TRANSCANADA HYDRO NORTHEAST INC.

ILP Study 24

DWARF WEDGEMUSSEL AND CO-OCCURRING MUSSEL STUDY

Development of Delphi Habitat Suitability Criteria

In support of Federal Energy Regulatory Commission Relicensing of:

Wilder Hydroelectric Project (FERC Project No. 1892-026)
Bellows Falls Hydroelectric Project (FERC Project No. 1855-045)
Vernon Hydroelectric Project (FERC Project No. 1904-073)

Prepared for

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May 16, 2016

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1-D	One-Dimensional Hydraulic Model (e.g., PHABSIM)
2-D	Two-Dimensional Hydraulic Model (e.g., River2D)
DWM	Dwarf Wedgemussel
FERC	Federal Energy Regulatory Commission
FWS	U.S. Department of the Interior-Fish and Wildlife Service
ILP	Integrated Licensing Process
ISR	Initial Study Report
RSP	Revised Study Plan
TransCanada	TransCanada Hydro Northeast Inc.
TNC	The Nature Conservancy

1.0 INTRODUCTION

This report presents the results of part of the Dwarf Wedgemussel and Co-occurring Mussel Survey (ILP Study 24) conducted in support of Federal Energy Regulatory Commission (FERC) relicensing of the TransCanada Hydro Northeast Inc. (TransCanada) Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855), and Vernon Hydroelectric Project (FERC No. 1904). TransCanada has initiated the Integrated Licensing Process (ILP) for these projects in order to renew their operating licenses beyond the current expiration date of April 30, 2019 for each project. Dwarf Wedgemussel (DWM) is a federally endangered species that currently inhabits select reaches of the Connecticut River within the project-affected areas of the Wilder and Bellows Falls projects.

Phase 1 fieldwork for Study 24 was completed in September 2013, in accordance with the study's Revised Study Plan (RSP) and the Phase 1 Study Report was prepared. The public version of the report was shared with the aquatics working group (Volume IV of the Initial Study Report [ISR] filed September 15, 2014). The privileged version of the report containing specific DWM locations was filed as Volume V of the ISR and provided to specific agency staff in August 2014, as requested.

A Phase 2 Study Plan was developed, distributed, and discussed with the working group at a May 23, 2014, consultation meeting and following comments received via email from The Nature Conservancy (TNC) in June 2014, a working group conference call was held on July 1, 2014. The proposed Phase 2 Study Plan was subsequently revised in response to those comments (revised plan filed as Volume VI of the ISR); however, it was not distributed prior to the 2014 field study because there was an indication that further comments were being prepared by US Fish and Wildlife Service (FWS), and the study plan might need to be revised again. Based upon all initial comments received previously, it was anticipated that further comments would be slight modifications on the previous discussions and draft study plan. Because the study field work time table was at risk, TransCanada initiated field work based upon its undistributed Revised Phase 2 Study Plan (filed as Volume VI of the ISR), presuming that any issues remaining could be addressed rather easily, and while field work was in progress. However, FWS provided substantial new comments in the form of a "counter proposal" on September 4, 2014.

Fieldwork for Phase 2 relied on the Revised Phase 2 Study Plan and consisted of establishing twenty 50x1 m monitoring transects distributed among six general locations in the Wilder impoundment, riverine reach, and upper Bellows Falls impoundment. Most were surveyed in the period from August 20-29, 2014 and one pair (Cornish Covered Bridge – North) was surveyed on October 1. Data collection followed the methods outlined in the Revised Phase 2 Study Plan. The 2014 fieldwork also included quadrat surveys in the 2,400-meter reach that included Cornish Covered Bridge and Chase Island, as described in the Revised Phase 2 Study Plan. This work was completed under low-flow conditions and warm temperatures in September. A total of 405 2.25-m^2 quadrats were sampled in this reach; 385 were distributed in a systematic random pattern across the channel (bank to bank) and 20 additional quadrats were distributed in areas where mussel densities were higher. Counts for all mussel species, and several habitat parameters, were recorded for each quadrat as described in the Revised Phase 2 Study Plan.

A consultation meeting was held on October 9, 2014 to discuss the FWS counter proposal. FWS subsequently provided a revised counter proposal along with that agency's comments on the Initial Study Report (ISR). TNC also provided comments on the ISR. TransCanada provided a response to ISR comments filed with FERC on December 15, 2014 which included responses to the numerous comments on Study 24, and reported that the revised FWS counter proposal was under internal review, and that additional stakeholder consultation would occur once that review was completed. The Phase 2 Study Progress Report (public version and privileged version with supporting privileged geodata) was filed on March 2, 2015 in accordance with FERC's September 2013 SPD. The FWS revised counter proposal was included as Appendix A, and TransCanada's proposed habitat suitability methodology was included as Appendix B of that report.

On January 22, 2015, FERC issued a Determination on Requests for Study Modifications and New Studies in which the requested study modifications in the FWS' revised counter proposal were not adopted at that time. FERC acknowledged that consultation on this study remained ongoing, and that specific methodologies for development of habitat suitability criteria for DWM and/or other study methodologies would be the subject of this consultation. FERC also noted on page 3 of its determination, "[i]f agreement cannot be reached on the phase 2 study methods, we recommend that TransCanada seek a determination from the Commission and file the comments received, a response to comments, and any updates to the phase 2 study plan at least 30 days prior to commencing any additional field work."

A consultation conference call was held on March 5, 2015 to review TransCanada's proposed habitat suitability methodology which had been provided to the working group in advance (and filed on March 2, 2015 as part of the study report). On the conference call, the working group agreed on an approach to developing habitat suitability criteria (HSC) for DWM and co-occurring mussel species. HSC would be hybrids of Category I (qualitative) and Category II (quantitative, using empirical data), depending on the amount of data available for each parameter. Criteria would be developed by reviewing and synthesizing existing data, and by soliciting input from regional experts using a Delphi approach.

2.0 STUDY GOALS AND OBJECTIVES

As stated in the RSP, one of the goals of Study 24 was to assess the influence of flow regime (which includes water-level fluctuations) on DWM, co-occurring mussel species, and mussel habitat. This report specifically addresses the development of HSC, which is one component of Objective 5 (Phase 2): Assess the potential effects of flow regime on DWM and their habitat. HSC represent a critical and influential factor in 1-D and 2-D modeling of the flow:habitat relationship for any given species.

3.0 METHODOLOGY

3.1 Approach to Development of HSC

Assessing flow effects on DWM habitat will be conducted using several tools, including 1-Dimensional (1-D) and 2-Dimensional (2-D) hydraulic modeling as part of the Instream Flow Study (ILP Study 9). Both 1-D and 2-D modeling requires descriptions of the microhabitat selectivity of target species, including DWM. The indices describing habitat selectivity are termed Habitat Suitability Criteria (HSC), which are microhabitat variables believed to influence the position choice and health of the target organism. Most HSC variables used in instream flow studies are those that directly interact with streamflow, such as water depth and velocity (and derivatives thereof), but may also include variables such as substrate composition or instream cover.

HSC are defined as "graphical or statistical models that depict the relative utility of increments or classes of macro- or microhabitat variables (e.g., depth, velocity, cover type) to a life stage of a target species" (Bovee et al., 1998). The relative utility of the variables ranges from zero (unsuitable) to 1.0 (fully suitable) for any increment or class of the variable. HSC are used within the hydraulic habitat modeling component of computer software (e.g., PHABSIM, River2D) associated with the Instream Flow Incremental Methodology (IFIM) to evaluate potential habitat impacts of flow alterations or flow regime alternatives. The shape of an HSC for any specific variable can either be binary (suitable/unsuitable) or univariate. Univariate HSC can be continuous functions (unsuitable transitioning to suitable), step-functions (histograms or non-parametric tolerance limits), smooth functions defined by equations, or smooth functions created or adjusted by professional judgment. HSC can also be multivariate and incorporate interactions between variables such as velocity and depth, where any given velocity is suitable at a particular range of depth. HSC can even be conditional, where a velocity or depth for a sample point is suitable only if suitable cover occurs within a specified distance from the sample point. Binary HSC are the easiest to create, but are inconsistent with normal biological responses, while many higher-level HSC require observational data.

HSC can be developed in several ways, ranging from intensive field measurements of habitat use and habitat availability, to professional judgment. In accordance with FERC's SPD, the Delphi process was used.

3.2 Delphi Process Overview

The Delphi process of HSC development is a formal judgment-based process. The following description is taken[1] from Crance (1987), Guidelines for Using the Delphi Technique to Develop Habitat Suitability Index [HSC] Curves, U.S. Fish and Wildlife Service Biological Report 82(10.134), April 1987:

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[1] Edited for spelling, terminology, and format.

"Delphi was the name of a meeting site in ancient Greece where Oracles (people through whom a deity was believed to speak) met, held discussions, and gave wise or authoritative decisions or opinions. The modern day Delphi was first applied to a strategic planning exercise sponsored by the United States Air Force in about 1953 (Dalkey and Helmer, 1963)[2]. Subsequently, the methodology was widely accepted and applied in corporate planning (Fusfeld and Foster, 1971) and used in the field of renewable resources management (Ludlow 1972a, 1972b; Zuboy, 1981; Heller et al,. 1983). More recently, it has been used to develop expert-opinion-based SI [HSC] curves for some fish species (Crance, 1984, 1986, 1987a, 1987b; Stier and Crance, 1985).

"Pill (1971) gave a comprehensive review of the Delphi technique and provided an annotated bibliography on the subject. Basically, a Delphi exercise is a discussion by knowledgeable participants in hopes of reaching an agreeable conclusion. The concept is based on the premise that: (1) opinions of experts are justified as inputs to decision-making where absolute answers are unknown; and (2) a consensus of experts will provide a more accurate response to a question than a single expert. If these premises are valid or acceptable to those that will receive and act on the product of the exercise, the conclusions reached (or SI curves developed using the technique) should have utility.

"At least three separate groups of individuals that perform three different roles are needed to conduct a Delphi exercise (Turoff, 1970): (1) the decision makers – the group that will receive and act on the product of the exercise; (2) a group (or person) that designs the initial questionnaire, summarizes the returns, and redesigns the follow-up questionnaire; and (3) a respondent group whose judgments are being sought and are asked to respond to the questionnaires.

"The general procedures for a Delphi exercise are as follows: (1) the experts are polled on a question or series of questions; (2) the responses are tabulated, analyzed, and fed back to the experts; and (3) the experts re-answer the questions in light of the information generated by the aggregate response. This process is repeated until a consensus is reached.

"The primary characteristic of Delphi is anonymity. Correspondence is the communication mode normally used. An exercise to develop Delphi-based SI [HSC] curves for a species would likely operate as follows: (1) a group of experts is identified; (2) the objectives and procedures of the Delphi exercise are explained to each expert; (3) the experts agree to participate as panelists; (4) each panelist gives his opinion or estimate on the inquiry; (5) the results, including rationale given by each panelist, are summarized and fed back to each panelist,

[2] Citations in original document.

> ending the first iteration or round; (6) panelists answer the inquiry again, in light of the information generated by the collective response to round 1; (7) this process is repeated until a consensus or acceptable level of agreement is reached; (8) the exercise is terminated (usually after four rounds) and the procedures and results are documented, including all rationale for agreement or disagreement."

The Delphi process for developing HSC can vary according to several factors, including the number of participants, the number of available datasets from which to evaluate, the project schedule, etc. Below is a description of the process used to develop Delphi HSC for DWM for this study.

3.3 Selection of Delphi Participants

As described above, a Delphi HSC process typically consists of a panel moderator and a group of panelists who are expert in the species of interest. For this study, Tom Payne and Mark Allen of Normandeau served as the moderator, and Ethan Nedeau of Biodrawversity (as study lead for Study 24) developed a list of DWM experts to serve as potential panelists for the Delphi exercise. Potential panelists were contacted to see if they were willing and able to serve on the Delphi panel. Four experts were initially willing to serve on the panel:

- David Strayer, Ph.D: Aquatic scientist at the Institute of Ecosystem Studies (NY) who has more than 30 years of experience studying the ecology and habitat of native freshwater mussels, including seminal works on Alasmidonta heterodon.
- Dr. Barry Wicklow, Ph.D: Professor and aquatic scientist at St. Anselm College (NH), who has conducted research on the biology and host-fish relationships of Alasmidonta heterodon and other riverine mussel species in New England.
- William Lellis: Deputy Associate Director, Ecosystems Mission Area, USGS and former head of the N. Appalachian Research Lab who led all the mussel research for many years. Declined the offer to be a panelist, and recommended Heather Galbraith.
- Heather Galbraith, Ph.D: Aquatic scientist at the USGS Northern Appalachian Research Laboratory (PA) who is leading several studies on the biology and ecology of Alasmidonta heterodon in the Delaware River and other rivers in the species' range.
- Ethan Nedeau, M.S: Aquatic scientist and owner of Biodrawversity, who has been conducting inventory and research on Alasmidonta heterodon throughout the Northeast, especially the Connecticut River watershed, for 17 years.

However Ms. Gailbraith was ultimately unable to participate, resulting in three expert panelists. The identity of each panelist and their recommendations remained anonymous throughout the Delphi process, although panelist identities were known to the moderator. Mr. Nedeau, who had developed the initial list of candidate experts knew the identities of panelists but after initial contact to solicit participation, had no further contact with other panelists.

3.4 Selection of Candidate Variables and HSC Curves

After selection of the expert panel, the moderator developed a candidate list of proposed HSC variables and associated HSC curves, based on review of literature describing DWM ecology provided by Mr. Nedeau who had no other communication with the moderator. The initial variable list included:

1. Water depth,
2. Mean column water velocity,
3. Benthic water velocity, and
4. Substrate composition

Three additional variables were added following panelist review of the initial variable list. These were:

5. Bed shear stress,
6. Relative (dimensionless) shear stress, and
7. Shear velocity

3.5 Preparation and Distribution of Proposed HSC Curves

The moderator prepared and distributed a document listing each of the selected habitat variables along with proposed HSC curves for each variable. Each "transmittal document" included a description of the Delphi HSC development process, figures and associated data tables displaying HSC curves for each variable, and a set of instructions for panelist review of each HSC curve. The panelists were asked to review each HSC curve and asked to either indicate an acceptance of the proposed curve, or else suggest modifications to the curve with associated rationale. Panelists were also asked to comment on whether a particular variable was unnecessary (e.g., redundant or else not thought to influence position choice or organism health), or if additional variables should be added. Each transmittal document included a requested due date for panelist responses.

3.6 Panelist Responses and HSC Revisions

After receiving responses from the three panelists to a transmittal document, the moderator reviewed panelist comments and prepared the next transmittal. HSC curves were modified by the moderator according to the panelist comments, unless each panelist indicated agreement with the HSC curve in question. For each modified HSC curve, the pertinent panelist comments were summarized and/or quoted (anonymously) to justify the curve revisions. The moderator also summarized any other panelist comments pertaining to HSC curve points, variable importance, or modeling procedures. Inclusion of the panelist comments was intended to help panelists understand the reasoning behind curve modifications and to help bring the process towards convergence. These comments and HSC revisions were incorporated into the new transmittal document and redistributed to the three panelists for their input on the revised HSC curves.

Each combination of paired transmittal document and panelist response documents represented a Delphi "round". For example, the "1st round" consisted of the initial transmittal document and the subsequent panelist responses. The "2nd round" consisted of a revised transmittal document (with modified HSC curves) and the subsequent panelist responses. This process was repeated until each panelist indicated that all HSC curve revisions were "acceptable" to them. "Acceptable" does not indicate complete agreement, but that the panelist felt the HSC curve was adequate for use in modeling DWM habitat in the study area. These HSC curves were treated as final HSC and the Delphi process was terminated.

Transmittal documents and anonymous panelist responses are included in Appendix A for the 1st round, Appendix B for the 2nd round, and Appendix C for the 3rd round of the Delphi process.

4.0 RESULTS

The HSC Delphi process was conducted over three rounds, resulting in unanimous agreement on four variables, and majority agreement on the three remaining variables (one panelist did not comment on these variables). This concluded the Delphi process. Each of the proposed HSC curves and pertinent Delphi results are presented below.

4.1 Depth

Figure 4.1 shows the initial proposed HSC curve for total water depth (left column), and the final depth curve (right column) which was accepted by all panelists on the 2nd round. The depth curve sets maximum suitability at 2.0 with no upper limit (Table 4.1).

4.2 Mean Column Velocity

The mean column velocity curve (Figure 4.1, Table 4.1) was agreed upon by all panelists on the 3rd round, although one panelist thought suitability likely declined to zero at somewhat lower velocities than indicated by the curve (but the panelist was willing to accept the curve). This 3rd round curve gave maximum suitability for mean column velocities from 0.5-2.0 ft/s, with a tail declining to zero suitability at 6.0 ft/s.

4.3 Benthic Velocity

The benthic velocity curve was accepted by all panelists on the 3rd round, although one panelist thought the maximum velocity was somewhat high, but within acceptable limits. This benthic velocity curve gave maximum suitability for velocities from 0.1-1.0 ft/s, with declining suitability to 3.0 ft/s (Figure 4.1, Table 4.1).

4.4 Substrate Particle Size

The suitability of substrate particles was agreed upon by all panelists on the 2nd round, giving maximum suitability for substrates dominated by sand and fine gravel, zero suitability for boulder and bedrock, and intermediate suitability for the remaining types (Figure 4.1, Table 4.1). Substrate size definitions are given below:

Code	Description
1	Submerged Aquatic Vegetation (25 mm)
2	Clay/Silt (0.01 mm)
3	Sand (1 mm)
4	Fine Gravel (5 mm)
5	Gravel (36 mm)
6	Cobble (160 mm)
7	Boulder (256 mm)
8	Bedrock (1000 mm)

4.5 Bed Shear Stress

The three shear-related variables (bed shear stress, relative shear stress, and shear velocity) were all added in the 2nd round following recommendations by each of the three panelists, although one of the panelists did not comment on the actual HSC curves. The HSC curve for bed shear stress was acceptable to the two remaining panelists on the 3rd round, and showed maximum suitability for shear stresses from 0.0 to 0.5 lbs/ft^2, and declining suitability to zero at 1.0 lbs/ft^2. HSC curves and curve points are shown in Figure 4.1 and listed in Table 4.1.

4.6 Relative (Dimensionless) Shear Stress

This variable was agreed upon by the two commenting panelists on the 3rd round. Maximum suitability for relative shear stress (RSS) was 0.0 to 1.5, declining to zero suitability at 2.5 (Figure 4.1, Table 4.1).

4.7 Shear Velocity

The shear velocity HSC curve was acceptable to the two commenting panelists on the 3rd round, although both panelists believed that shear velocity was likely redundant with the two shear stress variables described above, and ultimately might not be useful in the flow modeling process. The final HSC curve for shear velocity showed maximum suitability from 0.0 to 0.1 ft/s, declining to zero suitability at 0.72 ft/s (Figure 4.1, Table 4.1).

4.8 Other Topics

Some confusion over the application of the HSC curves in the modeling process led to clarification of how the hydraulic habitat modeling might be accomplished to account for the essentially sessile mussels. Specifically, it is expected that a process similar to “effective habitat analysis” will be employed when modeling habitat over a range of peaking flows (Bovee et al., 1998). This method fixes a specific location's combined suitability (based on all modeled HSC variables) to the minimum value over the range of modeled flows. For example, if a specific location yields a combined suitability of zero because it becomes dewatered at low flow, or because the velocities become excessive at high flow, that location will remain at zero suitability, even if conditions are suitable at other flows. This process accounts for the inability of the mussels to rapidly respond to changes in flow by altering their location on the stream bed, unlike fish which can move with changes in flow to avoid stranding or locate to more suitable rearing areas.

Additional discussion among the panelists also dealt with the treatment of juvenile mussels. Panelists agreed that the velocity HSC curves may be too high to allow settlement of juvenile mussels after leaving their host fish, but conceded that available information on juvenile settling velocities was too limited to recommend development of separate HSC curves for this life stage.

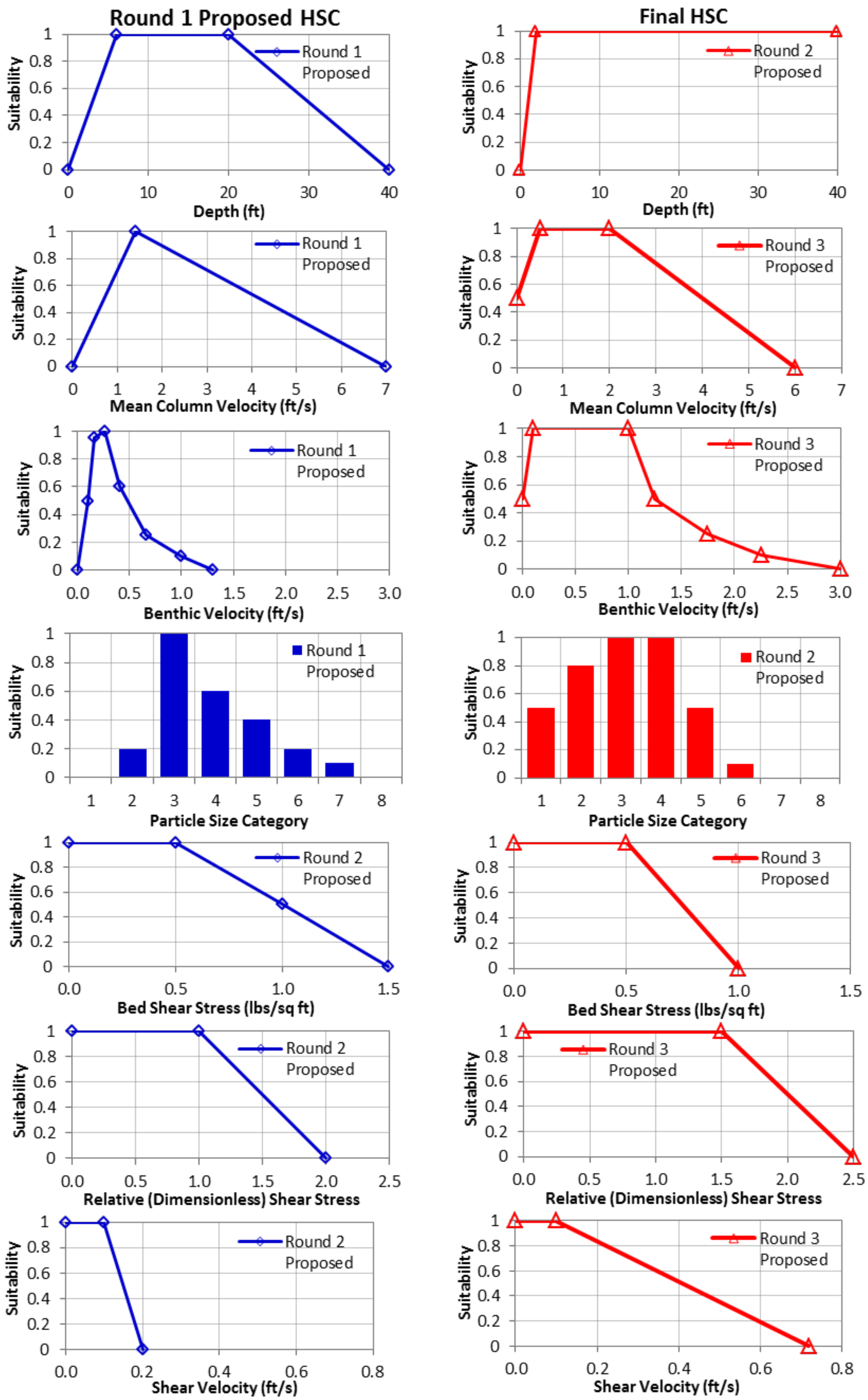

Figure 4.1. Initial proposed HSC (left column) and final Delphi HSC (right column) for DWM.

Table 4.1. Final Delphi HSC curve points for DWM.

Variable	Value	Suitability
Depth (ft)	0	0.00
	2	1.00
	40	1.00
Mean Column Velocity (ft/s)	0	0.50
	0.5	1.00
	2	1.00
	6	0.00
Benthic Velocity (ft/s)	0	0.50
	0.1	1.00
	1	1.00
	1.25	0.50
	1.75	0.25
	2.25	0.10
	3	0.00
Substrate Particle Size[a]	1	0.50
	2	0.80
	3	1.00
	4	1.00
	5	0.50
	6	0.10
	7	0.00
	8	0.00
Bed Shear Stress (lbs/ft^2)	0.0	1.00
	0.5	1.00
	1.0	0.00
Relative Shear Stress	0.0	1.00
	1.5	1.00
	2.5	0.00
Shear Velocity (ft/s)	0.0	1.00
	0.1	1.00
	0.72	0.00

a. See substrate code in text.

4.9 Next Steps

This report concludes the Delphi process, which followed an established procedure for soliciting expert opinion on habitat suitability in the absence of more complete empirical data. The resultant draft HSC curves reflect the expert opinion of three panelists. As outlined in the FERC-approved Study Plan for Study 24, the development and use of HSC would integrate:

- the qualitative and quantitative mussel and habitat data collected in the study area from 2011 to 2014;
- review of relevant publications and case studies;
- supporting data from TransCanada's other relicensing studies;
- and expert opinion (i.e., the Delphi panel).

The draft HSC developed via the Delphi process will now be evaluated, tested, and possibly modified based on the other information sources above, and on results of preliminary modeling and analyses using the draft HSC. Any modifications to the draft HSC will be thoroughly justified in subsequent reports.

Concurrently, TransCanada will develop HSC curves for co-occurring mussel species that may be based on DWM HSC but will account for preferences of other species. Once completed, the HSC curves for DWM and co-occurring mussels will be used in the 1-D and 2-D habitat modeling process (Study 9) to assess the potential effects of flow level and flow fluctuations on these mussel species in the study area.

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APPENDIX A

1st Round Transmittal Letter and Panelist Responses

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From:	Thomas Payne
Subject:	First Round Delphi Exercise for Dwarf Wedgemussel
Date:	Thursday, November 19, 2015 4:07:05 PM
Attachments:	DWM Delphi First Round.docx

Dear Delphi Panel Member,

Thank you for agreeing to serve as a panelist for the dwarf wedgemussel (DWM, *Alasmidonta herterodon*) Delphi exercise. The purpose of the exercise is to develop Habitat Suitability Criteria (HSC) curves for use with instream flow aquatic habitat relicensing studies for the Wilder, Bellows Falls and Vernon hydroelectric projects located on the Connecticut River in New Hampshire and Vermont. The Delphi technique is being used because field data and information available in the literature are inadequate for developing HSC curves for the species, and the Federal Energy Regulatory Commission (FERC) has determined that the Delphi panel approach is consistent with accepted scientific practice. Any available information on DWM should be used in the process, but opinions of the Delphi panelists will be the primary basis for the resultant HSC.

General information about the Delphi technique, HSC curve development, and instructions and materials for completing the first round of the exercise are enclosed. A few hours of your time will be required to complete the series of rounds required to perform the exercise. You, no doubt, have many demands on your time but please respond to each round promptly. We should complete the exercise in about 2 to 3 months, assuming that three or four rounds will be required and that all panelists respond to each round within 10 days (or the specified period of time, considering the holidays) after receipt of material. You may wish to get an associate to serve as panelist in your behalf if you are unable to respond within the number of days allotted to each round.

I will serve as the moderator for the exercise. This means that I will prepare the material for each round, receive and summarize responses for subsequent rounds, and complete a final report, including rationale for the curves developed. To maintain the integrity of the Delphi technique, I request that you maintain anonymity within the panel and do not communicate with others regarding the topic until the exercise is completed.

Thank you again for consenting to be a panelist, and let me know if you have any questions. I look forward to receipt of your input, which should be in about 10 days (accounting for Thanksgiving), or December 2, 2015.

Sincerely,

Tom Payne

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Round 1 - The Delphi Technique

The following description is taken[1] from Crance (1987), Guidelines for Using the Delphi Technique to Develop Habitat Suitability Index [HSC] Curves, U.S. Fish and Wildlife Service Biological Report 82(10.134), April 1987.

“Delphi was the name of a meeting site in ancient Greece where Oracles (people through whom a deity was believed to speak) met, held discussions, and gave wise or authoritative decisions or opinions. The modern day Delphi was first applied to a strategic planning exercise sponsored by the United States Air Force in about 1953 (Dalkey and Helmer 1963)[2]. Subsequently, the methodology was widely accepted and applied in corporate planning (Fusfeld and Foster 1971) and used in the field of renewable resources management (Ludlow 1972a, 1972b; Zuboy 1981; Heller et al. 1983). More recently, it has been used to develop expert-opinion-based SI [HSC] curves for some fish species (Crance 1984, 1986, 1987a, 1987b; Stier and Crance 1985).

“Pill (1971) gave a comprehensive review of the Delphi technique and provided an annotated bibliography on the subject. Basically, a Delphi exercise is a discussion by knowledgeable participants in hopes of reaching an agreeable conclusion. The concept is based on the premise that: (1) opinions of experts are justified as inputs to decision-making where absolute answers are unknown; and (2) a consensus of experts will provide a more accurate response to a question than a single expert. If these premises are valid or acceptable to those that will receive and act on the product of the exercise, the conclusions reached (or SI curves developed using the technique) should have utility.

“At least three separate groups of individuals that perform three different roles are needed to conduct a Delphi exercise (Turoff 1970): (1) the decision makers – the group that will receive and act on the product of the exercise; (2) a group (or person) that designs the initial questionnaire, summarizes the returns, and redesigns the follow-up questionnaire; and (3) a respondent group whose judgments are being sought and are asked to respond to the questionnaires.

“The general procedures for a Delphi exercise are as follows: (1) the experts are polled on a question or series of questions; (2) the responses are tabulated, analyzed, and fed back to the experts; and (3) the experts re-answer the questions in light of the information generated by the aggregate response. This process is repeated until a consensus is reached.

“The primary characteristic of Delphi is anonymity. Correspondence is the communication mode normally used. An exercise to develop Delphi-based SI [HSC] curves for a species would likely operate as follows: (1) a group of experts is identified; (2) the objectives and procedures of the Delphi exercise are explained to each expert; (3) the experts agree to participate as panelists; (4) each panelist gives his opinion or estimate on the inquiry; (5) the results, including rationale given by each panelist, are summarized and fed back to each panelist, ending the first iteration or round; (6) panelists answer the inquiry again, in light of the information generated by the collective response to round 1; (7) this process is repeated until a consensus or acceptable level of agreement is reached; (8) the exercise is terminated (usually after four rounds) and the procedures and results are documented, including all rationale for agreement or disagreement.”

[1] Edited for spelling, terminology, and format.
[2] Citations in original document.

Habitat Suitability Criteria

Habitat Suitability Criteria (HSC) are defined as “graphical or statistical models that depict the relative utility of increments or classes of macro- or microhabitat variables (e.g. depth, velocity, cover type) to a life stage of a target species” (Bovee et al. 1998). The relative utility of the variable ranges between zero (unsuitable) and 1.0 (fully suitable) for any increment or class of the variable. HSC are used within the hydraulic habitat modeling component of computer software (e.g. PHABSIM) associated with the Instream Flow Incremental Methodology (IFIM) to evaluate potential habitat impacts of flow alterations or flow regime alternatives.

An alternative term, Habitat Suitability Index (HSI or SI), is often used synonymously with HSC, a practice that often leads to confusion. Originally, HSI were developed to be used with the Habitat Evaluation Procedures (USFWS 1976, http://www.fws.gov/policy/esm102.pdf), a method for impact assessment and project planning in terrestrial situations where acreage is involved. HSC were developed to be used within the IFIM process “to assess the impacts of altered stream-flow regimes on a stream habitat” (Bovee and Cochnauer 1977). HSI values are mostly “fixed” for any given sample location, while HSC values for sample locations can vary with discharge. The distinction can be complicated by some variables (such as cover types or substrate composition) that do not vary with discharge and can be used in either habitat assessment method. HSI are also typically considered to be mesohabitat, or category characteristics, while HSC are considered microhabitat, or specific animal location characteristics. This Delphi exercise will use the term HSC to be consistent with the identified need to evaluate project effects on mussel habitat due to flow alteration with hydraulic habitat modeling and the IFIM.

The shape of an HSC for any specific variable can either be binary (suitable/unsuitable) or univariate. Univariate HSC can be coarse functions (unsuitable transitioning to suitable), step-functions (histograms or non-parametric tolerance limits), smooth functions defined by equations, or smooth functions created or adjusted by professional judgment. HSC can also be multivariate and incorporate interactions between variables such as velocity and depth, where any given velocity is suitable at a particular range of depth. HSC can even be conditional, where a velocity or depth for a sample point is suitable only if suitable cover occurs within a specified distance from the sample point. Binary HSC are the easiest to create, but are inconsistent with normal biological responses, while many higher-level HSC require observational data. The Delphi technique is most compatible with binary and coarse-function HSC, since they are related to minimal observational data in combination with professional judgment.

Citations

Bovee, K.D., and T. Cochnauer (eds.) 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments; fisheries. Instream Flow Information Paper No. 3, FWS/OBS-77/63, Cooperative Instream Flow Service Group, Ft. Collins, CO. 49 pp.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131 pp.

U.S. Fish and Wildlife Service (USFWS). 1976. Habitat evaluation procedures. Division of Ecological Services. Washington, D.C. vi + 30 pp.

Background for panelists to begin Round 1 of the Delphi exercise to develop HSC curves for Dwarf Wedgemussel.

Some research studies of the factors that most influence mussel community (including DWM) richness and distribution have identified mesohabitat (HSI) features such as percent open canopy, mean channel width, and mean bank width, and macrohabitat features such as elevation, drainage area, and water quality (Baldigo et al. 2003-2004). Others describe bottom material composition, water velocity, and shear stress at bankfull discharge as principal factors affecting mussel species (including DWM) richness (Strayer and Ralley 1993, Baldigo et al. 2008). Allen and Vaughn (2010) and Hardison and Layzer (2001) add more complex hydraulic variables such as relative shear stress ratio at high flow and *Fliesswasserstammtisch* (FST) hemisphere number (Bockelmann-Evans et al. 2008) to this list.

Mussel habitat modeling studies (both research and applied) have used various combinations of HSC to assess mussel habitat and density, including depth, velocity (mean column and benthic, grain size, embeddedness, shear velocity, shear stress, slope, stream power, Froude number, and Reynolds number (Maloney et al. 2012, Parasiewicz et al. 2012, Krstolic 2001, Ostby 2006, TRPA and LBG 2008, Aadllund and Kuitunen 2006, Hart 1995, Steuer et al. 2008, Zigler et al. 2008).

The selection of variables to be defined by the Delphi panel will proceed in two phases, or groups of variables. The first group will be those variables that can be more readily described by personal experience or knowledge obtained through sampling or observation; these are depth, velocity (both mean column and benthic), and substrate composition by percent grain size. The second group will be the more complex hydraulic variables such as shear velocity, shear stress, stream power, Froude number, Reynolds number, and FST hemisphere number, which are mostly not directly observable and must be determined through sampling and computation or modeling. The panel will be polled as to the feasibility of adding variables from the second group into the first group through the Delphi exercise.

Hydraulic habitat modeling is being conducted for the Wilder, Bellows Falls, and Vernon hydroelectric project relicensing under ILP Study 9 Instream Flow Study, in coordination with ILP Study 4 Hydraulic Modeling Study. Study 4 will generate water surface elevation versus discharge relationships from a HEC-RAS model within the entire project area, which Study 9 will use as input to one-dimensional, transect-based PHABSIM-type models and two-dimensional hydrodynamic models at identified study sites. Data that have been collected include bottom profiles, velocity patterns, bed topography, and substrate particle size that are compatible with the first group of variables. Many of the second group can be computed within either one or both of the 1-D and 2-D models, or external to the models as necessary.

First-group strawman HSC have been developed for the Delphi exercise from information contained in the cited literature and data collected on DWM under ILP Study 24 Dwarf Wedgemussel and Co-Occurring Mussel Study. Please follow the steps outlined below to implement the exercise for the initial depth, mean column velocity, benthic velocity, and substrate composition (% particle and mean substrate size) HSC. Only the juvenile and adult life stages of the DWM are to be considered at this time. The parasitic larval stage is not being considered at this time due to the difficulty of modeling this unique stage that is reliant on host fish, but I welcome any suggestions or insight on how we may include this life stage.

Round 1 Instructions for Delphi Panelists

1. Consider the strawman HSC relationships on the following pages between riverine habitat suitability for adult DWM for each of the first-group variables: water depth, mean column water velocity, benthic water velocity, and substrate composition. What is your concept of the relationship (if any) between each variable and habitat suitability for adult DWM?

2. Next, comment on the shape of the HSC relationships. How should each HSC be modified to be consistent with your knowledge of adult DWM habitat requirements and also be applicable to the project area of the Connecticut River? There should be ranges of the variables that are unsuitable, partially suitable, and fully suitable or optimal.

3. Remember that HSC reflect the probability of habitat use and/or the density of DWM within the variable range; potential (<1.0 suitability) habitat is not the same as optimal (1.0 suitability) habitat. Information that you enter in response to the questions will serve as the basis for modified HSC curves that will be developed by the moderator from all responses and presented for consideration during Round 2.

4. List references, data sources, or any information available that you wish to use as the basis of your curves. It is important that you use your "gut" feeling or opinion, even if no data are available. You may choose to ignore all available data or information and use only your "gut" feeling or opinion as the basis of your curve. If you do mention a reference or incorporate data, please give the complete citation or data source or send the moderator a pdf copy of the report or a link to a download site.

5. Write comments, ideas, logic, reference, etc., at the bottom of each strawman page and return the pages to the moderator. Please use track-changes mode to display your comments.

6. Repeat Steps 1-5 for the juvenile life stage of DWM, if you believe their habitat requirements for the identified variables (or others) differ from the adult life stage.

7. If you feel that different variables or other life history phases are important and should be considered for a second-phase HSC curve, please clearly define the variable, explain how the variable is quantified, how it might be incorporated into the hydraulic habitat models, and provide an estimate of the unsuitable, partially suitable, and fully suitable habitat ranges.

8. If you have questions, you may call or email me. Please return your response no later than December 2, 2015.

Depth suitability for Adult DWM

Parasiewicz et al. 2012
"moderately deep HMUs provide good conditions for DWM"
"presence-abundance was positively correlated with depths between 75 and 100 cm"
The Delaware River is in places more than 2 m deep

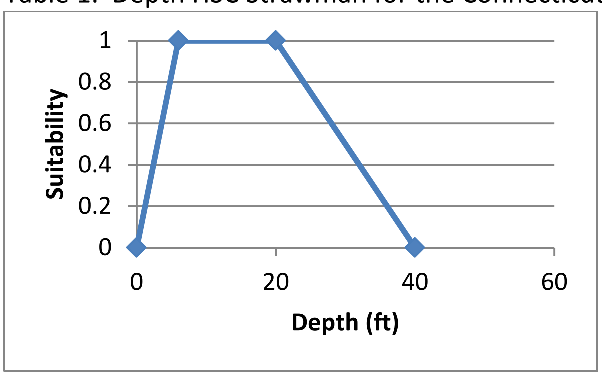
Strayer and Ralley 1993
"DWM occurred most often at intermediate values of depth"
"The Neversink is mostly less than 1 m deep at base flow"

ILP Study 24 Progress Reports
DWM found during qualitative surveys between 1.4 and 4.6 m
"Nearly all DWM were found by SCUBA diving in water depths of 6-20 feet"

Allen and Vaughn 2010
Little River, OK, "we measured water depth with a meter stick"

Maloney et al. 2012
Delaware River, depth at DWM locations 0.23-0.66 m at low flow
Lower depth threshold (binary criteria) for depth was 0.06 m

Table 1. Depth HSC Strawman for the Connecticut River



Mean Column Water Velocity Suitability for Adult DWM

ILP Study 24 Progress Reports
"Most DWM were found in areas with light to moderate flow velocities."

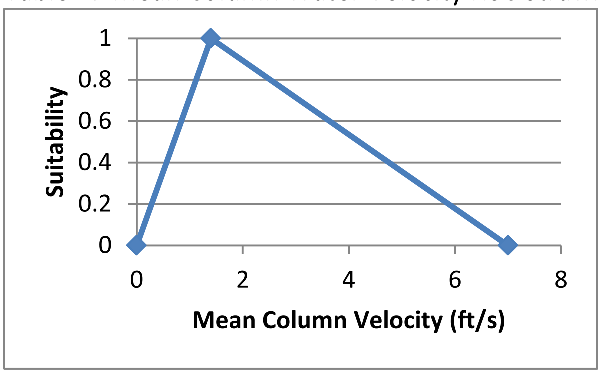
Maloney et al. 2012
Maximum velocity of a mussel was 3.3 m/s, used as upper threshold – 0.02 m/s as lower

Strayer and Ralley 1993
DWM were "found most frequently at moderate/intermediate current speeds"

Parasiewicz et al. 2012
"Meso-scale HSC defined…slow-flowing…HMUs as providing good conditions for DWM"

Baldigo et al. 2008
"Mussel species richness was highest where water velocities were between 0.4 and 1.0 m/s", and Figure 3, page 6.

Table 2. Mean Column Water Velocity HSC Strawman for the Connecticut River

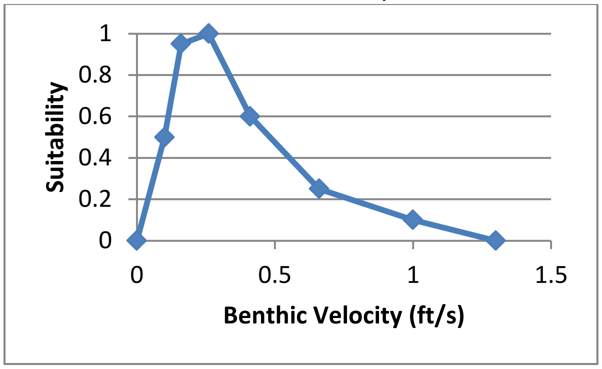


Benthic Water Velocity Suitability for Adult DWM

ILP Study 24 Progress Reports
"Most DWM were found in areas with light to moderate flow velocities."
Benthic water velocity between about 0.2 m/s and under .1 m/s

Strayer and Ralley 1993
"unionaceans were found most frequently at intermediate current speeds"
Figure 2. Frequency of occurrence…in relation to current speed.

Table 3. Benthic Water Velocity HSC Strawman for the Connecticut River



Substrate Suitability for Adult DWM

Baldigo et al. 2008
"Mussel species richness was highest where the amount of sand was between 10 and 17 percent of streambed material"

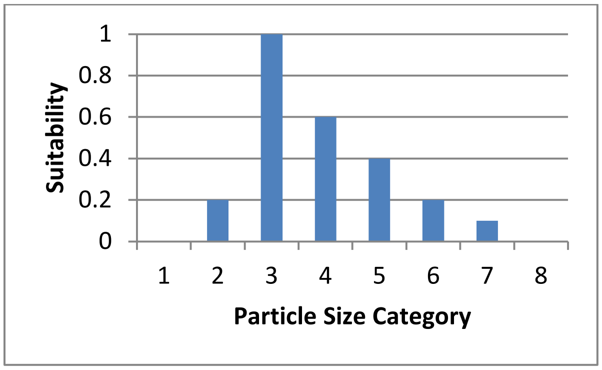
Strayer and Ralley 1993
DWM were found most frequently "in quadrats that contained many patches of fine sediments"
The proportion of fine sand was "correlated with unionacean numbers"

Baldigo et al. 2003-2004
DWM "abundance was positively correlated with substrate size"
DWM "may be affected by…percent gravel…[and]maximum substrate size"

Galbraith 2012
"In the historical Delaware River surveys, *A. heterodon* was most often found in sandy shoals"

Michaelson and Neves 1995
"DWM always referred the finer substratum offered"
"DWM preferred fine [0.063-0.850 mm) over coarse [3.37-8.00 mm] substratum"

Table 4. Substrate HSC Strawman for the Connecticut River



1 Vegetation (25 mm)
2 Silt (0.01 mm)
3 Sand (1 mm)
4 Fine Gravel (5 mm)
5 Gravel (36 mm)
6 Cobble (160 mm)
7 Boulder (256 mm)
8 Bedrock (1000 mm)

Note: Substrate habitat suitability is calculated from the percentage of each of eight substrate particle-size categories. The substrate suitability at each 1D or 2D model sample point is the sum of the suitability for each category, multiplied by the percentage of that substrate category at the point.

Citations

Allen, D.C., and C.C. Vaughn. 2010. Complex hydraulic and substrate variables limit freshwater mussel species richness and abundance. Journal of the North American Benthological Society, 29(2):383-394. DOI: 10.1899/09-024.1

Aadland, L.P. and A. Kuitunen. 2006. Habitat suitability criteria for stream fishes and mussels of Minnesota. Minnesota Department of Natural Resources, Section of Fisheries. 107 pp.

Baldigo, B.P., K. Riva-Murray, and G.E. Schuler. 2003-2004. Effects of environmental and spatial features on mussel populations and communities in a North American river. Walkerana, 2003-2004, 14(31):1-32.

Baldigo, B.P, A.G. Ernst, G.E. Schuler, and C.D. Apse. 2008. Relations of Environmental Factors with Mussel-Species Richness in the Neversink River, New York. USGS Open File Report 2007–1283, March 2008. 8pp.

Bockelmann-Evans, B.N., R. Davies, and R.A. Falconer. 2008. Measuring bed shear stress along vegetated river beds using FST hemispheres. Journal of Environmental Management, Vol. 88, Issue 4, pp. 627–637.

Galbraith, H.S. 2012. Phase 1 freshwater mussel survey and comparison to historical surveys at the Pond Eddy bridge, Delaware River, New York and Pennsylvania: U.S. Geological Survey Open-File Report 2012–1224, 17 pp.

Hardison, B.S., and J.B. Layzer. 2001. Relations between complex hydraulics and the localized distribution of mussels in three regulated rivers. Regulated Rivers Research and Management 17:77–84 (2001).

Hart, R.A. 1995. Mussel (Bivalva: Unionidae) habitat suitability criteria for the Otter Tail River, Minnesota. M.S. Thesis, Department of Zoology, North Dakota State University, Fargo. 60 pp.

Krstolic, J.L. 2001. A comparative study of freshwater mussel habitat along the Clinch River, Tennessee and Virginia, USA: hydraulic factors and their influences. MS Thesis, University of Tennessee, Knoxville, December 2001. 99pp.

Michaelson, D.L., and R.J. Neves. 1995. Life history and habitat of the endangered dwarf wedgemussel Alasmidonta heterodon (Bivalvia: Unionidae). Journal of the North American Bethological Society 14(2):324-340.

Ostby, B.J.K. 2005. Characterization of suitable habitats for freshwater mussels in the Clinch River, Virginia and Tennessee. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. March 2005. 203 pp.

Steuer, J.J., T.J. Newton and S.J. Zigler. 2008. Use of complex hydraulic variables to predict the distribution and density of unionids in a side channel of the Upper Mississippi River. Hydrobiologia, Volume 610, Issue 1, pp 67-82, September 2008.

Strayer, D.L., and J. Ralley. 1993. Microhabitat use by an assemblage of stream-dwelling unionaceans (Bivalvia), including two rare species of *Alasmidonta*. Journal of the North American Benthological Society, 1993, 12(3):247-258.

Thomas R. Payne & Associates and Louis Berger Group, Inc. 2008. Appalachian Power Company Claytor Hydroelectric Project No. 793-018 Instream Flow Needs Study. Final report prepared for American Electric Power/Appalachian Power Company by Thomas R. Payne & Associates, Arcata, CA and the Louis Berger Group, Inc., Needham, MA, dated December 30, 2008. 50 pp.

Zigler, S.J., T.J. Newton, J.J. Steuer, M.R. Bartsch and J.S. Sauer. 2008. Importance of physical and hydraulic characteristics to unionid mussels: a retrospective analysis in a reach of large river. Hydrobiologia, Volume 598, Issue 1, pp 343-360, February 2008

APPENDIX B

2nd Round Transmittal Letter and Panelist Responses

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Round 2 - Instructions for Delphi Panelists

1. Please review the changes made to the first round strawman HSC and the second round strawman HSC and comment on the shape of the HSC relationships. How should each HSC be modified to be consistent with your knowledge of adult DWM habitat requirements and also be applicable to the project area of the Connecticut River? There should be ranges of the variables that are unsuitable, partially suitable, and fully suitable or optimal.

2. List references, data sources, or any information available that you wish to use as the basis of your curves. It is important that you use your "gut" feeling or opinion, even if no data are available. You may choose to ignore all available data or information and use only your "gut" feeling or opinion as the basis of your curve. If you do mention a reference or incorporate data, please give the complete citation or data source or send the moderator a pdf copy of the report or a link to a download site.

3. Write comments, ideas, logic, reference, etc., at the bottom of each strawman page and return the pages to the moderator. Please use track-changes mode to display your comments.

4. If you feel that further variables or other life history phases are important and should be considered for a third-phase HSC curve, please clearly define the variable, explain how the variable is quantified, how it might be incorporated into the hydraulic habitat models, and provide an estimate of the unsuitable, partially suitable, and fully suitable habitat ranges.

5. If you have questions, you may call or email me. Please return your response no later than January 15, 2016.

Moderator's Analysis and Recommendations for Round 2

The changes suggested by the Delphi panelists to the first round strawman HSC increase the total suitable habitat ranges for depth, mean column velocity, benthic velocity, and substrate. The net effect of the changes will increase the total potential habitat area for DWM (i.e., less riverine area will be predicted to be unsuitable) and provide less discriminatory power to predict locations of DWM. This result is consistent with panelist comments that simple hydraulic variables are generally inadequate for determining DWM habitat suitability. The addition of more complex variables (bed shear stress, shear velocity, relative shear stress, and possibly others) should prove to be an improvement. However, the Delphi panel task of assigning suitabilities to these variables will likely be very difficult, since they are computed from depth, velocity, particle size, slope, kinematic viscosity of water, density of water, and others (see Allen and Vaughn 2010 Table 1, for example), and are often difficult to accurately measure in the field.

Regardless of which variables are ultimately utilized in the analysis, riverine areas subject to dewatering should be designated as unsuitable for DWM habitat, given that the species is sensitive to drying (Maloney et al. 2012, citing H. Galbraith, USGS, unpubl. data).

Finally, most comments indicated that first round habitat requirements of the juvenile life stage of DWM are sufficiently similar to those of adults to question whether separate juvenile HSC are warranted (panelists are free to disagree!). Juvenile HSC for the complex hydraulic variables (especially bed shear stress) remain likely, provided that the panelists are able to recommend applicable suitabilities.

Panelist C Response to Moderator's Analysis and Recommendations:
[In response to the second sentence of the first paragraph above "less riverine area will be predicted to be unsuitable and provide less discriminatory power to predict locations of DWM"]: Yes this is true, and seems to me to reflect our inability to predict mussel habitat from easily measured variables.

[In response to the first sentence of the last paragraph above]: I'd probably phrase this differently. I don't think that we know that juvenile requirements are similar to adult requirements; we just don't know of any differences, given our nearly non-existent knowledge of juvenile requirements.

Delphi Panelist Responses to Round 1

Three of the four Delphi panelists responded to the request for first round comments. Two provided suggestions for modifying the strawman HSC while the third argued that "these simple variables have almost no utility in determining whether habitat is suitable for DWM" and that "more complex variables will be required to produce a useful model." Suggested additional HSC included some measure or index of sediment stability (such as bed shear stress, shear velocity, relative (dimensionless) shear stress), likelihood of dewatering events, influence of groundwater inflow, and sensitivity to high temperatures. A few more papers were cited to add to the list of relevant literature. Changes from Round 1 are included as tracked changes below.

In response to the Round 1 comments, the following modifications to the strawman HSC have been made for Round 2:

Depth suitability for Adult DWM

Table 1. Depth HSC Strawman for the Connecticut River

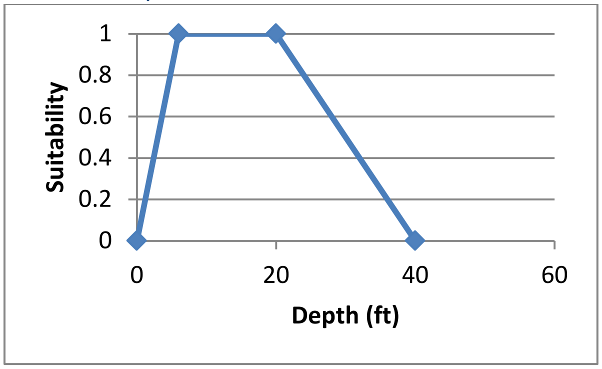
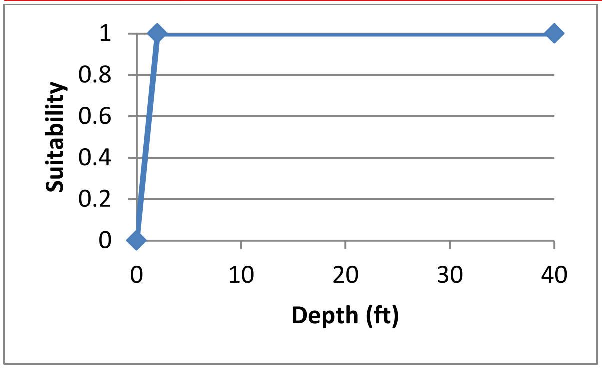


Table 1(2). Depth HSC for the Connecticut River – Round 2



Comments from Round 1:

"...there does not seem to be an upper depth limit [for DWM]"
"…increase in suitability between 0 and 2.0 ft…"
"…depth does not seem to be predictive of mussel distribution"

Panelist A Response: Agreed

Panelist B Response:
In terms of the suggested HSC listed above, I concur that variables such as likelihood of dewatering events, groundwater influence, and sensitivity to temperature may be important. I do think that the FERC study is aiming specifically at understanding the effects of project operations on dwarf wedgemussels and their habitat. HSC have been/should be selected that are relevant to project operations. So for groundwater influence and temperature sensitivity, I fail to see how HSC for these parameters are relevant unless studies have demonstrated that project operations influence groundwater inputs or significantly alter thermal regimes. For likehihood of dewatering events, I think this will be an important part of the analysis and will use information from the mussel study (including the water depth HSC), bathymetry studies, and hydraulic modeling. I am not sure that "likelihood of dewatering" is a standalone HSC…the depth ranges that a species occupy will help determine whether dewatering is possible, and the bathymetry and hydraulic modeling can show to what extent, and how frequently, this occurs.

There really is no basis for the decline in habitat suitability in water deeper than 20 ft. I concur that in the Connecticut River, dwarf wedgemussels are encountered less frequently areas from 0-5 ft, but this is not the case for other streams and rivers in the species' range. The scarcity of dwarf wedgemussels in shallow areas of the Connecticut River MAY be a consequence of project operations rather than habitat preference. It is important not to confound these two. The HSC should probably reflect a species preference/tolerance, rather than a species habitat use within a single regulated river (I think). If so, the HS score should probably be "1" (optimal) for anything over 2 ft. A result of this is that almost the entire Connecticut River will be mapped as "optimal habitat" based on water depth, which seems counterintuitive based on the limited range and low density of the species. But this may just be due to the fact that water depth is not as important as other variables. Also, the 1D and 2D modeling and IFIM should be able to identify areas of the river that are frequently dewatered or subjected to other poor conditions…and quantify what portion of shallow water habitats are not being used by DWM and other mussel species. So, the proposed Round 2 curve, below, is probably suitable.

Panelist C Response: Table 1(2), round 2 seems better than the initial HSC.

Mean Column Water Velocity Suitability for Adult DWM

Table 2. Mean Column Water Velocity HSC Strawman for the Connecticut River

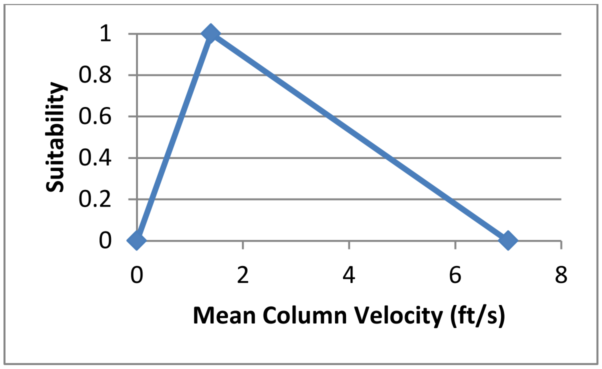
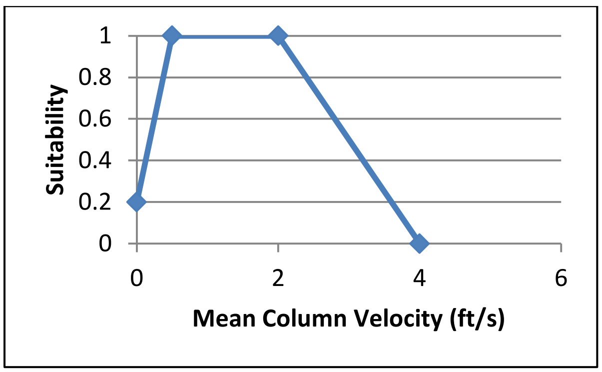


Table 2(2). Mean Column Water Velocity HSC Round 2 for the Connecticut River



Comments from Round 1:

"…DWM occur…in slow-flowing streams and rivers…"
"There is probably a wider range of optimal water velocities than [in Table 1]…"
"…benthic water velocities and bed shear stress are much more critical [for DWM]…"

Panelist A Response: Agreed

Panelist B Response:
Overall, I concur that benthic water velocities are more critical for DWM, and that it's the interaction between benthic velocities and the substrate type that really determine habitat suitability for DWM and other species. So its really shear stress and relative shear stress that are most important. Mussels can exist in areas with relatively high benthic velocities IF the substrate they are embedded in are relatively stable at those flows or if there are other habitat features that provide cover or flow refuge. So I am not sure that the mean column velocities are all that important. That said, I would not score a mean column velocity of 0 ft/s as entirely unsuitable….DWM do occur in quiet backwaters, eddies, near riverbanks, within areas of woody debris, etc where column velocities may be at or near zero. So I might recommend a HS score of 0.5 for 0 ft/sec, then it'll climb quickly to HS of 1.0 (at even a low column velocity of 0.5 ft/sec), begin to diminish after 2.0 ft/sec, and approach zero by ~6 ft/sec.

Panelist C Response:
Table 2(2) looks better than the first round, though suitability might go to 1 at a slow current speed (like 0.1 ft/s).

Benthic Water Velocity Suitability for Adult DWM

Table 3. Benthic Water Velocity HSC Strawman for the Connecticut River

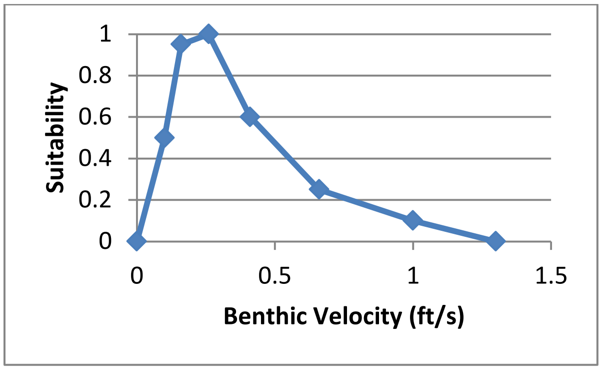
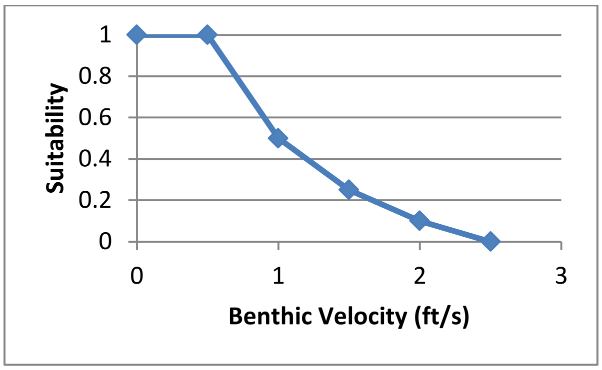


Table 3(2). Benthic Water Velocity HSC Round 2 for the Connecticut River



Comments from Round 1

"…DWM abundance decreased as you moved closer to higher benthic velocities…"
"…benthic water velocity of 0 is optimal for DWM…"

Panelist A Response: Do extremely low velocities allow DWM to obtain sufficient food and permit adequate gas exchange?

Panelist B Response: Again, it's the interaction with substrate that is more critical than specific velocity readings. I might extend the HS score of 1.0 at least to 1.0 ft/sec, then the curve can follow the same general shape, approaching 0 by 3 ft/sec.

Panelist C Response:
Table 3(2). I don't think you eve defined this variable (how far off the bottom, at what stage?), so it is hard to evaluate the quantitative HSC. It doesn't look unreasonable, if you're thinking about base flow measurements taken 1-2 cm off the bottom.

Substrate Suitability for Adult DWM

Table 4. Substrate HSC Strawman for the Connecticut River

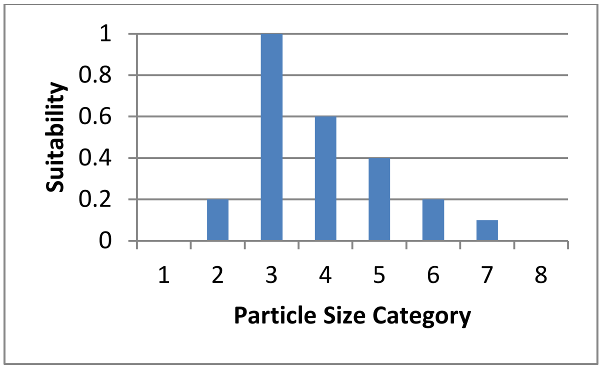
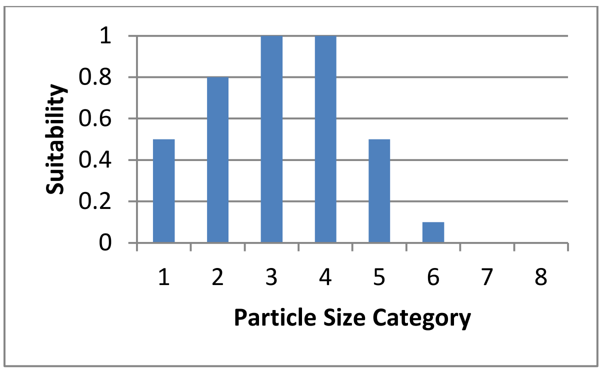


Table 4(2). Substrate HSC Round 2 for the Connecticut River



"DWM are fairly abundant in clay [and] they seem to prefer fine sands…"
"…adjust the suitability scores as follows…"

1 Submerged Aquatic Vegetation (25 mm)
2 Clay/Silt (0.01 mm)
3 Sand (1 mm)
4 Fine Gravel (5 mm)
5 Gravel (36 mm)
6 Cobble (160 mm)
7 Boulder (256 mm)
8 Bedrock (1000 mm)

Note: Substrate habitat suitability is calculated from the percentage of each of eight substrate particle-size categories. The substrate suitability at each 1D or 2D model sample point is the sum of the suitability for each category, multiplied by the percentage of that substrate category at the point.

Panelist A Response: Agreed

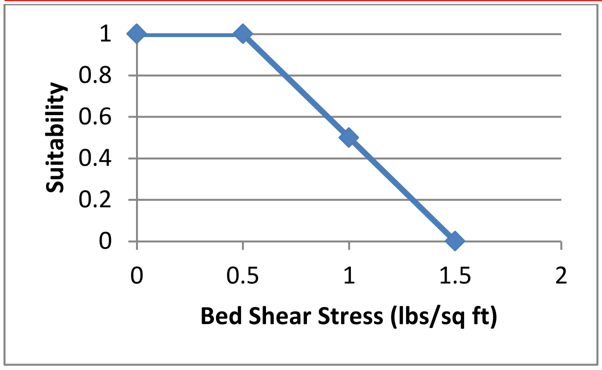
Panelist B Response: I think the Round 2 HS curve for substrate is probably reasonable.

Panelist C Response: Table 4(2) looks better than round 1 HSC.

In response to the comments in Round 1, the following strawman HSC have been added for Round 2:

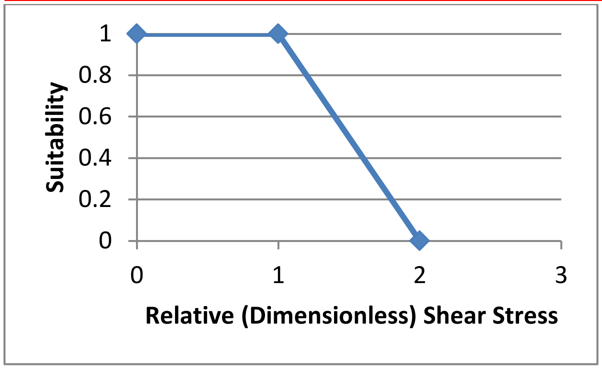
Bed Shear Stress Suitability for Adult DWM (Baldigo et al. 2008, Figure 3B)

Table 5. Bed Shear Stress HSC Strawman for the Connecticut River



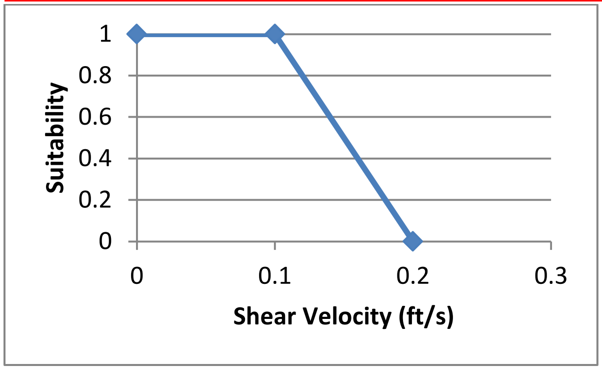
Relative (Dimensionless) Shear Stress Suitability for Adult DWM (Allen and Vaughn 2010, Figure 3H)

Table 5. Relative (Dimensionless) Shear Stress HSC Strawman for the Connecticut River



Shear Velocity Suitability for Adult DWM (Maloney et al. 2012, Figure 2C)

Table 5. Shear Velocity HSC Strawman for the Connecticut River



Panelist A Response:
Maloney et al. used maximum shear stress of 47.3 N per meter square (about 1 pound-force/ square foot) for their DWM habitat suitability calculations.

Allen and Vaughn found species richness was high when RSS was >1 but declined sharply when RSS was >2. However, they state that they used only D_{50} to estimate substrate movement and that the presence of embedded mussels may also help stabilize the substrate.

Maloney et al. found a maximum shear velocity over a mussel bed to be 0.22 m/s (0.72 ft/sec); this value was used as an upper threshold for their habitat suitability criteria.

Juvenile Dispersal May Constrain DWM Distribution: For recruitment to occur juveniles need to become established in the substrate. In a field study I've found that DWM glochidia are released from March through May in the CT River watershed; juveniles would then be released from host fish (tessellated darters) starting in a late April. Juveniles are easily entrained during periods of high shear stress that would be expected during spring floods (while only big episodic floods can scour out marginal mussel beds including adults). Thus, constrains on juvenile dispersal may limit DWM distribution in habitats that appear hydrologically suitable for adults. French and Ackermann (2014) found that the shear stress threshold of 0.26 N/m^2 (0.005 pound force/ft^2) allowed juveniles to become established on the substrate. (However, microhabitat refuges within mussel beds may have much lower shear stress values that may allow juveniles to become established.)

Panelist B Response:
It is hard to contextualize what these specific shear stress values actually mean, so therefore it is hard to comment on the shape of the strawman HS curve.

As DWM seem to prefer fine-grained sediments that are more easily mobilized, areas where they occur may have high (>>1.0) RSS values. Areas of the river with large coarse rock would have much lower RSS scores (at comparable flow velocities) because resistance to movement forms the denominator of the RSS equation (e.g., RSS values for areas of bedrock are essentially ZERO). Thus, RSS needs to account for a realistic range of flow velocities AND substrates that a target species is using, as well as other factors that may influence bed stability (aside from the parameters that are part of the RSS equation). Considering the quantitative DWM sampling that was conducted by TransCanada, the 1D and 2D studies, hydraulic modeling, and IFIM, it seems we ought to be using those data to help develop HSC, rather than a simple strawman and expert opinion whose relevance is uncertain.

My feeling is that shear velocity will be redundant with other parameters and can probably be omitted. It would be better to focus on shear stress and RSS. See comments above.

Panelist C Response:
This needs much more careful definition to be useful. The important shears probably are at bankful discharge, not at base flow or moderate flows. If this is going to be useful, it probably should be whether local-scale shears at bankful discharge are high enough to move substrata.

Citations

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APPENDIX C

3^{rd} Round Transmittal Letter and Panelist Responses

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Round 3 – Instructions for Delphi Panelists

1. Please review the changes made to the second round strawman HSC and comment on and proposed third round changes. How should each HSC be modified to be consistent with your knowledge of adult DWM habitat requirements and also be applicable to the project area of the Connecticut River (include actual values if possible)? There should be ranges of the variables that are unsuitable, partially suitable, and fully suitable or optimal.

2. List references, data sources, or any information available that you wish to use as the basis of your curves. It is important that you use your "gut" feeling or opinion, even if no data are available. You may choose to ignore all available data or information and use only your "gut" feeling or opinion as the basis of your curve. If you do mention a reference or incorporate data, please give the complete citation or data source or send the moderator a pdf copy of the report or a link to a download site.

3. Write comments, ideas, logic, reference, etc., at the bottom of each strawman page and return the pages to the moderator. Please use track-changes mode to display your comments.

4. If you feel that further variables or other life history phases are important and should be considered for a third-phase HSC curve, please clearly define the variable, explain how the variable is quantified, how it might be incorporated into the hydraulic habitat models, and provide an estimate of the unsuitable, partially suitable, and fully suitable habitat ranges.

5. If you have questions, you may call or email me. Please return your response no later than March 4, 2016.

Moderator's Analysis and Recommendations

Several pertinent comments were made by panelists that did not directly relate to HSC values, but will be critical in application of these HSC within the 1D and 2D hydraulic models.

First is the oft-repeated suggestion that shear stresses during high flows may be expected to limit the distribution of mussels, whereas shear stresses under lower flows may not be descriptive. This is a modeling issue that will be addressed through collaboration between the project's mussel expert and the hydraulic modelers. Similarly, the modeling approach will account for potential dewatering episodes and how such events may nullify suitability of specific locations as flows are increased and habitat is re-wetted. **If you have any additional comments or thoughts on these factors (i.e., modeling certain variables only at higher flows, accounting for periods of dewatering), please include them with your next (Round 3) responses.**

Panelist A Response: I do agree that high-flow SS and RSS are most important, and that accounting for any dewatering at low flows is also critical. I think these will be adequately addressed as the analysis continues.

Second, several comments were received addressing the question of whether juvenile mussel habitat requirements can be adequately represented by adult mussel HSC, or whether flows protective of adult mussels will be protective of juveniles. One commenter indicated that the paucity of data on juvenile mussel habitat severely limits our ability to assess juvenile habitat needs or limitations. This would seem to me to support our current direction of only including adult mussels in the habitat modeling process, as limiting as that may be. A panelist did forward some data suggesting that shear stresses allowing establishment of juvenile mussels into the substrate were far lower than shear stresses tolerated by attached adult mussels. French & Ackermann 2014 was cited stating that juvenile establishment did not occur at shear stresses over 0.005 lbs/sq ft, versus our Round 3 proposed maximum shear stress for adult mussels as 1.0 lbs/sq ft. It was also noted that instream cover or other refuge-forming elements could allow juvenile establishment at higher shear stresses. A panelist noted that data from the Connecticut River Basin suggests that DWM glochidia are released from host fish from March through May, which is a period when spring freshet high flows frequently exceed the capacity of the hydropower facilities and uncontrolled spill occurs. Thus it may be that high, uncontrolled flows will produce greater limitations on juvenile establishment than flows under the direct control of the project facilities. **If you have any specific thoughts or comments RE the need or manner for incorporating juvenile mussel HSC into this process (though it may be a bit late for that) please indicate in your next (Round 3) responses.**

Panelist A Response: I don't think we necessarily need separate juvenile HSC. As more is done with existing quantitative mussel data sets, hydraulic modeling, IFIM, and other available datasets, you might be able to consider how the HSC curves may be tweaked for juveniles…or at least be able to address the question.

Third, comments suggested that some variables may be redundant or non-descriptive. For example, one panelist suggested that mean column velocities may not be "all that important" since velocities near the stream bed (or more specifically, shear stresses) will dictate suitability of a particular location (although the hydraulic models may require mean velocities to calculate other velocity parameters). Another comment specifically suggested that shear velocity was redundant with shear stress and may not be useful or needed in the modeling of habitat suitability. Regardless of which variables are ultimately utilized in the analysis, riverine areas subject to dewatering should be designated as unsuitable for DWM habitat, given that the species is sensitive to drying (Maloney et al. 2012, citing H. Galbraith, USGS, unpubl. data). . **If you have any specific thoughts or comments RE the potential to reduce the number of HSC variables from the 7 currently under review please indicate in your next (Round 3) responses.**

Fourth, a panelist familiar with ongoing studies in the project area has suggested that site-specific data should be compared to the Delphi curves as a quality-control check, which may suggest areas of further change in the Delphi HSC. This option has been discussed and will likely be pursued, but not until after this Delphi process has been completed.

Thank you again for your effort and contributions to this process, it is hoped that following this next round that final decisions can be made on:

1. the list of variables to utilize in the flow modeling process; and
2. HSC curves for each of those variables.

Feel free to email me at mallen@normandeau.com or call at 707-822-8478 x301 with any additional questions or comments. Otherwise I hope to receive your next (and final?) round of comments by March 4, 2016.

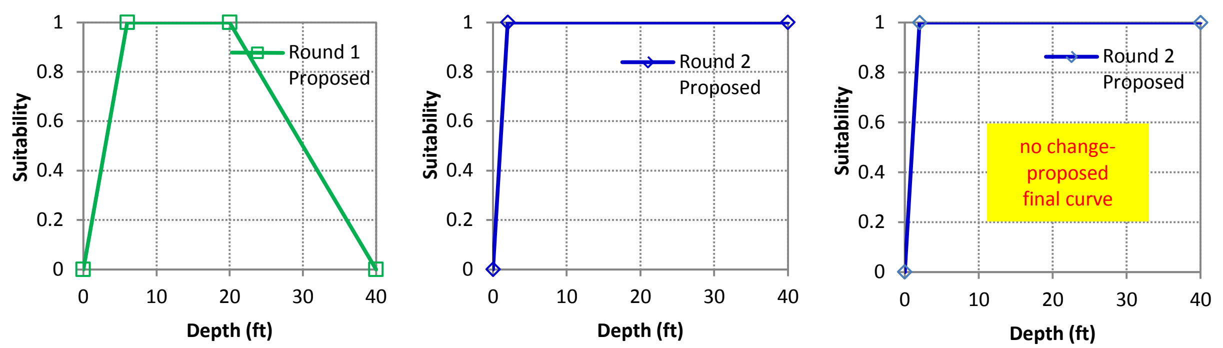
Comments Due: March 4, 2016 (*please!*)

Delphi Panelist Responses to Rounds 1 and 2

Three of the four Delphi panelists responded to the request for first and second round comments. Following is a summary of the individual responses to the 4 original HSC variable curves (depth, mean column velocity, benthic velocity, and substrate particle size) as well as responses to the 3 new HSC variable curves proposed during the second transmittal (bed shear stress, relative shear stress, shear velocity).

In response to the comments, the following modifications to the strawman HSC have been made (in tracked changes):

Depth suitability for Adult DWM



Second round comments on the Round 2 depth curve:

"… the proposed Round 2 curve … is probably suitable"

"This seems better than the initial HSC"

"Agreed"

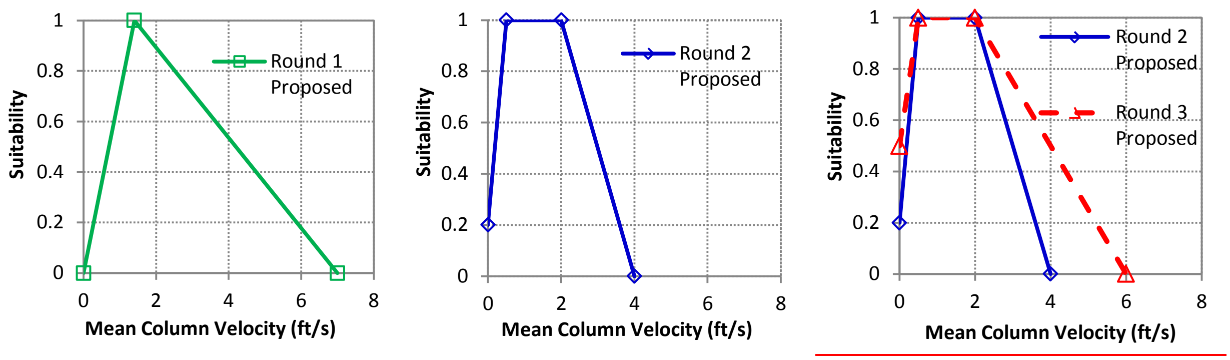
Based on these three favorable comments, I would like to consider the Round 2 depth curve as a final curve, with the following coordinates:

Depth (ft)	Suitability
0.0	0.0
2.0	1.0
>2.0	1.0

Please indicate if you agree to consider this the final HSC curve for depth.

Panelist A Response: Agreed.
Panelist B Response: Seems acceptable.
Panelist C Response: Yes.

Mean Column Water Velocity Suitability for Adult DWM



Second round comments on the Round 2 mean column velocity curve:

"Agreed"

"Again, this looks better than first round, though suitability might go to 1 at a slower current speed (like 0.1 ft/sec)"

"I might recommend a HS score of 0.5 for 0 ft/sec, then it'll climb quickly to HS of 1.0 (at even a low column velocity of 0.5 ft/sec), begin to diminish after 2.0 ft/sec, and approach zero by ~6 ft/sec"

As a result of the 2nd and 3rd comments above, which were consistent at suggesting somewhat higher suitability for slower velocities, I moved the HSC value for zero velocity up to 0.5, which increased suitability for all velocities <0.5 f/s. I also moved the maximum velocity from 4 f/s to 6 f/s, as per the 3rd comment.

These proposed Round 3 coordinates for mean column velocity are:

Mean Column Velocity (f/s)	Suitability
0.0	0.5
0.5	1.0
2.0	1.0
6.0	0.0

Please give me your feedback on modifying the Round 2 curve to the proposed Round 3 curve. If you disagree with these changes, please proposed new values (unless you want to maintain the Round 2 curve).

Panelist A Response: I think this curve is fine. The benthic velocity will probably be more informative, as it is influenced by benthic features that are important to mussels.

Panelist B Response: Assuming that these are base-flow velocities (which has been my assumption all along), this curve probably overvalues sites with very high velocities. Base-flow velocities of 6 ft/sec probably rarely occur in DWM sites (I doubt I've ever seen DWM at half of these velocities at base flow).

Furthermore, work done with marine bivalves – Wildish and Kristmanson, Benthic suspension-feeders and flow. Cambridge U Press, 1997) suggest to me that unionids would have trouble feeding at such high velocities. Again, assuming that these are base flow velocities, I'd suggest setting suitability to 0 at velocity >3 ft/sec. As I'm sure you're very well aware by now, a lot of this is not much more than informed guesswork. Personally, I'd probably trim or truncate the suitability curves at high velocities, but if you and the other panelists want to go ahead with the curves from the latest round, I can offer no firm objections and could certainly live with them.

Panelist C Response: I accept the Round 3 curve.

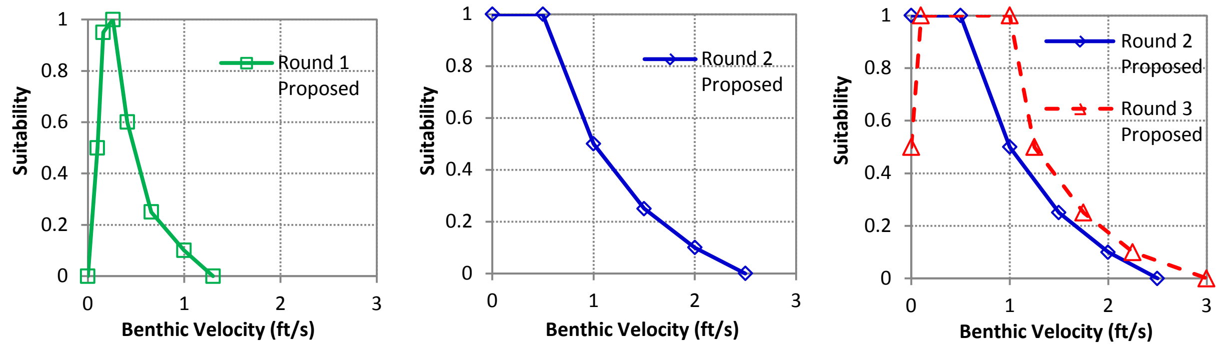
Additional input from the Moderator on velocity curves (after initial Round 3 comments were received):

I wanted to clear-up a couple of points about how the 1D and 2D modeling is likely to be conducted, and how that relates to the HSC curves, particularly in light of certain comments/questions posed in the last response.

We will be using a single HSC curve for each variable (e.g. mean column or benthic velocity) at all modeled flows. In other words, we won't be using one velocity curve at high flow and another velocity curve at base flow (e.g., the curves are not interactive). So if a particular location along a 1D transect or within the 2D study site has a predicted mean column velocity of 4fps, the calculated velocity suitability for that location (according to the Round 3 proposed curve) would be about 0.5, regardless of whether that occurs at high flow or base flow. However, because we are modeling a relatively sessile organism under fluctuating flow scenarios, we will employ a method by which any location that becomes unsuitable at any particular flow will remain unsuitable at all flows. So for example, if mean column velocity reaches 6 fps at a high simulated flow, that location will remain unsuitable for DWM even if the calculated velocity is only 2 fps at a lower flow. Ditto for the remaining variables, including depth - which will result in zero suitability for any locations that become dewatered at any time. Also keep in mind that the Connecticut River is large and relatively deep, so a high mean column velocity can still provide fairly low benthic velocities near the bottom, in contrast to a small, shallow stream where a high mean column velocity will likely result in a high benthic velocity also.

Panelist B Response:
Your explanation of the procedure is very helpful (how you plan to deal with a nearly sessile organism). I still think that mean velocities of 6 ft/s and near-bed velocities of 3 ft/s are likely to be poorly suited or unsuited to DWM, for 2 pretty different reasons. First, these velocities ought to mobilize at least fine sediments and may wash away or bury mussels. This could be a deal-breaker, and would be well handled by the modeling approach you suggested (if the site is unsuitable at any flow, it is unsuitable at all flows). Second, high and/or turbulent flows should make it hard for mussels to feed. I don't know of any work on this for DWM or indeed for any freshwater mussel, but work on marine bivalves suggests that it should pose problems for DWM. However, this isn't the same sort of dealbreaker as sediment scour/fill. Instead, I'd expect a mussel just to shut down or feed inefficiently as long as unacceptably high flows occur. However, as I'm sure you're very well aware by now, a lot of this is not much more than informed guesswork. Personally, I'd probably trim or truncate the suitability curves at high velocities, but if you and the other panelists want to go ahead with the curves from the latest round, I can offer no firm objections and could certainly live with them. I still have no comment about the absolute shear stress curves; the relative shear curve seems ok to use in the way that you're suggesting (if a site is unsuitable at any flow, it's just treated as unsuitable).

Benthic Water Velocity Suitability for Adult DWM



Second round comments on the Round 2 benthic velocity curve:

"Doesn't look unreasonable, if you're thinking about base flow measurements taken 1-2 cm off the bottom"
"I might extend the HS score of 1.0 at least to 1.0 ft/sec, then the curve can follow the same general shape, approaching 0 by 3 ft/sec"
"Do extremely low velocities allow DWM to obtain sufficient food and permit adequate gas exchange?"

Based on comment #3, I dropped the suitability of zero velocity from 1.0 to 0.5, but gave maximum suitability at 0.1 f/s, so only the very lowest velocities (<0.1 f/s) have reduced suitability. I then increased the suitability of velocities >0.5 f/s by moving the peak out from 0.5 f/s to 1 fps and then followed the Round 2 declining limb to reach zero suitability at 3 f/s, as per comment #2. These proposed Round 3 coordinates for benthic velocity are:

Benthic Velocity (f/s)	Suitability
0.0	0.5
0.1	1.0
1.0	1.0
1.25	~~0.5~~ .75
1.75	~~0.25~~ .5
2.25	~~0.1~~ .25
3.0	0.0

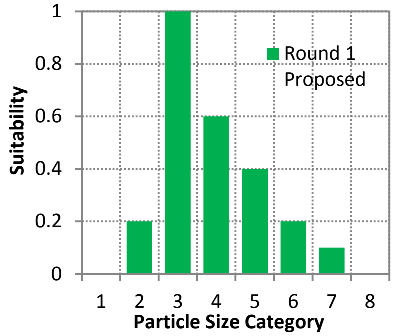
Please give me your feedback on modifying the Round 2 curve to the proposed Round 3 curve. If you disagree with these changes, please proposed new values (unless you want to maintain the Round 2 curve).

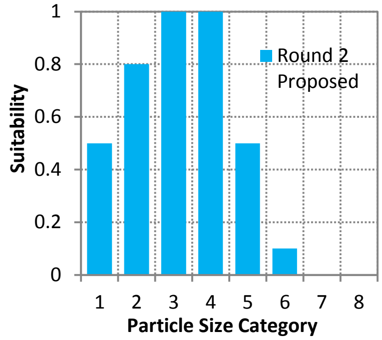
Panelist A Response: I think this is pretty good. The curve may not need to drop so quickly though. See suggested values in the table above (tracked changes).

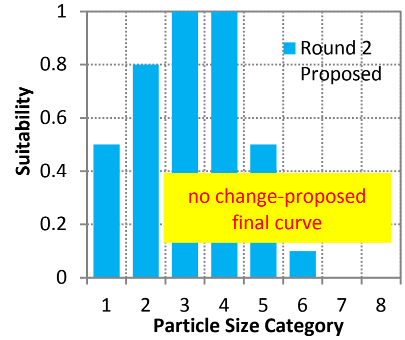
Panelist B Response: Same comment as for mean water column velocities – you probably overvalue high-velocity sites. Assuming these are velocities 1-2 cm above the bottom at base flow, I'd say that suitability ought to be 0 at velocities above ~1 ft/sec…but if you and the other panelists want to go ahead with the curves from the latest round, I can offer no firm objections and could certainly live with them.

Panelist C Response: I agree with the changes in the Round 3 curve.

Substrate Suitability for Adult DWM







Second round comments on the Round 2 substrate HSC (see size classes below):

"Looks better than round 1 HSC"

"I think the Round 2 HS curve for substrate is probably reasonable"

"Agreed"

Based on these three favorable comments, I would like to consider the Round 2 substrate HSC as a final HSC relationship, with the following coordinates:

Substrate Composition	Suitability
1	0.5
2	0.8
3	1
4	1
5	0.5
6	0.1
7	0
8	0

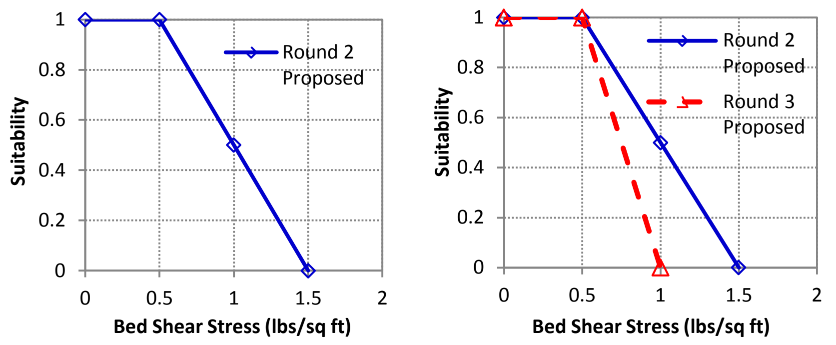
Code	Description
1	Submerged Aquatic Vegetation (25 mm)
2	Clay/Silt (0.01 mm)
3	Sand (1 mm)
4	Fine Gravel (5 mm)
5	Gravel (36 mm)
6	Cobble (160 mm)
7	Boulder (256 mm)
8	Bedrock (1000 mm)

Note: Substrate habitat suitability is calculated from the percentage of each of eight substrate particle-size categories. The substrate suitability at each 1D or 2D model sample point is the sum of the suitability for each category, multiplied by the percentage of that substrate category at the point.
Please indicate if you agree to consider this the final HSC curve for substrate particle size.

Panelist A Response: Agreed.
Panelist B Response: Seems reasonable.
Panelist C Response: Yes, this curve looks good.

The following new HSC variables were added in the Round 2 Transmittal:

Bed Shear Stress Suitability for Adult DWM



Second round comments on the Round 2 bed shear stress curves:

"Maloney et al. used maximum shear stress of ...(about 1 pound-force/square foot) for their DWM habitat suitability calculations"

"The important shears probably are at bankfull discharge, not at base flow or moderate flows"

"it's hard to contextualize what these specific shear stress values actually mean, so therefore it's hard to comment on the shape of the strawman HS curve"

Based on comment #1, I reduced the maximum tolerated bed shear stress from 1.5 lbs/sq ft to 1.0. No other specific HSC values were suggested.

These proposed Round 3 coordinates for bed shear stress are:

Bed Shear Stress	Suitability
0.0	1.0
0.5	1.0
1.0	0.0

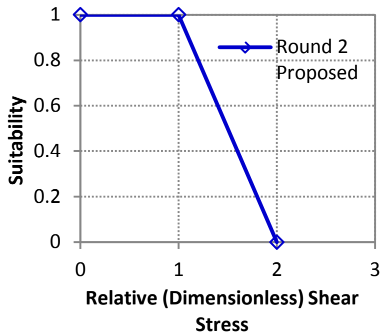
Please give me your feedback on modifying the Round 2 curve to the proposed Round 3 curve. If you disagree with these changes, please proposed new values (unless you want to maintain the Round 2 curve).

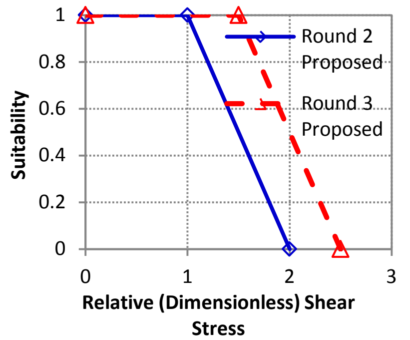
Panelist A Response: I think this is a reasonable starting point. I do think much could be done to improve/refine this curve using existing field-collected mussel and habitat data in the Connecticut River.

Panelist B Response: No response.

Panelist C Response: These coordinates look reasonable especially for displaying females near the surface in spring.

Relative (Dimensionless) Shear Stress Suitability for Adult DWM





Second round comments on the Round 2 relative bed shear stress curves (one panelist did not comment):

"Allen and Vaughn found species richness was high when RSS was >1 but declined sharply when RSS was >2"

"as DWM seems to prefer fine-grained sediments that are more easily mobilized, areas where they occur may have high (>>1.0) RSS values"

Based on both comments above, I extended the range of maximum suitability out 1 to 1.5, and then followed the Round 2 trailing limb down to zero suitability at 2.5.

These proposed Round 3 coordinates for relative shear stress are:

Relative Shear Stress	Suitability
0.0	1.0
1.5	1.0
2.5	0.0

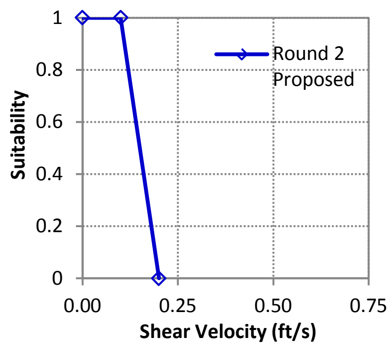
Please give me your feedback on modifying the Round 2 curve to the proposed Round 3 curve. If you disagree with these changes, please proposed new values (unless you want to maintain the Round 2 curve).

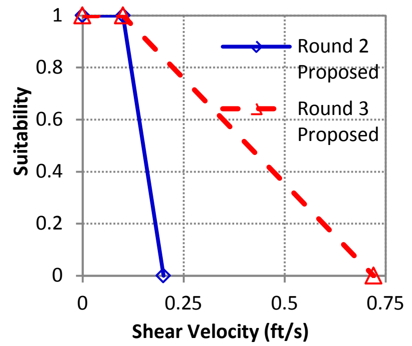
Panelist A Response: Again, I think this is a reasonable starting point if we just look at values suggested in currently available research papers. I do think much could be done to improve/refine this curve using existing field-collected mussel and habitat data in the Connecticut River.

Panelist B Response: I suppose that you might guess that bankful RSS>1 would be unsuitable, but this assumes that you have good local estimates of velocity and bed grain size, and that the bed actually mobilizes at RSS>1. The only other use of shear that I can imagine would be to guess that areas of high base flow shear would preclude juvenile settlement, but again this assumes good micro-scale estimates of shear. I didn't comment on the specific proposed curves before and I can't now because they don't provide any information about what water stage they refer to.

Panelist C Response: The Round 3 curve is suitable.

Shear Velocity Suitability for Adult DWM





Second round comments on the Round 2 shear velocity curves (one panelist did not comment):

"My feeling is that shear velocity will be redundant with other parameters and can probably be omitted. It would be better to focus on shear stress and RSS"

"Maloney et al. found a maximum shear velocity over a mussel bed to be … (0.72 ft/sec); this was used as an upper threshold for their habitat suitability criteria"

Based on comment #2 above, I moved the maximum tolerable shear velocity out from 0.2 f/s to 0.75 f/s. However I would like to hear from the panelists RE comment #1 and whether this variable is redundant and can be dropped in lieu of using the preceding 2 shear variables.

These proposed Round 3 coordinates for shear velocity are:

Shear Velocity	Suitability
0.0	1.0
0.1	1.0
0.72	0.0

Please give me your feedback on modifying the Round 2 curve to the proposed Round 3 curve. If you disagree with these changes, please proposed new values (unless you want to maintain the Round 2 curve). Also indicate if you feel that shear velocity is a redundant variable.

Panelist A Response: I think there is a good chance that this is a redundant variable…I think more can be done for this and the SS and RSS curves using existing data from TransCanada's mussel and habitat studies. As these curves take their final shape and they are used in the IFIM, redundancy would become more apparent. Thus, you don't need to eliminate this parameter now…but might later.

Panelist B Response: No response.

Panelist C Response: I agree with the first Second Round comment above. We should omit shear velocity.

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