frequency. Data suggest that frequency of riffles or pools leads to a score that is too high and thus alone does not adequately represent the conditions of hydraulic features at the study sites.

The comparison between the old channel flow status parameter and the new hydrologic characteristics parameter shows generally increasing together. The variability observed in this relationship is most likely associated with changes in flow between observation times and interpretation by assessors.

The old embeddedness parameter increases with the new bed substrate cover parameter, yet the new parameter score appears to be generally lower for each site. This pattern is again likely the result of more variables being assessed to score the new parameter. Embeddedness in the channel and margin, fining, riffle stability, sediment stability, and periphyton cover are now assessed to determine bed substrate cover. Data indicate that embeddedness alone does not describe the bed condition and that the new parameter is likely a better descriptor of conditions on the bed. Also, avoiding sole reliance on embeddedness to describe the bed condition is preferable for the new RHA given the subtle variations on the embeddedness measurement and the typical resultant variability (Sylte and Fischenich, 2002; Sennatt et al., 2006 and subsequent discussions).

The old channel condition parameter is generally flat or slightly increasing with the new channel morphology parameter. Channel morphology includes the width/depth, entrenchment, and incision rations, as well as the channel alteration information. It appears that the new parameter score is larger for sites where the old parameter score was less than or equal to 12, while the new parameter score is lower for larger old for old parameter scores. Again, it's the additional information in the new parameter that is likely the reason for the difference in scores. e geomorphic information refines the parameter score suggesting that the channel has varied response to alteration over time and in space.

Comparisons between the old and new bank and riparian parameters reveal a lot of scatter in the data. The likely main reason for the scatter is the difference in data included in the parameters. The new bank parameter combines measured of stability, vegetation, and habitat. The new riparian area parameter describes buffer width, vegetation, and the level of corridor development while the old riparian zone with parameter is solely a measure of width of natural vegetation.

Variable Scores

New RHA variables were compared to related parameters in the old RHA. Bivariate correlation analysis was performed to explore the relationships between old RHA parameters and the new RHA parameters and variables. For this analysis, condition categories were quantified as "reference" = 3, "good" = 2, "fair" = 1, and "poor" = 0. Parameters and variables scored separately for each side of the channel, such as for river banks and riparian areas, were averaged together for the analysis. The results show many significant relationships between the old and new RHA. For example, the new COPM abundance and riffle stability index variables are correlated with the old epifaunal substrate cover parameter. Strong correlations exist between the old embeddedness observation and most of the variables assessed under the new bed substrate cover parameter. Good agreement generally exists when the same variable is being measured, such as between the old riparian vegetation zone width and the variables under the new riparian areas parameter. The variables describing vegetation on the river banks and bank canopy are correlated with the old bank vegetative cover parameter.

The riffle stability index (Kappesser, 2002) variable now in the new RHA is correlated to the old epifaunal substrate cover, embeddedness, sediment deposition, channel flow, and channel alterations parameters. The new variable qualitatively describing the presence of fine sediment deposition was correlated with the old embeddedness parameter.

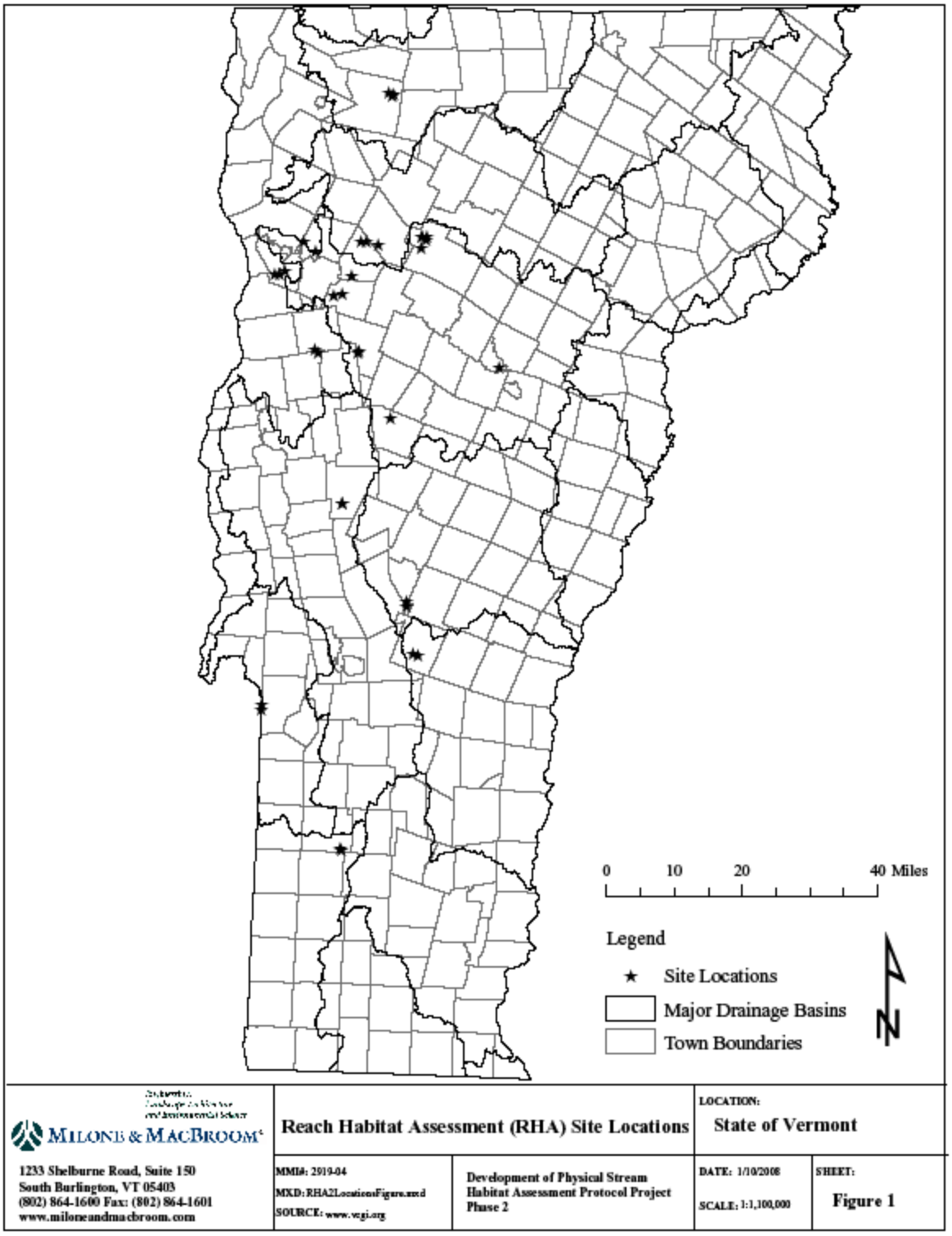
The new channel alteration variable and the old channel alteration parameter were correlated, with the condition category groups accounting for 61% of the variation in the data. This result suggests that there is consistency in qualitatively assessing human changes to the channel over a reach. The new bed feature pattern and diversity of width-velocity combinations variable was also correlated with the channel alteration parameters.

All of the new variables describing the riparian zone are correlated with the old riparian buffer width parameter. The relationships make sense as the new variables describe a similar set of information previously used to score the old parameter

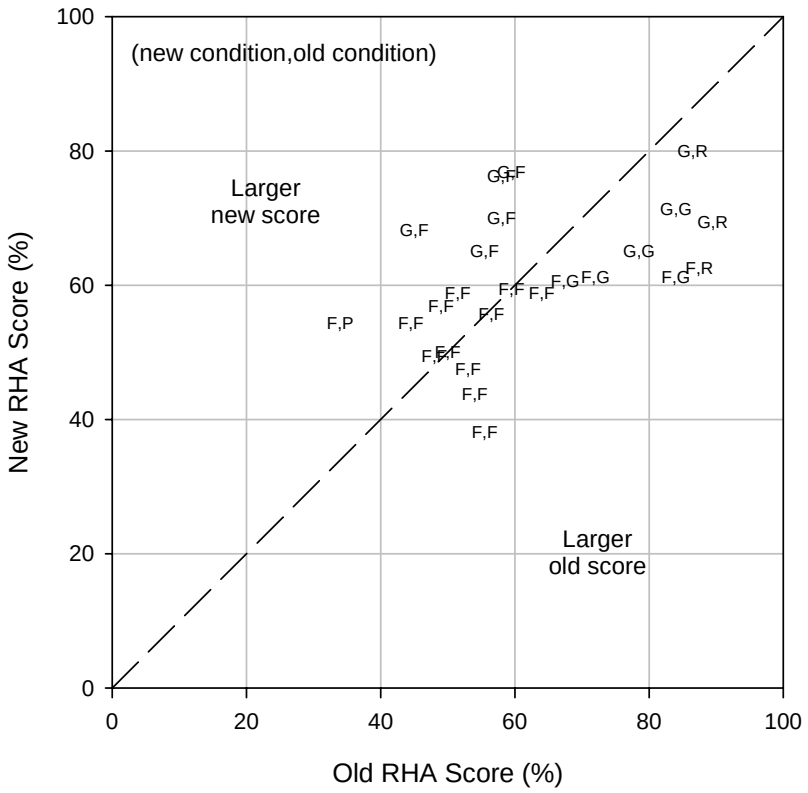
The agreement between the old and new RHA is limited mostly when new data are being assessed. For example, the new RHA considers undercuts in the river banks parameter and the new undercut variables do not relate to the old bank stability or vegetation parameters since they were previously not assessed thoroughly.

Study Sites

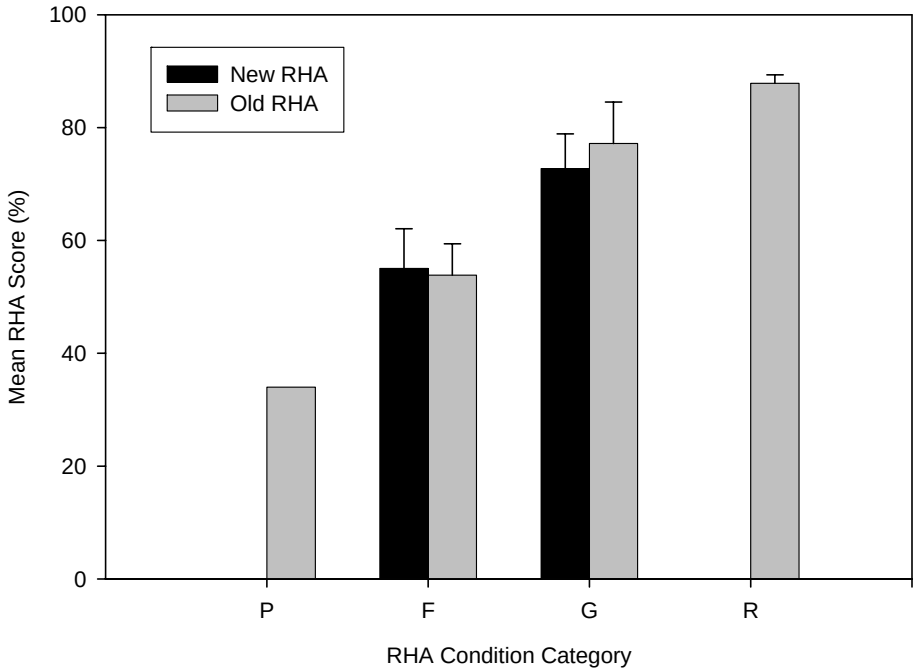
#	Project Phase	Date	Stream Name	Channel Type	Segment I.D.	Length (ft)	Town
1	Initial Testing	7/14/2007	Potash Brook	Riffle-Pool	M6	2,025	South Burlington
2	Initial Testing	7/16/2007	Clay Brook	Step-Pool	T9.3 S1.01 A	2,231	Warren
3	Initial Testing	7/23/2007	Huntington River	Riffle-Pool	M14 A	1,000	Huntington
4	Initial Testing	7/23/2007	Huntington River	Riffle-Pool	M14 B	924	Huntington
5	Initial Testing	8/3/2007	Winooski River	Riffle-Pool	R18 B	3,156	Montpelier
6	Initial Testing	8/15/2007	South Branch Middlebury River	Plane-Bed	T4.04	3,141	Ripton
7	Initial Testing	8/15/2007	South Branch Middlebury River	Plane-Bed	T4.04	3,141	Ripton
8	Initial Testing	8/20/2007	Johnnie Brook	Step-Pool	M.02	1,447	Richmond
9	Pilot Study	8/31/2007	Tweed River	Riffle-Pool	T6.04 A	4,500	Pittsfield
10	Pilot Study	8/31/2007	Tweed River	Riffle-Pool	T6.04 B	1,600	Pittsfield
11	Pilot Study	9/14/2007	Browns River	Riffle-Pool	M16-A	5,110	Underhill/Jericho
12	Pilot Study	9/14/2007	Browns River	Riffle-Pool	M16 B	12,261	Underhill
13	Pilot Study	9/14/2007	Browns River	Riffle-Pool	M16 C	1,115	Underhill
14	Pilot Study	9/20/2007	Batten Kill	Riffle-Pool?	M12 A	2,476	East Dorset
15	Pilot Study	9/20/2007	Batten Kill	Riffle-Pool	M12 B	4,290	East Dorset
16	Pilot Study	9/26/2007	Poultney River	Riffle-Pool	M9 A	7,704	Poultney
17	Pilot Study	9/26/2007	Poultney River	Riffle-Pool	M9 B	3,058	Poultney
18	Pilot Study	9/27/2007	Chester Brook	Riffle-Pool	2.3 & 2.4 BASS	2,497	Fairfield
19	Pilot Study	9/27/2007	Wanzer Brook Tributary	Riffle-Pool	T3.3S 1.01	2,566	Fairfield
20	Pilot Study	9/27/2007	Chester Brook	Plane-Bed	2.5 BASS	790	Fairfield
21	BASS	10/16/2007	West Branch - upstream	Step-Pool	BASS	2,340	Stowe
22	BASS	10/16/2007	Ranch Brook	Step-Pool	BASS	1,200	Stowe
23	BASS	10/30/2007	West Branch Little River	Plane-Bed	BASS	594	Stowe
24	BASS	10/30/2007	Big Spruce Brook	Step-Pool	BASS	1,100	Stowe
25	BASS	10/30/2007	Pinnacle Brook	Step-Pool	BASS	1,600	Stowe
26	FEA testing	11/2/2007	Potash Brook	Riffle-Pool	M02-B	2,100	South Burlington
27	FEA testing	11/2/2007	Potash Brook	Riffle-Pool	M08-B	2,000	South Burlington
28	BASS	11/2/2007	West Tributary Roaring Brook	Step-Pool	BASS reference	1,000	Killington
29	BASS	11/2/2007	East Tributary Roaring Brook	Step-Pool	BASS	2,500	Killington
30	Initial Testing	11/7/2007	Lewis Creek	Riffle-Pool	M15 A	5,528	Hinesburg / Monkton
31	Initial Testing	11/7/2007	Lewis Creek	Riffle-Pool	M15 B	4,623	Monkton / Starksboro
32	FEA testing	11/13/2007	Johnnie Brook	Riffle-Pool	M06	1,589	Richmond
33	FEA testing	11/13/2007	Mill Brook	Plane-Bed	M03	2,773	Richmond
34	FEA testing	11/13/2007	Indian Brook	Step-Pool	M09-B	1,995	Essex Junction
35	FEA testing	11/13/200	Indian Brook	Step-Pool	M12	1,680	Essex


0 10 20 40 Miles
Legend
Site Locations
Major Drainage Basins
Town Boundaries
N
MILONE & MACBROOM
1233 Shelburne Road, Suite 150
South Burlington, VT 05403
(802) 864-1600 Fax: (802) 864-1601
www.miloneandmacbroom.com
Reach Habitat Assessment (RHA) Site Locations
LOCATION:
State of Vermont
MMI#: 2919-04
MXD: RHA2LocationsFigure.mxd
SOURCE: www.vcgi.org
Development of Physical Stream Habitat Assessment Protocol Project Phase 2
DATE: 1/10/2008
SCALE: 1:1,100,000
SHEET:
Figure 1

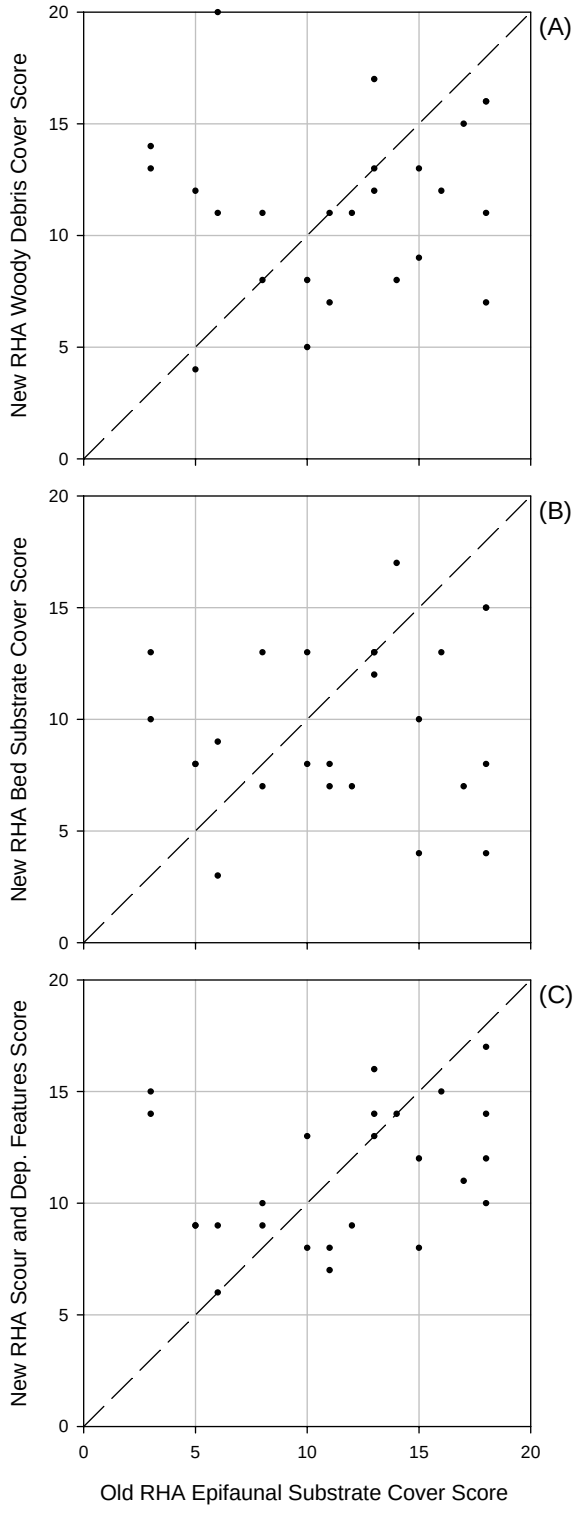
Study Sites



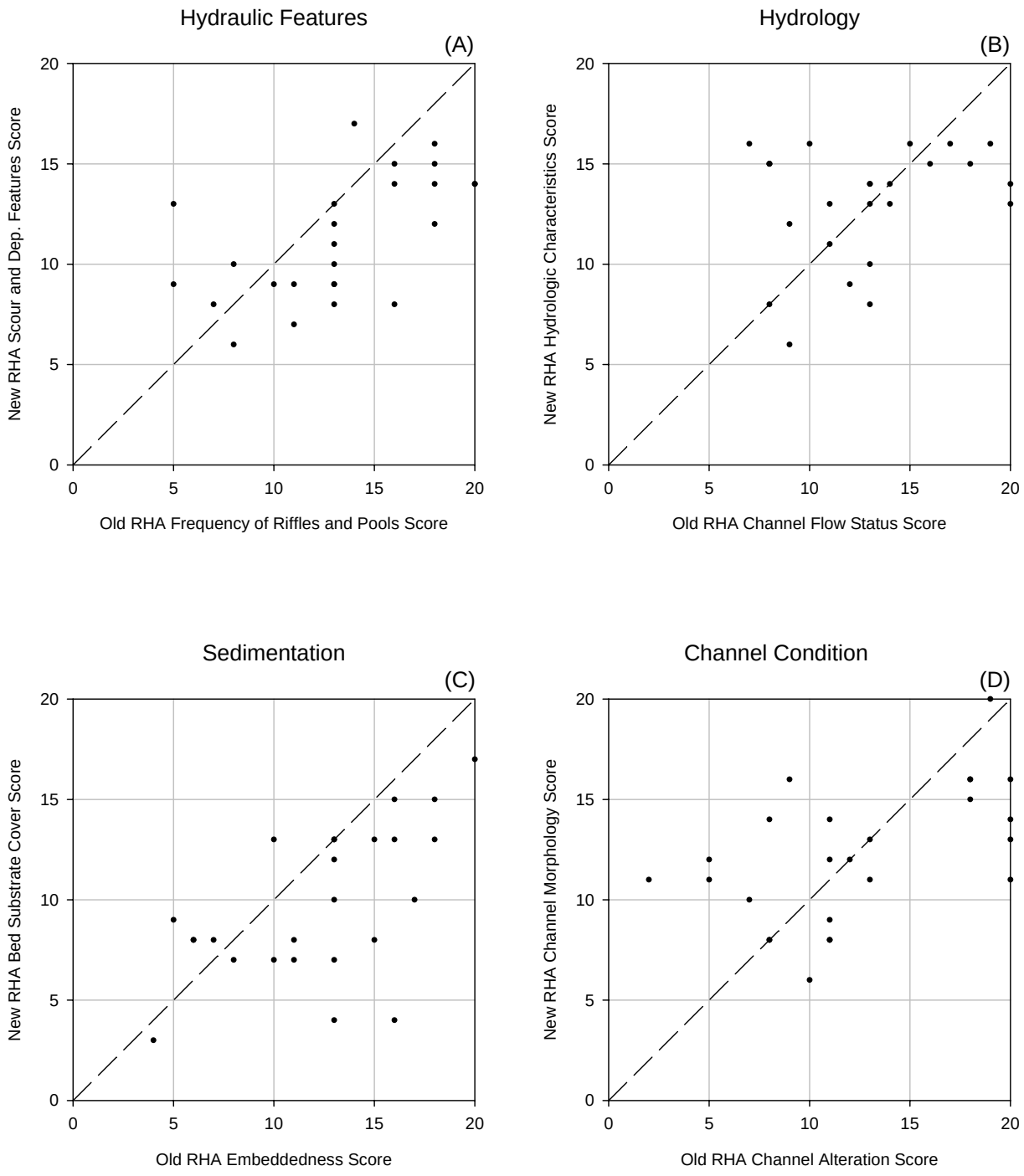
Comparison of Old and New Overall RHA Scores



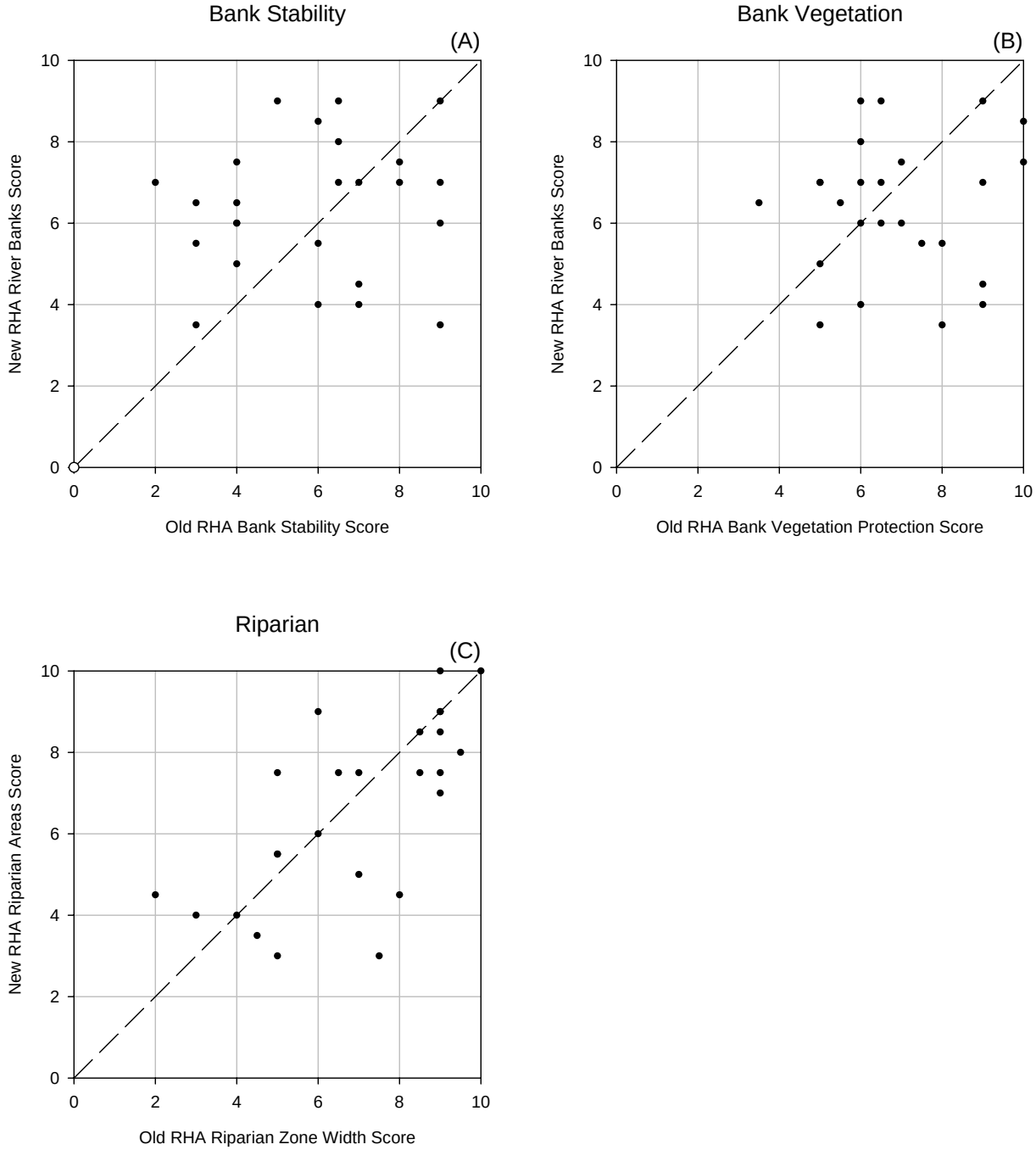
Comparison of Old and New Overall Condition Categories



Comparison between the old RHA epifaunal substrate cover parameter and the new RHA parameters of woody debris cover (A), bed substrate cover (B), and scour and depositional features (C).



Comparison between the old and new RHA parameters describing hydraulic features (A), hydrology (B), sedimentation (C), and channel condition (D).



Comparison between the old and new RHA parameters describing bank stability (A), bank vegetation (B), and the riparian zone.

Correlations Between New and Old RHA

NEW RHA	OLD RHA: Epifaunal Substrate - Available Cover	Embeddedness	Velocity / Depth Patterns	Sediment Deposition	Channel Flow Status	Channel Alteration	Frequency of Riffles / Steps	Bank Stability - Mean	Bank Vegetation Protection - Mean	Riparian Vegetation Zone Width - Mean	Score	Percentage	N
Woody Debris Cover	0.10	-0.05	0.19	-0.11	-0.22	0.16	0.01	0.00	-0.15	**0.46**	0.08	0.06	25
LWD Pieces / Mile	-0.15	-0.23	-0.03	**-0.37**	**-0.38**	0.01	-0.12	-0.04	-0.27	0.25	-0.15	-0.18	25
LWD Size Rank	-0.35	-0.23	-0.05	-0.36	-0.22	-0.05	-0.10	-0.15	**-0.40**	0.14	-0.16	-0.25	21
Debris Jams / Mile	-0.19	-0.18	0.16	-0.21	-0.20	**0.37**	-0.05	-0.08	-0.07	**0.46**	0.05	0.01	25
Woody Debris Recruitment Potential	0.33	0.19	0.12	0.32	0.08	0.17	0.10	0.09	**0.34**	**0.39**	0.25	0.31	25
CPOM Abundance	**0.56**	**0.35**	0.30	**0.41**	**0.41**	0.05	0.09	0.24	0.15	0.31	**0.41**	**0.41**	25
Bed Substrate Cover	0.14	**0.58**	0.15	0.32	0.27	0.28	**0.45**	0.16	0.26	-0.14	**0.34**	**0.35**	25
Riffle Embeddedness Percentage	0.17	**0.44**	**0.36**	0.28	0.24	0.31	**0.45**	0.04	0.13	-0.10	**0.40**	0.34	24
Fining Percentage	0.05	**0.43**	0.13	0.20	0.14	0.24	**0.44**	0.08	0.12	-0.15	0.32	0.24	25
Riffle Stability Index	**0.38**	**0.68**	0.25	**0.58**	**0.60**	**0.42**	0.26	0.34	**0.45**	-0.17	**0.53**	**0.59**	20
Sediment Stability Observed	0.00	**0.53**	0.08	0.18	0.25	0.32	**0.35**	**0.42**	**0.38**	0.06	0.31	**0.37**	24
Dense Algae Growth	0.28	0.05	0.33	**0.36**	0.33	0.05	0.00	-0.27	0.11	0.11	0.22	0.19	24
Scour and Deposition Features	0.31	**0.68**	**0.36**	**0.34**	0.25	**0.41**	**0.59**	**0.39**	0.26	0.15	**0.53**	**0.54**	25
Pools / Mile	0.19	**0.37**	0.09	0.07	0.27	0.05	0.26	0.15	-0.08	-0.05	0.25	0.18	22
Pool Size Rank	0.30	0.28	0.28	0.16	0.11	-0.10	0.33	0.34	-0.29	0.01	0.27	0.20	21
Pool Surface Cover	0.32	-0.04	0.13	0.19	0.01	0.17	0.02	0.00	0.29	**0.44**	0.16	0.21	22
Pools Formation	0.50	0.50	0.50	0.50	0.50	0.50	-0.50	-0.50	0.50	0.50	0.50	0.50	3
Riffle Formation	1.00	1.00	1.00	1.00	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00	1.00	3
Depth / Velocity Combinations Present	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	3
Step Formation	0.35	0.57	0.51	0.86	0.78	0.49	0.00	0.80	0.69	0.67	0.55	0.75	4
Step Spacing (wbkf)	**0.90**	**0.98**	**0.99**	0.88	0.81	**0.98**	0.71	0.00	-0.13	**0.96**	**0.93**	**0.97**	4
Depth- Velocity Combinations Present	0.86	0.70	0.85	**0.94**	**0.99**	0.86	0.19	0.38	0.00	**0.94**	**0.95**	**0.91**	4
Riffle Coverage / Formation	0.10	0.36	-0.01	0.20	0.08	0.13	0.36	-0.03	0.20	-0.20	0.11	0.17	18
Meandering Thalweg Identifiable	1.00	1.00	1.00	1.00	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00	1.00	3
Riffle Spacing (wbkf)	0.18	0.16	-0.07	-0.02	-0.09	-0.27	0.19	0.13	0.15	-0.06	-0.02	0.04	18
Riffle- Run-Pool-Glide Pattern	0.28	0.35	0.01	0.08	0.09	-0.20	0.28	**0.45**	0.07	-0.19	0.24	0.21	17
Finer Deposition Observed	0.14	**0.52**	0.18	0.32	0.14	0.30	**0.52**	0.25	**0.49**	0.16	**0.37**	**0.43**	25
Channel Morphology	0.20	0.32	**0.38**	0.28	0.27	**0.53**	0.28	0.30	0.16	**0.54**	**0.48**	**0.47**	25
Width / Depth Ratio	0.06	0.09	-0.16	-0.04	0.24	-0.16	-0.16	0.14	-0.32	-0.02	0.04	-0.04	25
Entrenchment and Incision Ratios	0.15	0.24	0.24	0.25	0.21	**0.41**	0.28	0.14	**0.42**	**0.45**	**0.37**	**0.40**	25
Channel Alteration	0.29	0.33	**0.58**	**0.36**	0.14	**0.61**	**0.39**	**0.40**	**0.37**	**0.68**	**0.57**	**0.60**	25
Hydrologic Characteristics	0.16	0.21	**0.36**	0.19	0.25	0.27	0.27	0.10	0.04	**0.41**	**0.39**	0.32	25
Wetted Width / Wbkf	0.03	-0.14	0.10	0.02	-0.06	0.01	0.10	-0.09	0.13	**0.37**	-0.02	0.06	25
Substrate Exposure Percentage	0.12	0.11	0.18	**0.33**	**0.39**	0.16	-0.06	0.07	0.24	0.11	0.19	0.23	25
Adjacent Springs, Seeps, Wetlands	0.15	0.01	0.26	-0.05	-0.11	**0.34**	0.24	-0.20	0.04	**0.56**	0.15	0.19	25
Flow Alteration	-0.04	0.39	0.19	0.08	0.22	0.11	0.31	**0.40**	-0.20	0.08	**0.40**	0.22	25
Connectivity	-0.18	0.01	0.14	-0.25	-0.16	-0.09	0.27	-0.10	**-0.42**	-0.04	0.04	-0.11	25
Obstructions in Reach	-0.24	0.14	-0.02	-0.21	0.02	-0.17	0.20	-0.04	**-0.49**	-0.26	0.00	-0.15	25
System Obstructions	**-0.43**	-0.12	-0.26	**-0.40**	-0.22	**-0.34**	0.03	-0.18	**-0.42**	-0.31	-0.21	**-0.38**	25
Refuge Observed	**0.41**	0.25	**0.59**	0.30	0.16	0.22	0.26	0.20	-0.05	0.23	**0.46**	**0.37**	25
River Banks - Mean	0.09	0.32	**0.37**	0.11	-0.10	**0.51**	**0.46**	0.11	0.08	**0.38**	**0.41**	**0.34**	25
Bank Erosion Percentage	0.07	**0.39**	**0.34**	0.29	0.13	**0.46**	**0.39**	0.25	**0.43**	0.19	**0.39**	**0.42**	25
Bank Vegetation Percentage / Type	0.33	0.18	0.28	**0.39**	0.12	**0.34**	0.13	0.02	**0.49**	**0.45**	0.31	**0.39**	25
Bank Canopy Percentage	**0.36**	0.11	0.26	**0.40**	0.16	0.27	0.01	-0.11	**0.47**	**0.33**	0.25	0.32	25
Undercut Banks / Mile	-0.01	**0.34**	**0.35**	0.12	0.11	0.32	**0.53**	0.06	0.06	0.03	0.32	0.27	25
Undercut Bank Size Rank	0.25	0.21	0.23	-0.17	-0.22	0.13	0.35	0.08	-0.27	0.25	0.19	0.15	18
Undercut Bank Stability / Adjacency	0.15	**0.40**	**0.40**	0.12	-0.05	**0.48**	**0.47**	0.26	0.09	**0.35**	**0.39**	**0.39**	25
Mass Failures in Valley	0.11	0.24	-0.09	0.03	0.12	-0.05	0.12	**0.37**	-0.18	-0.04	0.26	0.10	25
Riparian Area - Mean	0.09	0.11	**0.37**	0.14	-0.04	**0.55**	0.33	0.08	0.27	**0.68**	**0.43**	**0.37**	25
Buffer Width	0.12	0.06	**0.39**	0.02	-0.18	**0.46**	**0.35**	0.03	0.13	**0.62**	0.33	0.29	25
Riparian Vegetation Percentage / Type	0.21	-0.01	0.19	0.16	0.00	0.26	0.05	-0.07	0.32	**0.50**	0.22	0.23	25
River Corridor Development	-0.01	0.08	**0.44**	0.07	-0.11	**0.60**	**0.35**	0.12	0.20	**0.53**	**0.42**	0.33	25
Score	0.18	**0.44**	**0.49**	0.20	0.09	**0.56**	**0.56**	0.21	0.10	**0.53**	**0.56**	**0.48**	25
Percentage	0.18	**0.44**	0.49	0.20	0.09	**0.56**	**0.56**	0.21	0.10	**0.53**	**0.56**	**0.48**	25

Statistical significance of Pearson Correlation: **p<0.1**; **p<0.05**

a=Cannot be computed because at least one of the variables is constant.

APPENDIX K: Results of Initial Year of Pilot Study

Macroinvertebrates

Community score and biotic index are statistically significantly related to overall RHA score for the single-season collections at the 12 pilot study segments. Clear trends of increasing community score with RHA score and decreasing biotic index (i.e., improving health) with increasing RHA score are evident. Some outliers obscure the expected of increasing EPT richness with increasing habitat quality. However, more variation is anticipated for individual metrics due to different biological expectations associated with variations in stream type. For example, it is known that reference conditions for single metrics such as EPT richness vary between small high-gradient streams (SHG) and medium-size high-gradient streams (MHG) (VTDEC, 2004).

Plots of the RHA parameters versus single-season macroinvertebrate metrics for the pilot study sites help illustrate factors driving the relationships with the overall RHA score. For example, the riparian areas parameter is significantly correlated with community score and biotic index, and describes a large amount of the variation in the macroinvertebrate metrics. The river banks parameter also significantly describes variation in the macroinvertebrate metrics. Connectivity is significantly related to macroinvertebrate community score.

Inspection of bed substrate cover parameter score versus macroinvertebrate metrics shows the presence of an outlier that weakens relationships. This sample site was identified to be a riffle-pool stream type, yet is more commonly dune-ripple with finer substrate dominating the bed. Furthermore, this site is the only one in the pilot study identified as a (medium) low-gradient stream (VTDEC, 2004). The discrepancy resulted in a low bed substrate cover score as the site was evaluated with the riffle-pool RHA form. Removal of this outlier leads to a significant and strong correlation. This example highlights the importance of accurately identifying reference geomorphic stream type, and biological expectations, when considering habitat quality.

Further inspection of the correlations between macroinvertebrate metrics and assessed habitat variables over the reach reveals some potential stressors at the pilot study sites. Of the significantly correlated parameters, the refuge area variable seemed to be driving the connectivity correlation to metrics. Bank erosion and bank vegetative cover were the key variables in the river banks parameter, while all of the riparian area variables were correlated to macroinvertebrate metric scores. The investigation of variables confirms the possibility of bank and riparian conditions as stressors at some of the pilot study sites.

Note that the Bonferroni correction (Sokal and Rohlf, 1995) ($p < \alpha / K$) was not applied to limit the error rate associated with family-wise correlation testing (Van Sickle, 2003) for this initial exploratory study.

The qualitatively assessed CPOM abundance variable was significantly related to community score (0.52) and biotic index (-0.58). Riffle embeddedness and fining also were related to macroinvertebrate metrics suggesting that there may be an excess of fines in the systems. The qualitative measure of excessively dense algae growth was also related to metrics.

Biotic index was related to pool density (-0.53) suggesting that lack of pools could be influencing community health. The same holds for well-formed riffles as EPT richness (0.73) and biotic index (-0.52) indicated higher community health with clean riffles.

Water quality data collected at each of the pilot study sites confirms that macroinvertebrate metrics are also influenced by water quality as well as habitat condition. Water temperature, alkalinity, conductivity, ion concentrations, and nutrient concentrations are all significantly related to habitat score. Bivariate correlations suggest that water quality and habitat score accounts for approximately the same amount of variation in the macroinvertebrate metrics.

Stepwise redundancy analysis (ter Braak and Smilauer, 1997, 1998) and variance partitioning (Leps and Smilauer, 2003) indicate that the majority of variation in macroinvertebrate community score and biotic index is associated with the riparian parameter score (67.5%) and the two bank variables of system obstructions and abundance of mass failures (17.9%). A triplot

ordination diagram (Leps and Smilauer, 2003) shows that riparian area parameter score is closely positively correlated with community score and negatively correlated with biotic index. Weak correlations exist between the metrics and bank variables. Response variables were centered and standardized (i.e., mean of 0 and variance of 1) to account for different units of measurement. The entry of explanatory variables into the model was performed interactively in descending order of the amount of improvement to the model, and at a significance level of 0.05, using partial Monte Carlo permutation testing (n = 499). Previously entered variables were used as covariates to avoid redundancy associated with correlated variables.

Although an effort was made to remove redundancy and identify key variables, the limited number of data points, large number of potential explanatory varibles, and correlation between variables leads to potential multicollinearity in the multivariate analysis. This could influence the estimation of the relative importance of each variable. This issue will likely be resolved in the future as more data are collected to add to this initial data set.

The strength of relationships between RHA score and macroinvertebrate metrics appears to increase when RHA score is related to mean metrics from multiple seasons of data. The amount of variation described is greater for community score (0.82), biotic index (-0.75)), and EPT richness (0.79). Some of the improvement in the relationships is likely the averaging over the expected natural variation in collections, but there is likely a component that is related to the fact that long-term collections were from more similar SHG mountain streams that are mostly smaller step-pool channels with more consistent physical instream conditions (e.g., low w:d ratio, coarse bed). It also should be noted that the observed long-term sites consist of streams impacted by the operation of nearby ski areas along with nearby reference or local control sites. Metrics thus may represent a disturbances and subsequent recovery, continued disturbance, and natural variation. A potential future study component would be to add the RHA to long-term investigations of impacts to track how both habitat and biological communities respond to disturbances.

The RHA parameter scores for the seven long-term BASS Lab study sites indicate that connectivity score is an important factor driving mean macroinvertebrate metrics. Connectivity

significantly accounts for a lot of variation in community score, richness, and EPT richness. The obstruction variables were driving the relationships. Mean community score and biotic index are also significantly influenced by bank condition, which appeared to be due to significant relationships to the bank canopy cover variable. The woody debris recruitment potential variable was also significantly related to community score (0.78) and EPT richness (0.83).

The mean macroinvertebrate metrics for six Chittenden County streams investigated by Fitzgerald Environmental Associates as part of the RHA initial testing illustrated that the RHA aptly characterizes stream habitat over a range of habitat quality. The mean macroinvertebrate metrics are strongly correlated with RHA score. The RHA parameters range more widely in the Chittenden County streams assessed, and show expected relationships with mean macroinvertebrate metrics. For example, bed substrate cover, scour and depositional features, and connectivity are all strongly correlated with biotic index and EPT richness. Important features that are limiting habitat quality in the non-attainment Chittenden County streams include reduced CPOM abundance, increased embeddedness, reduced riffle stability, the absence of large pools, increased channel entrenchment/incision, a high level of flow alteration, and the limitation of stable undercut banks.

Fish

The relationships between fish metrics and RHA score are neither strong nor significant. Fish index of biotic integrity, consisting of a combination of cold water (CW-IBI) and mixed waters (MW-IBI) metrics (Langdon, 2001; VTDEC, 2004), appears to loosely follow the expected trends of increasing community health with increasing habitat quality, yet several outliers weaken the relationship. The three SHG streams of the sample sites are located away from the cluster of the MHG sites. Increased habitat quality for the SHG sites does not translate to increased IBI scores as it tends to do for the MHG streams.

Total salmonid density, excluding Atlantic salmon that are stocked in the Tweed River, tends to increase with increasing RHA score. The relationship between salmonid density and RHA score appears to have an upper and lower limit with variability within likely due to natural annual

variation or other factors influencing the fish community such as water quality. Fish IBI is significantly correlated with connectivity that is driven by the system obstructions variable (0.73). Salmonid density is related to bank vegetation coverage and type (0.68), as well as riparian vegetation buffer width (0.53) and coverage and type (0.77).

The relationships between RHA parameters and fish metrics show SHG sites occasionally lying away from the cluster of MHG sites. For example, the scour and depositional features parameter appears as though it would have a stronger correlation with fish IBI if only MHG sites were considered.

Fish metrics are strongly correlated with water quality for the single-season metrics at the pilot study sites. Unlike for the macroinvertebrate metrics, the strength of the relationship between water quality and fish is much stronger than the relationship to habitat.

The possibility exists that the lack of correlation between fish and habitat is due to the variability of both fish populations and habitat features. Another potential cause for not seeing expected patters is that the fish sampling methods covered a limited portion of the segment assessed for habitat quality. This inherent difference in scale of observation and habitat formation and maintenance complicates studying the relationship between habitat and biological communities, and is a topic for continued research as this study moves forward.

Stepwise redundancy analysis (ter Braak and Smilauer, 1997, 1998) and variance partitioning (Leps and Smilauer, 2003) indicate that the majority of variation in fish index of biotic integrity and total salmonid density (excluding Atlantic salmon) is associated with the habitat variables of refuge area presence, the amount of exposed substrate, width:depth ratio, the presence of adjacent wetlands, and large woody debris size (32.2%); the concentration of total nitrogen (18.3%); and the elevation of the site (4.1%). A triplot shows a strong negative correlation between fish index of biotic integrity and total nitrogen. The habitat variables of exposed substrate and refugia are also correlated with index of biotic integrity, although to a lesser degree.

The density of salmonids increases with the presence of adjacent wetlands, site elevation, and to a lesser extent presence of refugia. Salmonid density is negatively correlated with LWD size, a counterintuitive finding that is likely due to assessed streams having more wood tended to have less large wood.

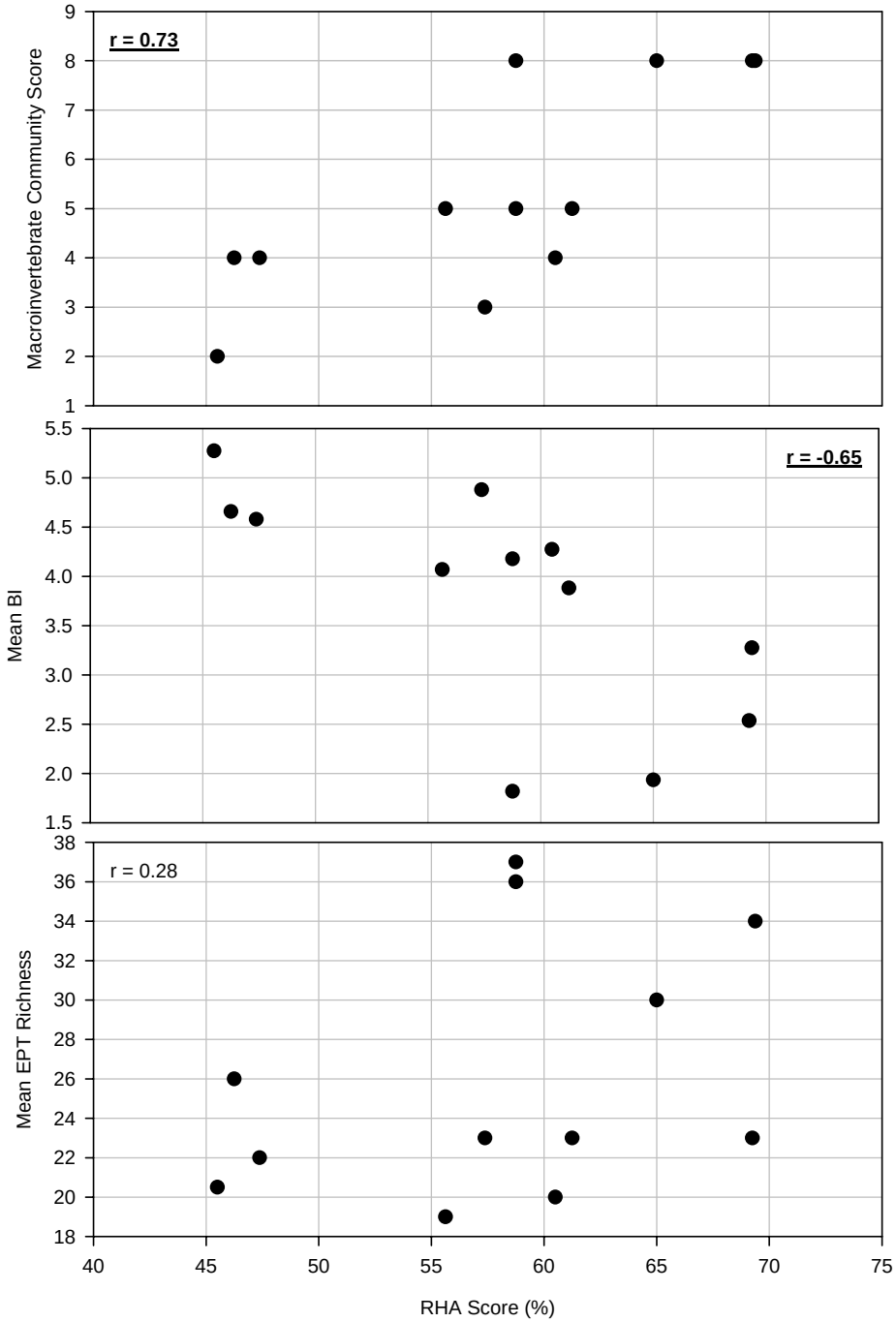
Channel Evolution

Following previous findings showing the influence of stage of channel evolution model versus EPT richness (Fitzgerald, 2007), RHA scores and macroinvertebrate metrics were plotted versus evolution stage. In general, habitat conditions tend to decline during stages of channel instability and widening (II-IV). For example, a decrease in woody debris cover, channel morphology, and hydrologic characteristics scores are evident for stages II-IV. Overall RHA score is lower for CEM stage III. Macroinvertebrate community score and Salmonid density indicate lower community health for stages III and IV. As more data are collected the relationships between CEM stage and habitat observed here should be re-visited.

New RHA Score v. Single-Season Macroinvertebrate Metrics for 12 Pilot Study Segments

Sites: Batten Kill M12A/B; Browns River M16A/B/C; Chester Brook BASS 2.3/2.5;
Poultney River M9A/B; Tweed River T6.04A/B; Wanzer Brook T3.3S1.01

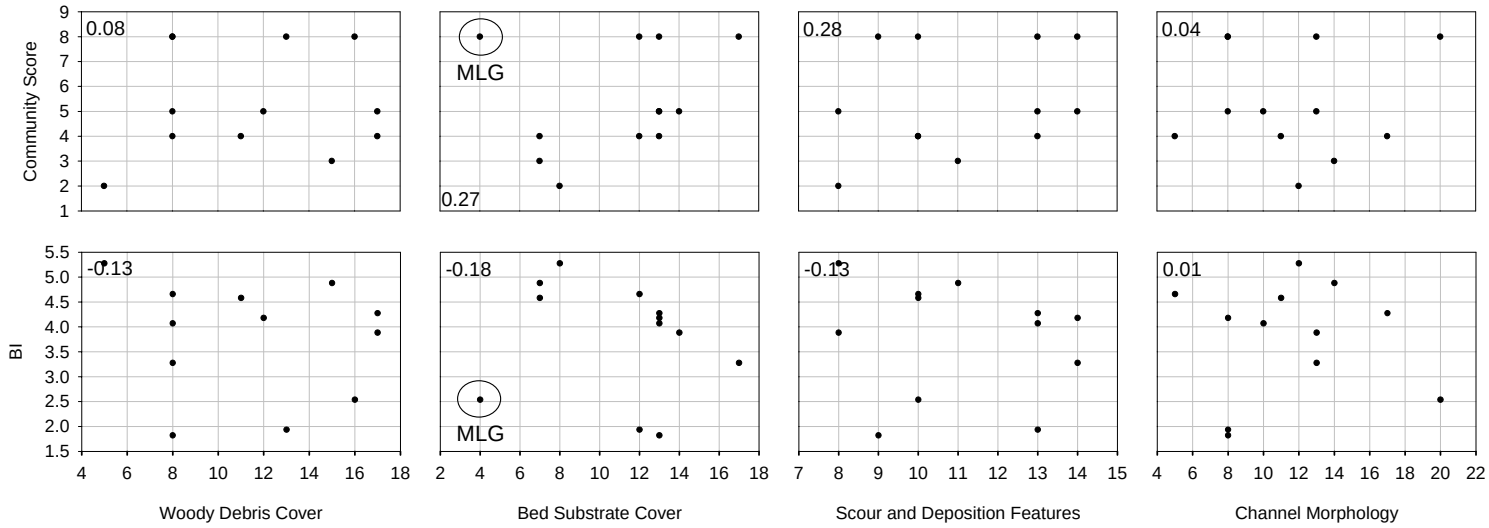
Statistics: r = Pearson Correlation Coefficient; statistical significance: **p < 0.10** and **p < 0.05**

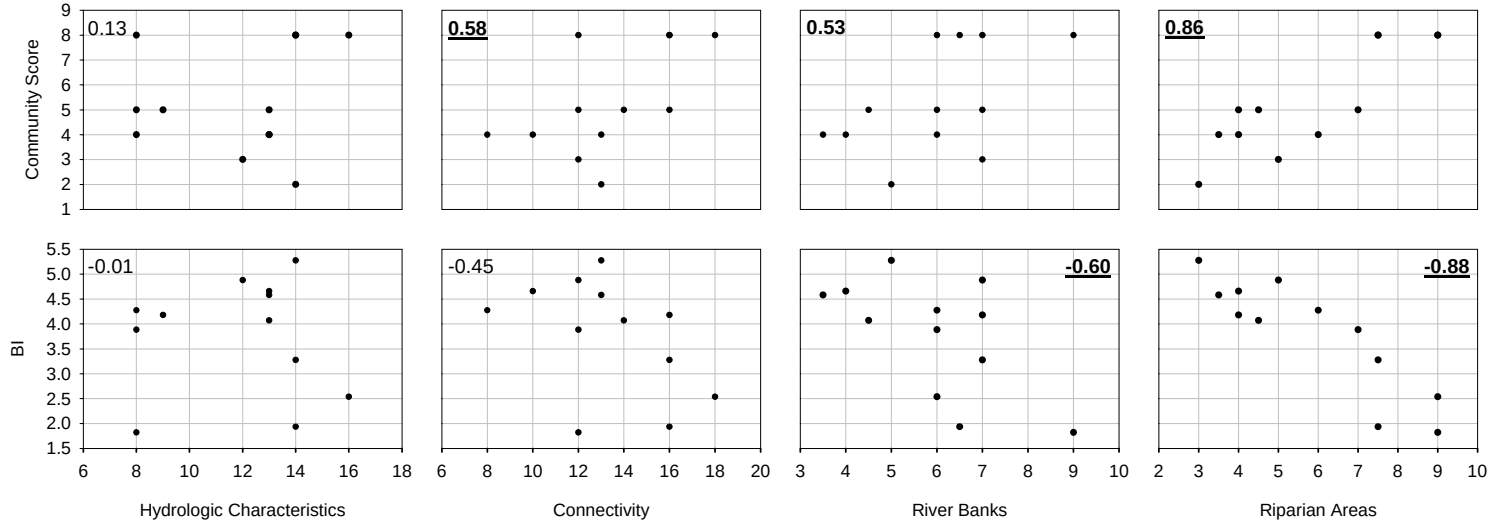


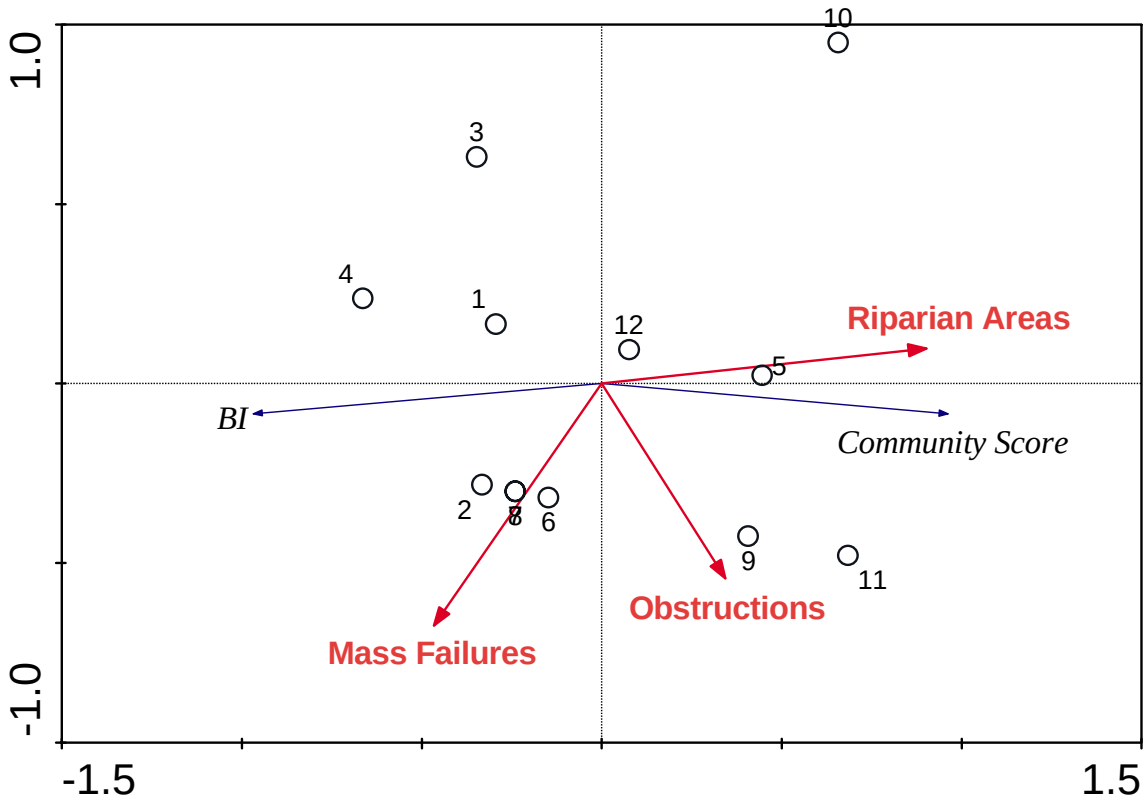
New RHA Parameter Scores versus Single-Season Macroinvertebrate Metrics for 12 Pilot Study Segments

Sites: Batten Kill M12A/B; Browns River M16A/B/C; Chester Brook BASS 2.3/2.5; Poultney River M9A/B; Tweed River T6.04A/B; Wanzer Brook T3.3S1.01

Statistics: r = Pearson Correlation Coefficient; statistical significance: **p < 0.10** and **p < 0.05**





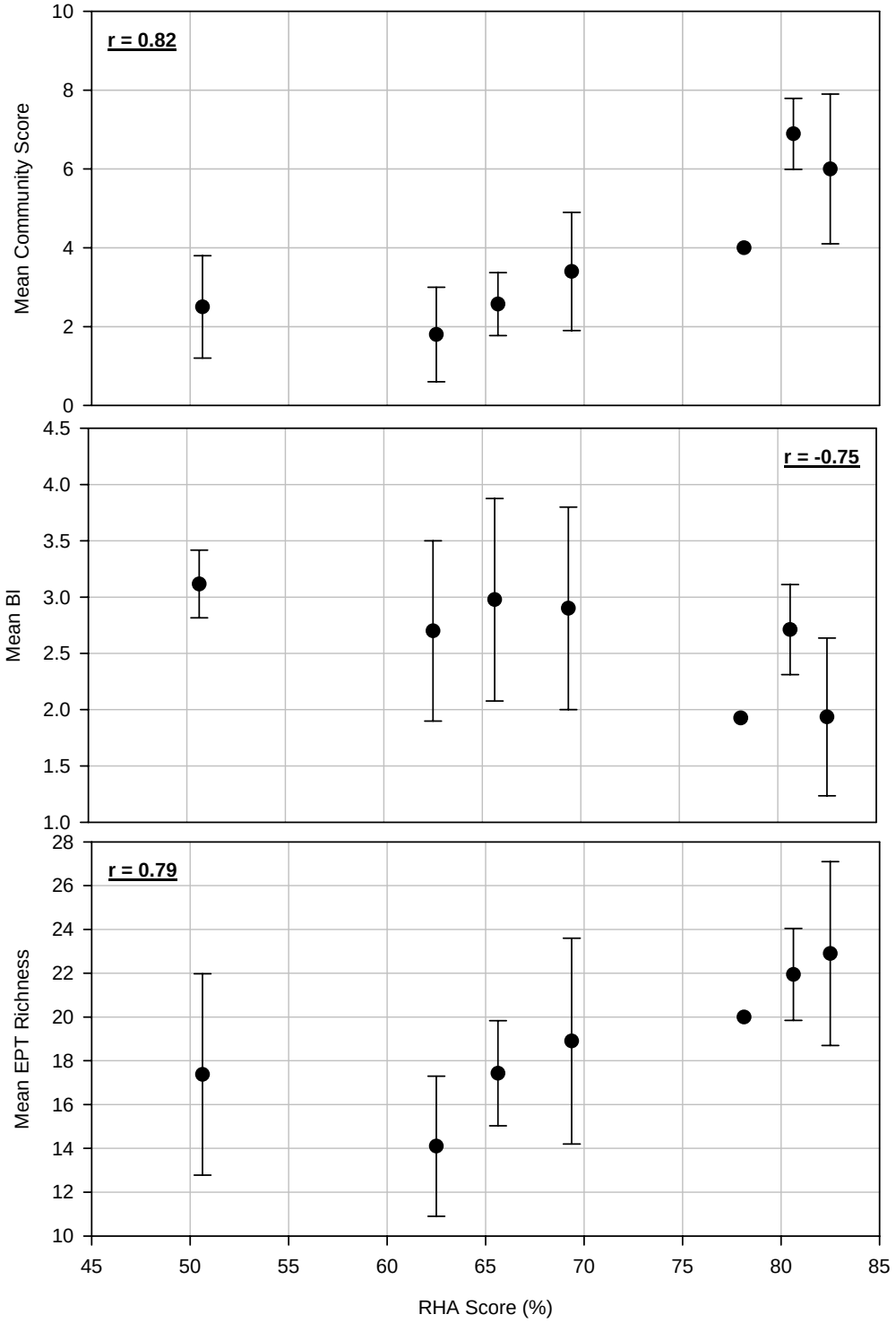

1.0
-1.0
-1.5
1.5
10
3
4
1
12
5
Riparian Areas
BI
Community Score
2
8
6
9
11
Obstructions
Mass Failures

New RHA Score versus Mean Macroinvertebrate Metrics for 7 BASS Lab Sites

Sites: West Branch Little River 6.5 (N=10) and 7.5 (N=11); Ranch Brook 1.5 (N=9); Big Spruce Brook 0.2 (N=7); Pinnacle Brook 1.3 (N=1); East Tributary of Roaring Brook 0.3 (N=4); West Tributary of Roaring Brook 0.2 (N=5)

Statistics: r = Pearson Correlation Coefficient; statistical significance: **p < 0.10** and **p < 0.05**;

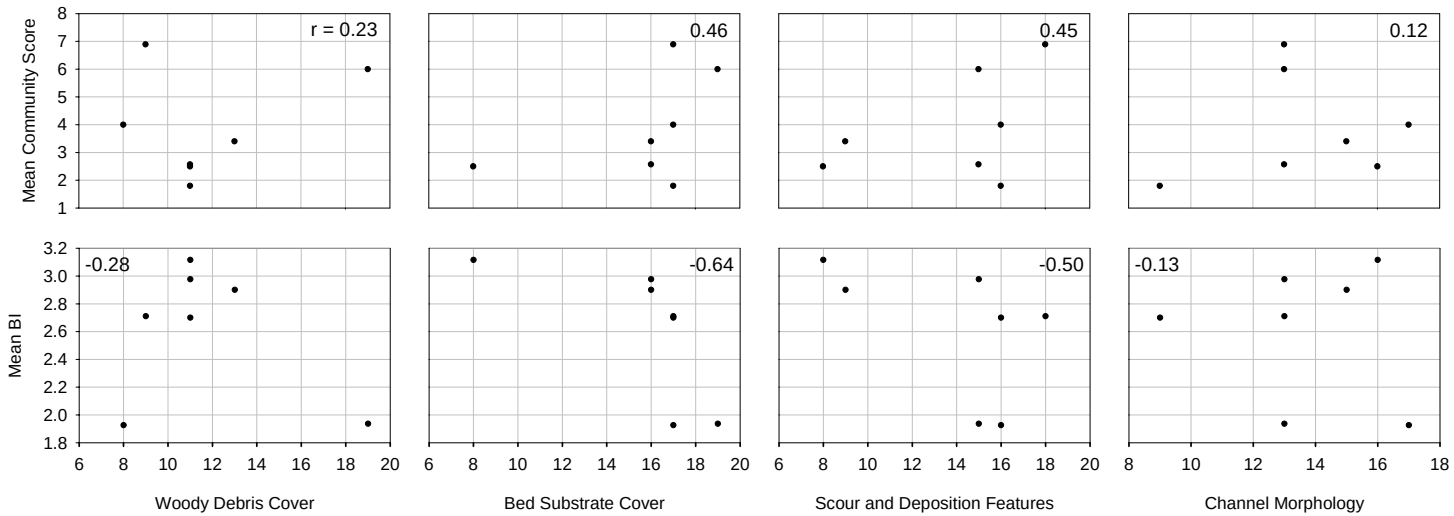
Error bars +/- 1 standard deviation.

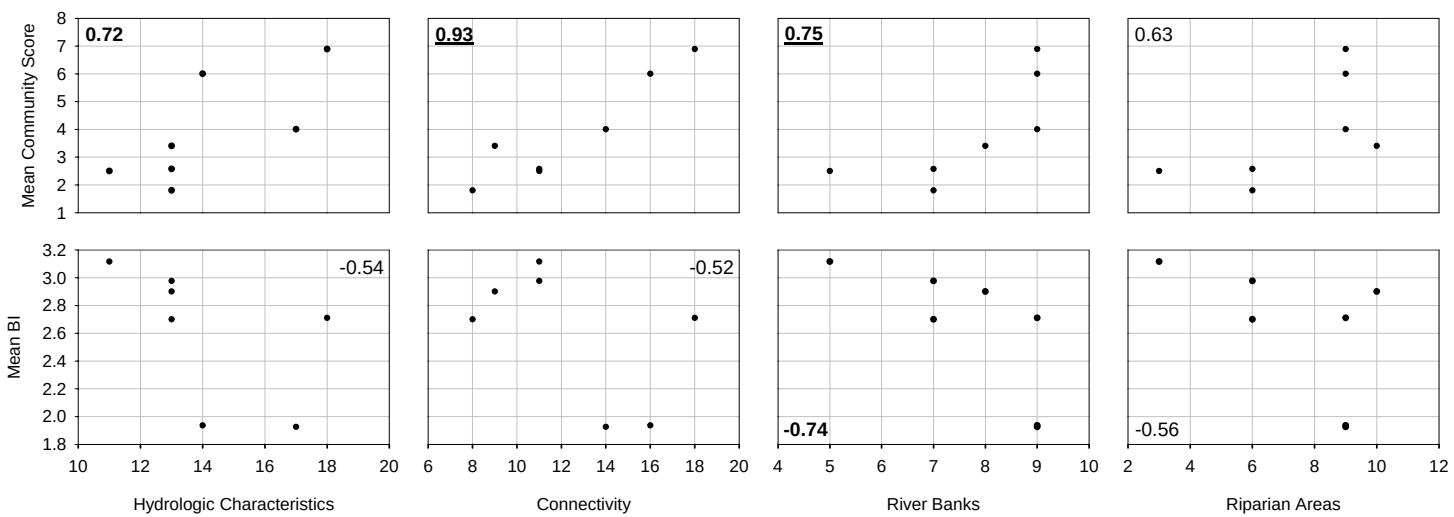


New RHA Parameter Scores versus Mean Macroinvertebrate Metrics for 7 BASS Lab Sites

Sites: West Branch Little River 6.5 (N=10) and 7.5 (N=11); Ranch Brook 1.5 (N=9); Big Spruce Brook 0.2 (N=7); Pinnacle Brook 1.3 (N=1); East Tributary of Roaring Brook 0.3 (N=4); West Tributary of Roaring Brook 0.2 (N=5)

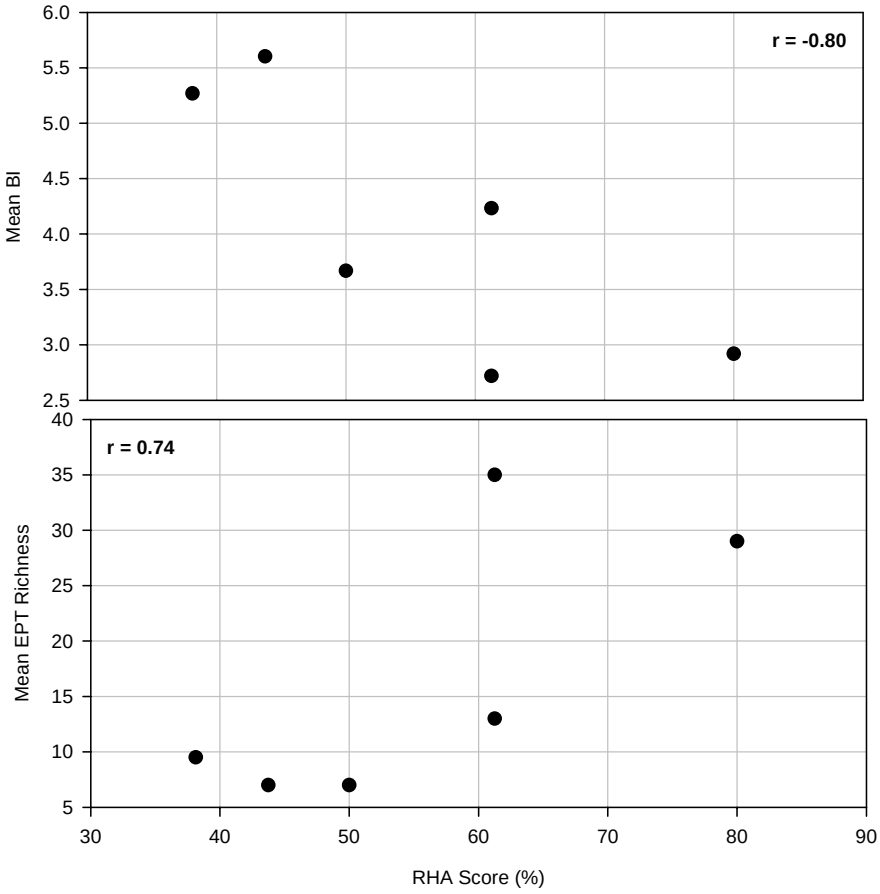
Statistics: r = Pearson Correlation Coefficient; statistical significance: **p < 0.10** and **p < 0.05**





New RHA Score v. versus Mean Macroinvertebrate Metrics for 6 FEA Initial Testing Segments

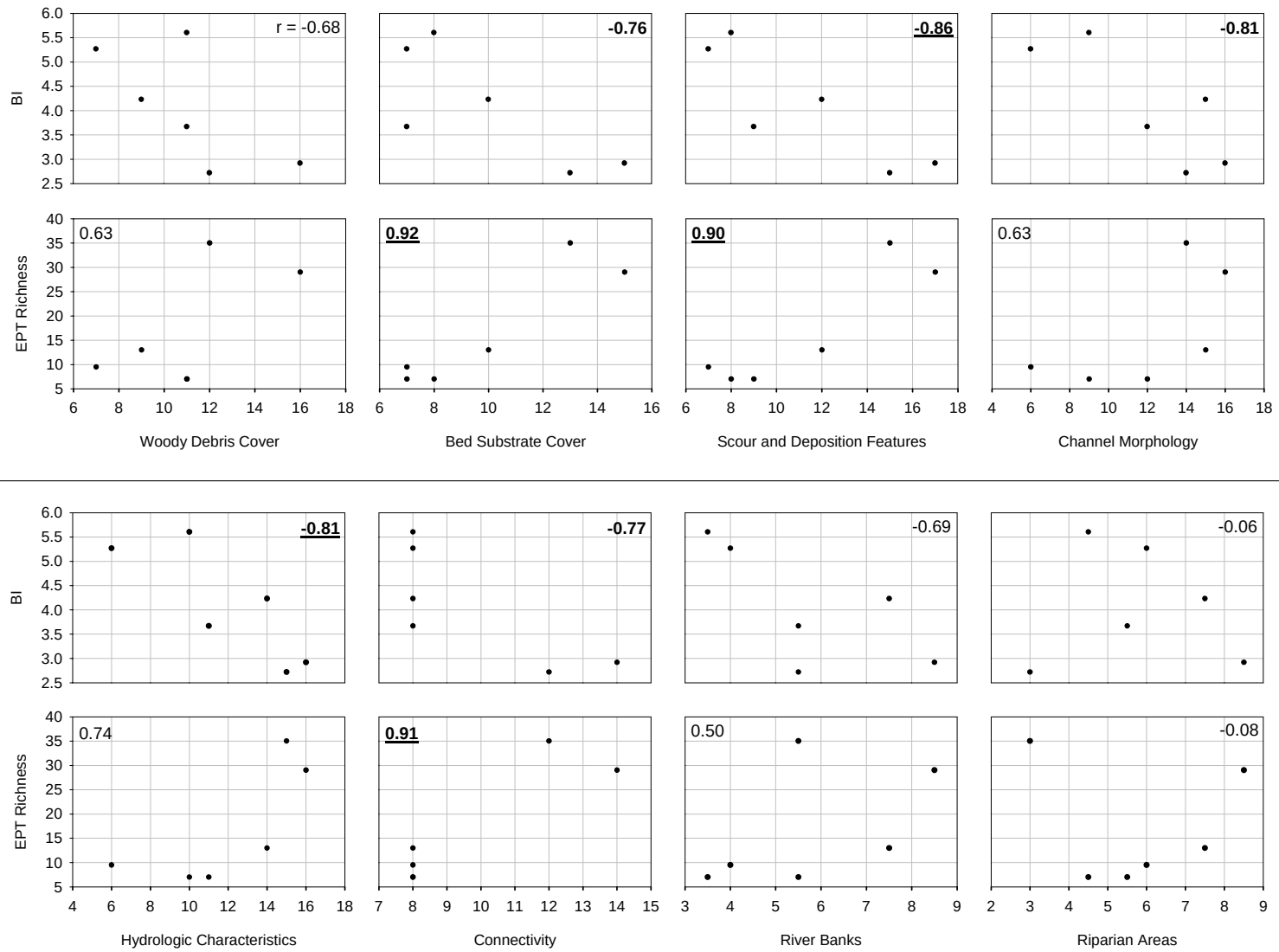
Sites: Potash Brook M02-B (N=6) and M08-B (N=2); Johnnie Brook M06 (N=1);
Mill Brook M03 (N=1); Indian Brook M09B (N=2) and M12 (N=1)
Statistics: r = Pearson Correlation Coefficient; statistical significance: **p < 0.10** and **p < 0.05**



New RHA Parameter Scores versus Mean Macroinvertebrate Metrics for 6 FEA Initial Testing Segments

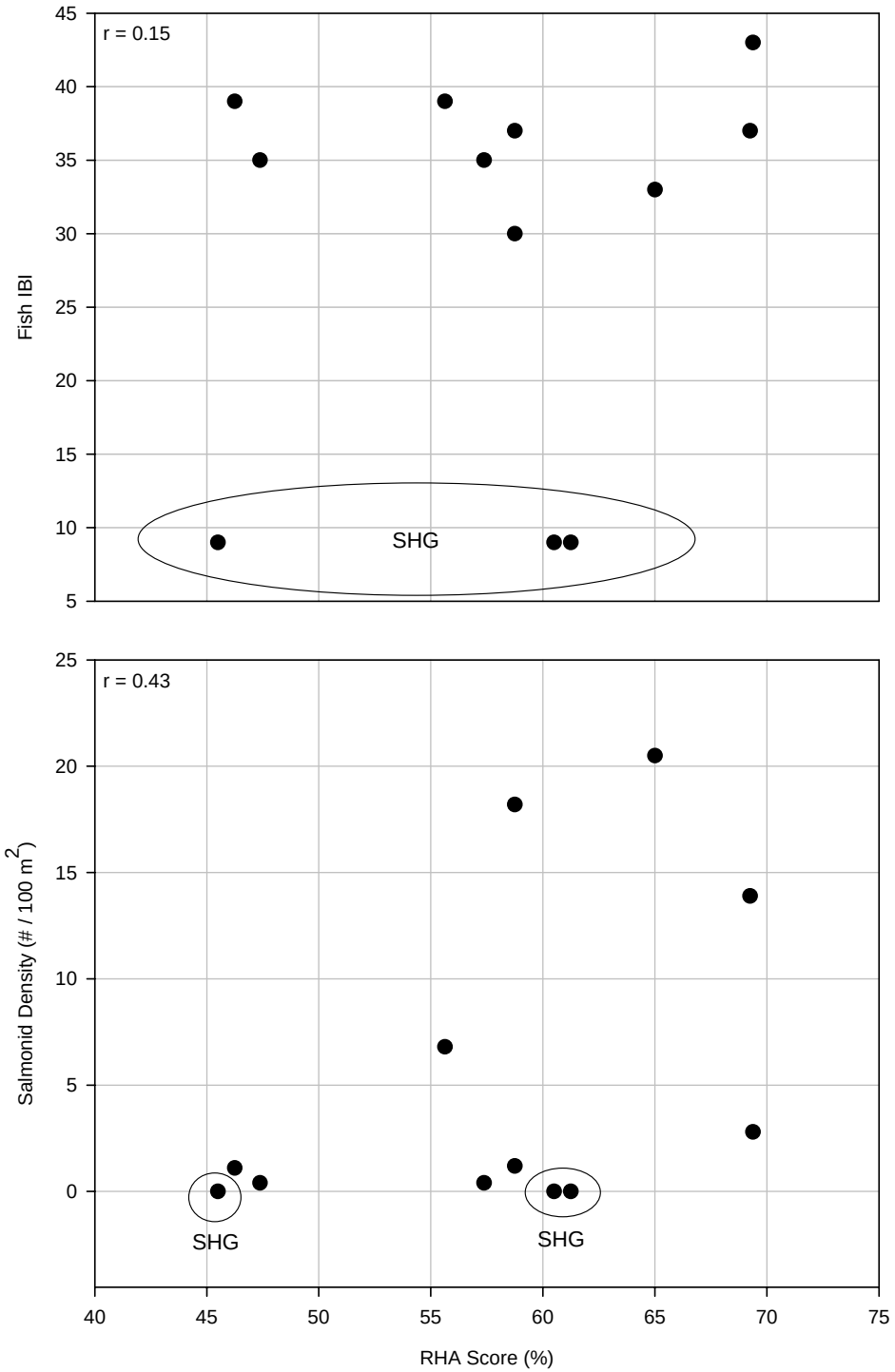
Sites: Potash Brook M02-B (N=6) and M08-B (N=2); Johnnie Brook M06 (N=1); Mill Brook M03 (N=1); Indian Brook M09B (N=2) and M12 (N=1)

Statistics: r = Pearson Correlation Coefficient; statistical significance: **p < 0.10** and **p < 0.05**



New RHA Overall Score versus Single-Season Fish Metrics for 12 Pilot Study Segments

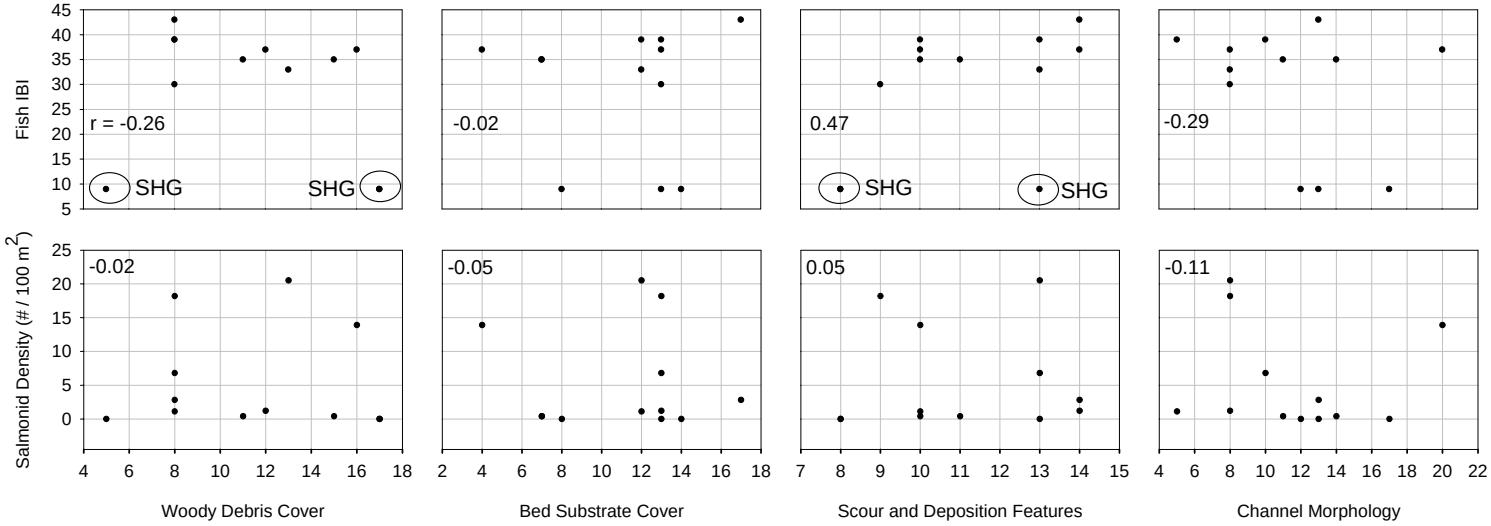
Sites: Batten Kill M12A/B; Browns River M16A/B/C; Chester Brook BASS 2.3/2.5;
Poultney River M9A/B; Tweed River T6.04A/B; Wanzer Brook T3.3S1.01
Statistics: r = Pearson Correlation Coefficient; statistical significance: **p < 0.10** and **p < 0.05**

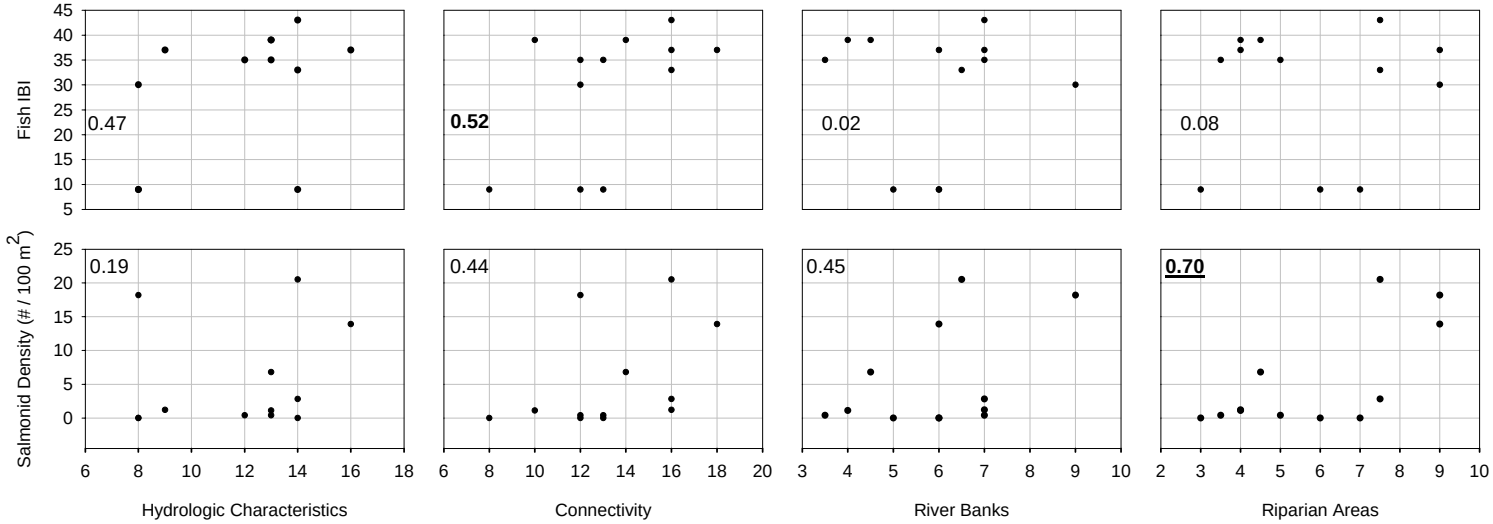


New RHA Parameter Scores versus Single-Season Fish Metrics for 12 Pilot Study Segments

Sites: Batten Kill M12A/B; Browns River M16A/B/C; Chester Brook BASS 2.3/2.5; Poultney River M9A/B; Tweed River T6.04A/B; Wanzer Brook T3.3S1.01

Statistics: r = Pearson Correlation Coefficient; statistical significance: **p < 0.10** and **p < 0.05**





Statistical significance of Pearson Correlation: **p<0.1**; **p<0.05**
a=Cannot be computed because variable is constant.

		Pilot Study Data					BASS Mean Data						FEA Mean data	
		Fish IBI	Salmonid Density	BMI Com. Score	Ept Richness	BI	Mean Com Scr	SDEV Com Scr	Mean EPT	SDEV EPT	Mean BI	SDEVE BI	Ept Richness	Mean BI
Woody Debris Cover	Pearson Correlation	-0.26	-0.02	0.08	-0.23	-0.13	0.23	0.89	0.35	0.53	-0.28	0.28	0.63	-0.68
	Sig. (2-tailed)	0.42	0.96	0.80	0.48	0.69	0.61	0.02	0.45	0.28	0.54	0.59	0.18	0.14
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
LWD Pieces / Mile	Pearson Correlation	-0.23	-0.09	-0.08	-0.37	0.02	0.15	0.70	0.36	0.60	-0.13	0.14	0.14	-0.21
	Sig. (2-tailed)	0.47	0.79	0.82	0.24	0.95	0.78	0.18	0.49	0.28	0.80	0.82	0.80	0.69
	N	12.00	12.00	12.00	12.00	12.00	6.00	5.00	6.00	5.00	6.00	5.00	6.00	6.00
LWD Size Rank	Pearson Correlation	-0.27	-0.09	0.02	0.40	-0.07	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	0.36	-0.51
	Sig. (2-tailed)	0.49	0.81	0.95	0.29	0.86	.	.	.	.	.	.	0.49	0.30
	N	9.00	9.00	9.00	9.00	9.00	6.00	5.00	6.00	5.00	6.00	5.00	6.00	6.00
Debris Jams / Mile	Pearson Correlation	**-0.62**	-0.07	-0.05	**-0.52**	-0.03	0.27	**0.80**	0.45	0.58	-0.30	0.16	-0.35	0.05
	Sig. (2-tailed)	0.03	0.82	0.89	0.08	0.94	0.60	0.10	0.37	0.31	0.56	0.80	0.50	0.93
	N	12.00	12.00	12.00	12.00	12.00	6.00	5.00	6.00	5.00	6.00	5.00	6.00	6.00
Woody Debris Recruitment Potential	Pearson Correlation	-0.03	0.25	0.39	0.20	-0.45	**0.78**	0.45	**0.83**	0.13	-0.62	0.00	0.40	-0.56
	Sig. (2-tailed)	0.93	0.43	0.21	0.53	0.14	0.04	0.37	0.02	0.81	0.14	1.00	0.43	0.25
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
CPOM Abundance	Pearson Correlation	-0.06	**0.52**	**0.52**	-0.18	**-0.58**	-0.01	-0.02	0.07	-0.12	-0.04	-0.32	**0.91**	**-0.76**
	Sig. (2-tailed)	0.86	0.09	0.09	0.57	0.05	0.98	0.97	0.89	0.82	0.93	0.54	0.01	0.08
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Bed Substrate Cover	Pearson Correlation	-0.02	-0.05	0.27	0.47	-0.18	0.46	0.16	0.37	-0.38	-0.64	0.59	**0.92**	**-0.76**
	Sig. (2-tailed)	0.96	0.88	0.40	0.12	0.57	0.30	0.77	0.41	0.45	0.12	0.22	0.01	0.08
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Riffle Embeddedness Percentage	Pearson Correlation	0.00	0.38	**0.62**	0.36	**-0.56**	0.36	-0.18	0.23	-0.70	-0.57	0.46	**0.88**	-0.47
	Sig. (2-tailed)	1.00	0.25	0.04	0.27	0.07	0.43	0.74	0.63	0.12	0.18	0.36	0.02	0.35
	N	11.00	11.00	11.00	11.00	11.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Fining Percentage	Pearson Correlation	0.13	0.27	**0.51**	**0.53**	-0.45	0.36	-0.18	0.23	-0.70	-0.57	0.46	0.62	-0.37
	Sig. (2-tailed)	0.69	0.40	0.09	0.08	0.14	0.43	0.74	0.63	0.12	0.18	0.36	0.19	0.47
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Rffle Stability Index	Pearson Correlation	-0.02	-0.16	0.03	0.24	0.10	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	**0.96**	-0.75
	Sig. (2-tailed)	0.96	0.64	0.94	0.47	0.77	.	.	.	.	.	.	0.04	0.25
	N	11.00	11.00	11.00	11.00	11.00	1.00	1.00	1.00	1.00	1.00	1.00	4.00	4.00
Sediment Stability Observed	Pearson Correlation	-0.21	-0.17	0.02	-0.16	0.04	0.14	0.16	0.15	0.03	-0.13	**0.73**	**0.79**	-0.71
	Sig. (2-tailed)	0.53	0.63	0.95	0.65	0.91	0.77	0.77	0.75	0.96	0.78	0.10	0.06	0.11
	N	11.00	11.00	11.00	11.00	11.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Dense Algae Growth	Pearson Correlation	-0.03	**0.52**	**0.77**	**0.52**	**-0.73**	0.48	0.08	**0.71**	0.14	-0.08	-0.25	0.66	-0.43
	Sig. (2-tailed)	0.92	0.10	0.01	0.10	0.01	0.27	0.88	0.07	0.78	0.86	0.63	0.15	0.39
	N	11.00	11.00	11.00	11.00	11.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Scour and Depostion Features	Pearson Correlation	0.47	0.05	0.28	0.29	-0.13	0.45	-0.34	0.24	**-0.84**	-0.50	0.10	**0.90**	**-0.86**
	Sig. (2-tailed)	0.13	0.88	0.38	0.36	0.68	0.31	0.50	0.60	0.04	0.25	0.86	0.01	0.03
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Pools / Mile	Pearson Correlation	-0.44	0.46	0.46	0.14	**-0.53**	-0.01	.(a)	-0.16	.(a)	0.61	.(a)	0.24	-0.35
	Sig. (2-tailed)	0.17	0.16	0.15	0.68	0.09	0.99	.	0.77	.	0.20	.	0.70	0.56
	N	11.00	11.00	11.00	11.00	11.00	6.00	5.00	6.00	5.00	6.00	5.00	5.00	5.00
Pool Size Rank	Pearson Correlation	0.51	-0.07	0.10	-0.10	0.01	0.55	-0.58	0.41	**-0.92**	-0.18	0.14	**0.88**	-0.48
	Sig. (2-tailed)	0.11	0.85	0.76	0.78	0.97	0.26	0.31	0.42	0.02	0.74	0.83	0.05	0.41
	N	11.00	11.00	11.00	11.00	11.00	6.00	5.00	6.00	5.00	6.00	5.00	5.00	5.00

Statistical significance of Pearson Correlation: **p<0.1**; **p<0.05**
a=Cannot be computed because variable is constant.

		Pilot Study Data					BASS Mean Data						FEA Mean data	
		Fish IBI	Salmonid Density	BMI Com. Score	Ept Richness	BI	Mean Com Scr	SDEV Com Scr	Mean EPT	SDEV EPT	Mean BI	SDEVE BI	Ept Richness	Mean BI
Pool Surface Cover	Pearson Correlation	-0.13	0.03	-0.11	**-0.59**	0.06	0.57	-0.33	0.45	**-0.81**	-0.54	0.14	0.75	-0.64
	Sig. (2-tailed)	0.71	0.92	0.75	0.05	0.87	0.24	0.59	0.37	0.10	0.27	0.83	0.15	0.25
	N	11.00	11.00	11.00	11.00	11.00	6.00	5.00	6.00	5.00	6.00	5.00	5.00	5.00
Pools Formation	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.
	N	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Riffle Formation	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.
	N	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Depth / Velocity Combinations Present	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.
	N	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Step Formation	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	0.45	0.49	0.53	-0.13	**-0.94**	0.55	1.00	-1.00
	Sig. (2-tailed)	.	.	.	.	.	0.37	0.40	0.28	0.84	0.01	0.34	.	.
	N	0.00	0.00	0.00	0.00	0.00	6.00	5.00	6.00	5.00	6.00	5.00	2.00	2.00
Step Spacing (wbkf)	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	-0.01	.(a)	-0.16	.(a)	0.61	.(a)	1.00	-1.00
	Sig. (2-tailed)	.	.	.	.	.	0.99	.	0.77	.	0.20	.	.	.
	N	0.00	0.00	0.00	0.00	0.00	6.00	5.00	6.00	5.00	6.00	**5.00**	2.00	2.00
Depth- Velocity Combinations Present	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	0.53	0.36	0.37	-0.17	-0.73	0.07	1.00	-1.00
	Sig. (2-tailed)	.	.	.	.	.	0.28	0.55	0.47	0.79	0.10	0.91	.	.
	N	0.00	0.00	0.00	0.00	0.00	6.00	5.00	6.00	5.00	6.00	5.00	2.00	2.00
Riffle Coverage / Formation	Pearson Correlation	0.01	0.36	0.50	**0.73**	**-0.52**	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	0.87	-0.98
	Sig. (2-tailed)	0.98	0.28	0.12	0.01	0.10	.	.	.	.	.	.	0.33	0.12
	N	11.00	11.00	11.00	11.00	11.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00
Meandering Thalweg Identifiable	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.
	N	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Riffle Spacing (wbkf)	Pearson Correlation	-0.05	-0.27	-0.44	-0.33	0.36	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	1.00	-0.75
	Sig. (2-tailed)	0.88	0.43	0.17	0.33	0.27	.	.	.	.	.	.	.	0.46
	N	11.00	11.00	11.00	11.00	11.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00
Riffle- Run-Pool-Glide Pattern	Pearson Correlation	0.01	-0.32	-0.24	-0.19	0.29	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.98	0.37	0.51	0.61	0.42	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00
Finer Deposition Observed	Pearson Correlation	0.20	0.15	0.29	**0.56**	-0.28	0.07	-0.41	-0.06	-0.59	-0.15	0.65	0.46	-0.45
	Sig. (2-tailed)	0.53	0.65	0.37	0.06	0.39	0.88	0.41	0.90	0.22	0.75	0.16	0.35	0.38
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Channel Morphology	Pearson Correlation	-0.29	-0.11	0.04	-0.46	0.01	0.12	0.17	0.40	0.51	-0.13	-0.38	0.63	**-0.81**
	Sig. (2-tailed)	0.35	0.73	0.91	0.14	0.98	0.79	0.74	0.38	0.31	0.78	0.46	0.18	0.05
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Width / Depth Ratio	Pearson Correlation	-0.45	**-0.57**	**-0.54**	**-0.81**	**0.56**	-0.43	0.13	-0.42	0.09	0.19	0.05	0.12	-0.29
	Sig. (2-tailed)	0.14	0.05	0.07	0.00	0.06	0.33	0.81	0.35	0.86	0.69	0.93	0.82	0.58
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Entrenchement and Incision Ratios	Pearson Correlation	-0.12	0.13	0.05	**-0.59**	-0.08	-0.23	0.04	-0.06	0.46	-0.12	-0.70	**0.73**	**-0.86**
	Sig. (2-tailed)	0.70	0.68	0.87	0.04	0.80	0.63	0.94	0.90	0.36	0.79	0.12	0.10	0.03
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00

Statistical significance of Pearson Correlation: **p<0.1**; **p<0.05**
a=Cannot be computed because variable is constant.

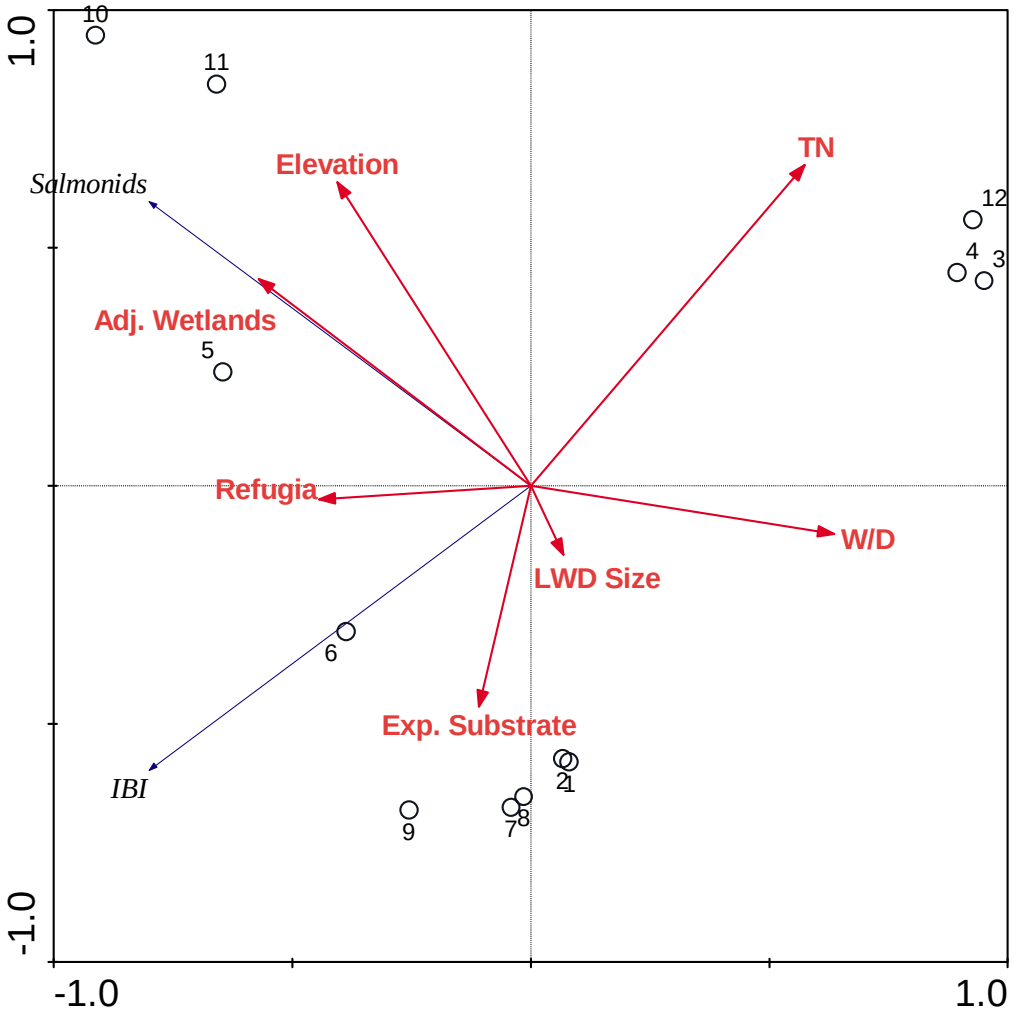
		Pilot Study Data					BASS Mean Data						FEA Mean data	
		Fish IBI	Salmonid Density	BMI Com. Score	Ept Richness	BI	Mean Com Scr	SDEV Com Scr	Mean EPT	SDEV EPT	Mean BI	SDEVE BI	Ept Richness	Mean BI
Channel Alteration	Pearson Correlation	-0.15	0.04	0.28	-0.19	-0.22	0.33	0.18	0.51	0.10	-0.42	0.48	0.27	-0.32
	Sig. (2-tailed)	0.64	0.90	0.37	0.56	0.50	0.47	0.74	0.25	0.85	0.35	0.34	0.60	0.54
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Hydrologic Characteristics	Pearson Correlation	0.47	0.19	0.13	-0.24	-0.01	**0.72**	-0.27	0.59	-0.65	-0.54	-0.19	**0.74**	**-0.81**
	Sig. (2-tailed)	0.12	0.56	0.69	0.46	0.97	0.07	0.61	0.16	0.16	0.21	0.72	0.09	0.05
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Wetted Width / Wbkf	Pearson Correlation	0.48	0.06	-0.06	-0.33	0.16	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	0.80	-0.71
	Sig. (2-tailed)	0.11	0.86	0.86	0.30	0.63	.	.	.	.	.	.	0.05	0.11
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Substrate Exposure Percentage	Pearson Correlation	0.36	-0.19	-0.13	-0.35	0.31	-0.27	-0.22	-0.05	0.01	-0.02	0.70	0.68	**-0.73**
	Sig. (2-tailed)	0.24	0.55	0.68	0.27	0.33	0.55	0.67	0.91	0.98	0.97	0.12	0.13	0.10
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Adjacent Springs, Seeps, Wetlands	Pearson Correlation	0.20	**0.72**	**0.58**	0.03	**-0.63**	0.43	-0.40	0.24	**-0.73**	-0.48	-0.03	0.27	-0.32
	Sig. (2-tailed)	0.54	0.01	0.05	0.93	0.03	0.34	0.43	0.61	0.10	0.28	0.96	0.60	0.54
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Flow Alteration	Pearson Correlation	-0.37	0.22	0.25	0.28	-0.38	**0.95**	0.21	**0.93**	-0.29	-0.65	-0.13	**0.96**	**-0.82**
	Sig. (2-tailed)	0.24	0.49	0.43	0.38	0.22	0.00	0.70	0.00	0.57	0.11	0.80	0.00	0.04
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Connectivity	Pearson Correlation	**0.52**	0.44	**0.58**	0.34	-0.45	**0.93**	0.04	**0.88**	-0.36	-0.52	-0.50	**0.91**	**-0.77**
	Sig. (2-tailed)	0.08	0.15	0.05	0.28	0.14	0.00	0.94	0.01	0.49	0.24	0.31	0.01	0.07
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Obstructions in Reach	Pearson Correlation	0.28	0.32	0.40	0.33	-0.33	**0.76**	0.34	**0.90**	0.16	-0.46	-0.13	**0.97**	**-0.81**
	Sig. (2-tailed)	0.38	0.31	0.20	0.29	0.30	0.05	0.50	0.01	0.76	0.30	0.81	0.00	0.05
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
System Obstructions	Pearson Correlation	**0.73**	0.32	0.38	**0.57**	-0.29	**0.96**	0.26	**0.87**	-0.26	-0.66	-0.35	-0.62	0.37
	Sig. (2-tailed)	0.01	0.31	0.23	0.05	0.37	0.00	0.62	0.01	0.62	0.11	0.50	0.19	0.47
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Refuge Observed	Pearson Correlation	0.37	0.34	**0.54**	0.29	-0.43	**0.70**	-0.45	0.44	-0.62	0.09	-0.51	0.69	-0.51
	Sig. (2-tailed)	0.23	0.28	0.07	0.36	0.16	0.08	0.38	0.32	0.19	0.84	0.31	0.13	0.30
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
River Banks - Mean	Pearson Correlation	0.02	0.45	**0.53**	**0.70**	**-0.60**	**0.75**	0.23	**0.71**	-0.29	**-0.74**	0.26	0.50	-0.69
	Sig. (2-tailed)	0.96	0.14	0.08	0.01	0.04	0.05	0.66	0.07	0.58	0.06	0.63	0.31	0.13
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Bank Erosion Percentage	Pearson Correlation	0.06	0.42	**0.73**	0.40	**-0.68**	0.62	0.03	**0.73**	-0.25	-0.42	0.35	0.40	-0.56
	Sig. (2-tailed)	0.86	0.18	0.01	0.20	0.02	0.14	0.95	0.06	0.63	0.35	0.50	0.43	0.25
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Bank Vegetation Percentage / Type	Pearson Correlation	0.24	**0.68**	**0.78**	**0.66**	**-0.82**	0.45	0.24	0.33	-0.21	-0.60	0.46	0.00	-0.22
	Sig. (2-tailed)	0.44	0.02	0.00	0.02	0.00	0.31	0.65	0.47	0.69	0.15	0.36	1.00	0.68
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Bank Canopy Percentage	Pearson Correlation	-0.30	0.15	0.33	0.16	-0.38	**0.77**	0.15	**0.70**	-0.43	**-0.80**	0.14	-0.15	-0.14
	Sig. (2-tailed)	0.35	0.64	0.30	0.62	0.23	0.04	0.77	0.08	0.39	0.03	0.80	0.78	0.79
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Undercut Banks / Mile	Pearson Correlation	-0.22	0.02	0.11	0.30	-0.09	0.10	0.54	-0.08	0.46	0.48	-0.60	**0.92**	**-0.85**
	Sig. (2-tailed)	0.49	0.96	0.73	0.34	0.78	0.85	0.34	0.88	0.43	0.34	0.28	0.01	0.03
	N	12.00	12.00	12.00	12.00	12.00	6.00	5.00	6.00	5.00	6.00	5.00	6.00	6.00

Statistical significance of Pearson Correlation: **p<0.1**; **p<0.05**
a=Cannot be computed because variable is constant.

		Pilot Study Data					BASS Mean Data						FEA Mean data	
		Fish IBI	Salmonid Density	BMI Com. Score	Ept Richness	BI	Mean Com Scr	SDEV Com Scr	Mean EPT	SDEV EPT	Mean BI	SDEVE BI	Ept Richness	Mean BI
Undercut Bank Size Rank	Pearson Correlation	0.05	0.27	-0.07	0.01	-0.06	0.65	-0.24	0.41	-0.85	-0.49	0.39	**0.99**	-0.96
	Sig. (2-tailed)	0.91	0.48	0.86	0.98	0.88	0.35	0.76	0.59	0.15	0.51	0.61	0.08	0.17
	N	9.00	9.00	9.00	9.00	9.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00
Undercut Bank Stability / Adjacency	Pearson Correlation	0.35	0.26	0.04	0.22	-0.12	0.67	0.27	0.66	0.10	-0.36	**-0.85**	**0.77**	**-0.82**
	Sig. (2-tailed)	0.27	0.41	0.91	0.50	0.71	0.15	0.60	0.15	0.86	0.49	0.03	0.07	0.04
	N	12.00	12.00	12.00	12.00	12.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Mass Failures in Valley	Pearson Correlation	-0.08	**-0.62**	-0.39	-0.19	**0.51**	0.61	0.51	**0.73**	0.50	-0.32	-0.55	-0.27	-0.18
	Sig. (2-tailed)	0.80	0.03	0.21	0.56	0.09	0.15	0.30	0.07	0.31	0.48	0.26	0.61	0.74
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Riparian Area - Mean	Pearson Correlation	0.08	**0.70**	**0.86**	0.39	**-0.88**	0.63	0.31	0.63	-0.06	-0.56	0.39	-0.08	-0.06
	Sig. (2-tailed)	0.81	0.01	0.00	0.21	0.00	0.13	0.55	0.13	0.92	0.19	0.44	0.87	0.91
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Buffer Width	Pearson Correlation	0.01	**0.53**	**0.70**	**0.50**	**-0.73**	0.65	0.19	0.65	-0.23	-0.60	0.43	-0.23	0.00
	Sig. (2-tailed)	0.97	0.07	0.01	0.10	0.01	0.11	0.71	0.11	0.66	0.15	0.39	0.66	1.00
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Riparian Vegetation Percentage / Type	Pearson Correlation	0.10	**0.77**	**0.73**	0.28	**-0.83**	**0.68**	0.28	**0.67**	-0.14	-0.64	0.35	-0.23	0.00
	Sig. (2-tailed)	0.76	0.00	0.01	0.38	0.00	0.09	0.59	0.10	0.78	0.12	0.50	0.66	1.00
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
River Corridor Development	Pearson Correlation	-0.08	0.37	**0.61**	0.35	**-0.58**	0.37	0.11	0.47	-0.11	-0.48	0.63	-0.34	0.32
	Sig. (2-tailed)	0.81	0.23	0.03	0.27	0.05	0.42	0.83	0.29	0.84	0.27	0.18	0.51	0.54
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Score	Pearson Correlation	0.15	0.43	**0.73**	0.28	**-0.65**	**0.82**	0.24	**0.79**	-0.31	**-0.75**	0.16	**0.74**	**-0.80**
	Sig. (2-tailed)	0.65	0.16	0.01	0.37	0.02	0.02	0.65	0.03	0.55	0.05	0.76	0.09	0.06
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Percentage	Pearson Correlation	0.15	0.43	**0.73**	0.28	**-0.65**	**0.82**	0.24	**0.79**	-0.31	**-0.75**	0.16	**0.74**	**-0.80**
	Sig. (2-tailed)	0.65	0.16	0.01	0.37	0.02	0.02	0.65	0.03	0.55	0.05	0.76	0.09	0.06
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
Elevation	Pearson Correlation	-0.06	**0.71**	**0.71**	0.45	**-0.78**	0.10	0.66	0.26	0.51	-0.35	-0.31	.(a)	.(a)
	Sig. (2-tailed)	0.86	0.01	0.01	0.14	0.00	0.84	0.15	0.57	0.30	0.44	0.55	.	.
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	0.00	0.00
Drainage Area	Pearson Correlation	0.47	-0.21	-0.25	-0.02	0.28	0.12	-0.18	-0.13	-0.17	0.22	0.10	.(a)	.(a)
	Sig. (2-tailed)	0.12	0.51	0.44	0.95	0.38	0.80	0.74	0.78	0.75	0.63	0.85	.	.
	N	12.00	12.00	12.00	12.00	12.00	7.00	6.00	7.00	6.00	7.00	6.00	0.00	0.00
Color pc units	Pearson Correlation	**-0.67**	-0.27	-0.58	-0.41	0.49	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.10	0.56	0.17	0.36	0.27	.	.	.	.	.	.	.	.
	N	7.00	7.00	7.00	7.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Time	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WaterTemp c	Pearson Correlation	**-0.58**	-0.46	**-0.67**	-0.29	**0.61**	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.10	0.21	0.05	0.46	0.08	.	.	.	.	.	.	.	.
	N	9.00	9.00	9.00	9.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO mg/l	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.
	N	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Statistical significance of Pearson Correlation: **p<0.1**; **p<0.05**
a=Cannot be computed because variable is constant.

		Pilot Study Data					BASS Mean Data						FEA Mean data	
		Fish IBI	Salmonid Density	BMI Com. Score	Ept Richness	BI	Mean Com Scr	SDEV Com Scr	Mean EPT	SDEV EPT	Mean BI	SDEVE BI	Ept Richness	Mean BI
Alk mg/l	Pearson Correlation	-0.11	-0.18	-0.23	-0.74	0.29	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.76	0.62	0.52	0.01	0.42	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FieldCond	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.
	N	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LabCond	Pearson Correlation	0.03	-0.11	-0.17	-0.66	0.24	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.93	0.76	0.64	0.04	0.51	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TCl mg/l	Pearson Correlation	0.88	0.42	0.42	0.48	-0.31	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.00	0.22	0.23	0.16	0.38	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dna mg/l	Pearson Correlation	0.90	0.39	0.45	0.54	-0.33	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.00	0.27	0.19	0.10	0.35	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DK mg/l	Pearson Correlation	-0.56	-0.32	-0.65	-0.40	0.54	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.09	0.37	0.04	0.25	0.11	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TSO4 mg/l	Pearson Correlation	-0.82	-0.59	-0.76	-0.29	0.63	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.00	0.07	0.01	0.42	0.05	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dca mg/l	Pearson Correlation	-0.43	-0.38	-0.48	-0.85	0.48	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.21	0.27	0.16	0.00	0.16	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DMg mg/l	Pearson Correlation	0.25	0.16	0.11	-0.52	-0.04	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.48	0.65	0.77	0.13	0.91	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
THC	Pearson Correlation	-0.13	-0.15	-0.23	-0.76	0.27	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.71	0.68	0.52	0.01	0.45	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turb NTU	Pearson Correlation	-0.50	-0.32	-0.63	-0.32	0.54	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.18	0.40	0.07	0.40	0.13	.	.	.	.	.	.	.	.
	N	9.00	9.00	9.00	9.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TP ug/l	Pearson Correlation	-0.56	-0.34	-0.65	-0.40	0.55	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.09	0.34	0.04	0.25	0.10	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDP ug/l	Pearson Correlation	-0.67	-0.38	-0.67	-0.44	0.56	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.03	0.28	0.03	0.20	0.09	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TN mg/l	Pearson Correlation	-0.93	-0.29	-0.56	-0.67	0.38	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	0.00	0.41	0.09	0.03	0.27	.	.	.	.	.	.	.	.
	N	10.00	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00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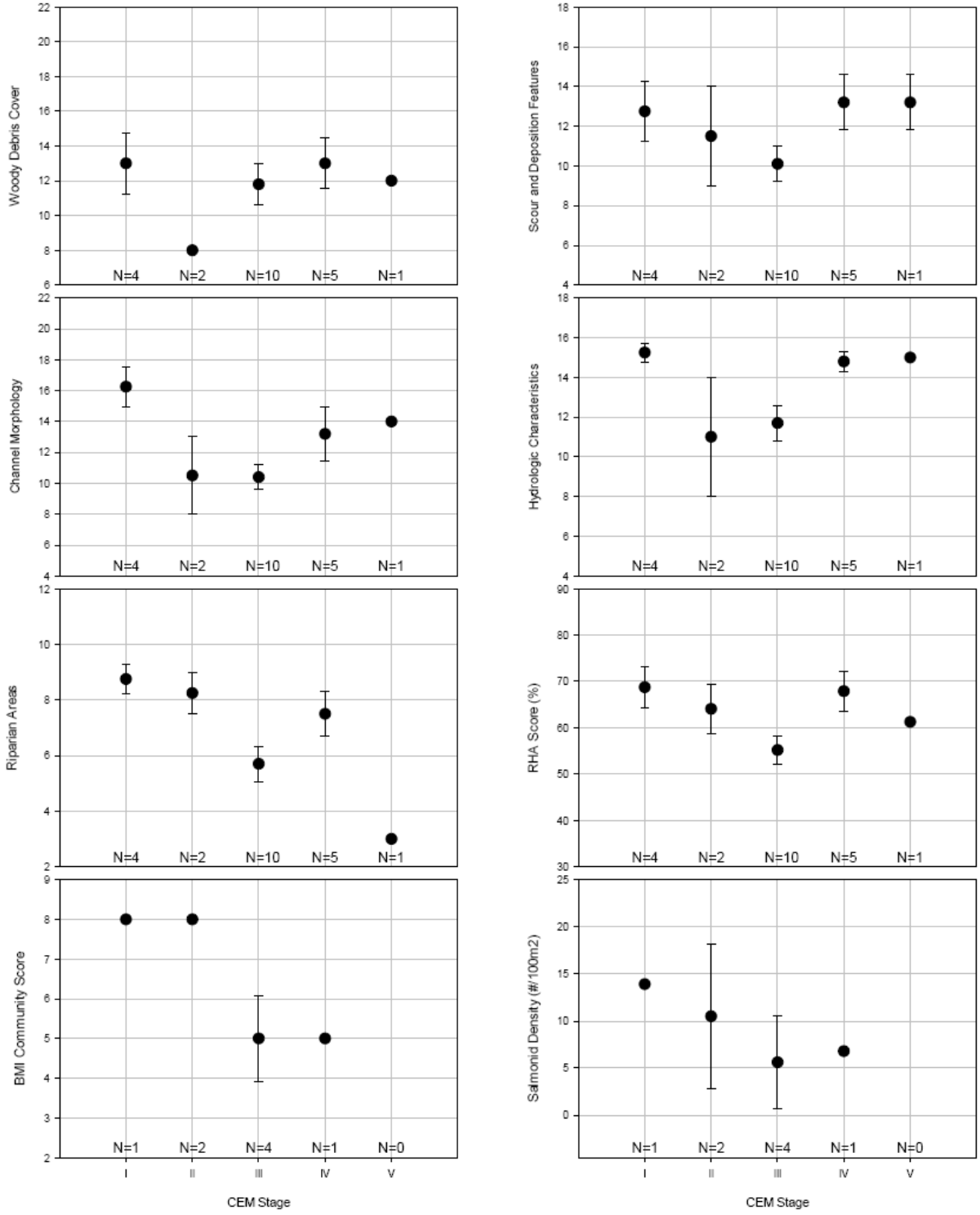
CEM Model F Stage versus RHA Parameters, Overall RHA Score, and Biological Metrics



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