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Calculating Functional Loss Using the Stream Quantification Tool and Debit Calculator

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1.0 Introduction

In April 2008, the United States Army Corps of Engineers (USACE) and the United States Environmental Protection Agency (EPA) jointly issued regulations clarifying compensatory mitigation requirements for Department of the Army permits (33 C.F.R. § 332/40 C.F.R. § 230). While traditional approaches to determining the appropriate amount of compensation involved reliance on measures of acres or linear feet, the USACE and EPA explicitly stated in the preamble to the Final Rule that *"With this rule, we are encouraging the use of functional and condition assessments to determine the appropriate amount of compensatory mitigation needed to offset authorized impacts, instead of relying primarily on surrogate measures such as acres and linear feet. In the future, there will be more assessment methods available to quantify impacts and compensatory mitigation*." And then the Final Rule stated that "*In cases where appropriate functional or condition assessment methods or other suitable metrics are available, these methods should be used where practicable to determine how much compensatory mitigation is required* (33 C.F.R. § 332.3FR Vol 73, 19633). The Rule clearly recognizes that science-based function or condition assessment methodologies provide a more objective, systematic and reliable approach to characterize and quantify the expected aquatic resource losses or debits at impact sites, as well as the potential aquatic resource gains or credits at compensatory mitigation sites.

This paper introduces a methodology to calculate the functional loss (debit) of permitted impacts to stream ecosystems. The purpose is to provide Interagency Review Teams (IRTs) with a conceptual model for calculating functional loss (debits) that can complement the existing Stream Quantification Tool (SQT) that calculates functional lift (credits). The concepts and ideas shared in this paper may need to be adapted and refined to fit the regulatory requirements and needs for a given state or Corps District. Likewise, the regression equations used in the Debit Calculator can be improved with local data from impacted streams.

The methods provided in this paper are based on the Stream Function Pyramid Framework (SFPF) described in *A Function-Based Framework for Stream Assessment and Restoration Projects* (Harman et al. 2012), published by EPA and the United States Fish and Wildlife Service (FWS). The methodology compliments a Stream Quantification Tool (SQT), which is typically used to calculate the functional lift of stream restoration/mitigation projects. Since the SQT is a

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delta tool that calculates the difference between an existing and proposed condition, it can show lift or loss depending on the quality of the proposed condition. However, to use the SQT, data must be available to verify the existing and proposed condition scores. For permitted impacts, it is common for the applicant to not monitor or have data available about the proposed condition. In these cases, the debit tool can be used with the SQT to calculate functional loss.

Background information on the SFPF and the SQT is provided below. Following the background section, methods for calculating functional loss are described in detail.

2.0 Background

As mentioned above, both the SQT and the debit calculations are based on the SFPF. The SQT was developed to provide an objective method for quantifying the functional lift associated with stream mitigation and restoration projects by scoring sites before and after the implementation of restoration activities. Since the SQT scores an existing and after condition, it can calculate functional lift *and loss* if both conditions are monitored. The key point here is that both the before and after conditions must be objectively determined in the field.

The primary challenge with estimating the functional loss caused by a permitted stream impact is that the after-impact condition is not monitored. Instead, it must be estimated through project design documents, modeling, literature reviews, and best professional judgement. This is the primary reason that a debit calculator is needed, rather than simply using the SQT alone to determine functional loss. Since the SQT and debit calculator are applications from the SFPF, the SFPF is described below prior to sections on the debit tool. Readers who are familiar with this framework can skip section 2.1.

<u>2.1 Stream Functions Pyramid Framework</u>

The Stream Functions Pyramid, shown below in Figure 1, includes five functional categories: Level 1 = Hydrology, Level 2 = Hydraulics, Level 3 = Geomorphology, Level 4 = Physicochemical, and Level 5 = Biology. This hierarchy or pyramid is based on the premise that lower-level functions support higher-level functions and that they are all influenced by local geology and climate. Each functional category is defined by a functional statement. For example, the functional statement for Level 1, Hydrology is “the transport of water from the watershed to the channel,” which supports all higher-level functions. The hierarchical structure of the pyramid provides the conceptual foundation to quantify functional lift in the SQT and functional loss in the debit tool. However, more detail is needed to develop function-based metrics and performance standards. This additional level of detail is provided in the Stream Functions Pyramid Framework.

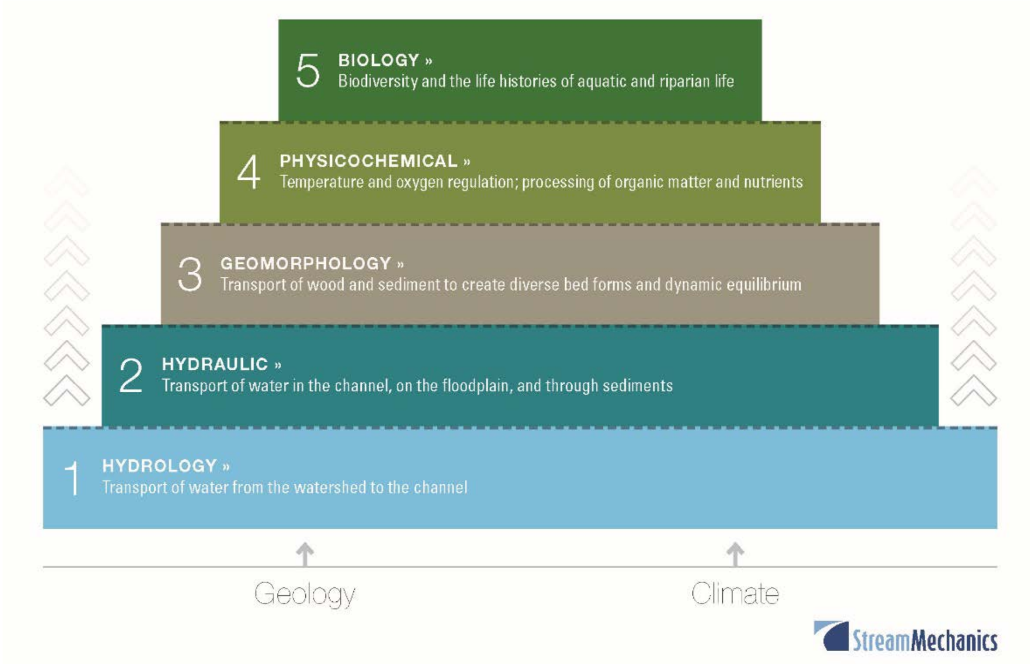

Figure 1: Stream Functions Pyramid

The full framework includes function-based parameters within each functional category to assess and provide information about the functional statement. For example, floodplain connectivity is a function-based parameter within the hydraulic functional category, and provides information about flood-water inundation of the floodplain as well as the spatial extent (e.g. width) of flooding. The specific metrics used to quantify the regularity and extent of flooding are the bank height ratio and entrenchment ratio. These are called measurement methods. They can include a wide variety of assessment methods that quantify the function-based parameter. As is shown here, there can be more than one measurement method per function-based parameter.

The last part of the framework is the performance standard, which is provided for each measurement method and then rolled up to the parameter level. The performance standard assesses the functional capacity of the function-based parameter, as represented by the measurement method(s). Functional capacity is expressed as functioning, functioning-at-risk, or not functioning and is based on comparison to a reference/natural condition. For example, a function-based parameter that is functioning, represents one healthy component of the stream ecosystem, e.g. functioning floodplain connectivity. An outline of the full SFPF is provided in Figure 2.

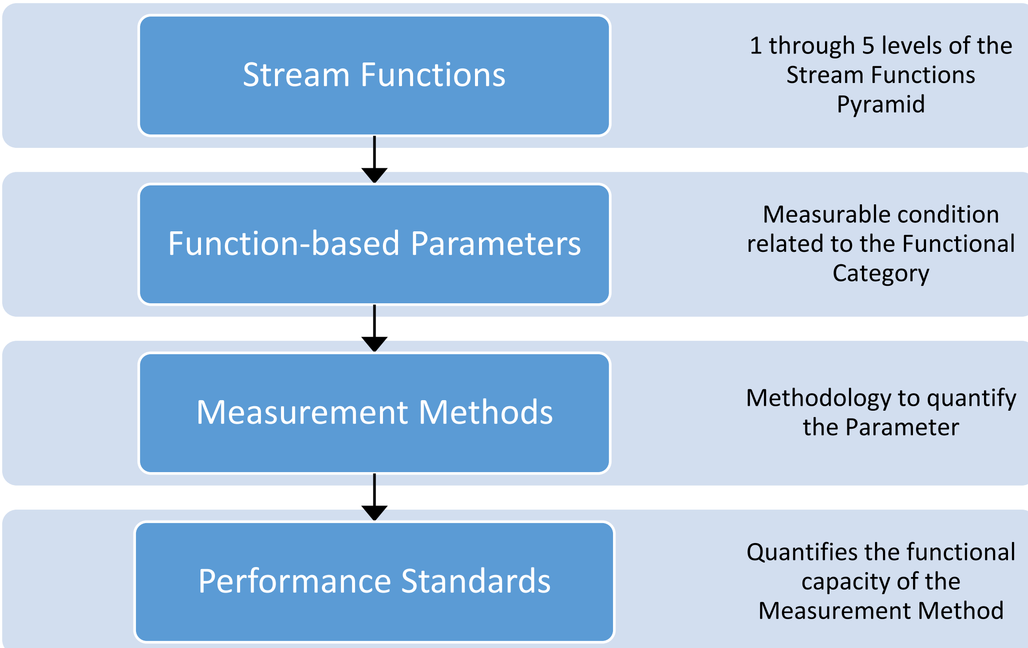

Figure 2: Stream Functions Pyramid Framework

2.2 Stream Quantification Tool (SQT)

The SQT is a spreadsheet tool that quantifies the functional lift of stream restoration and mitigation projects. As noted above, it can also calculate functional loss if the implemented activities lead to after-impact scores that are lower than pre-impact / existing condition scores. Instructions on how to operate the spreadsheet and collect and analyze data required for its use are provided in documents that can be downloaded from https://stream-mechanics.com/stream-functions-pyramid-framework/. These documents are adapted for different regions across the country that are actively using the SQT. The spreadsheet user manual describes key concepts and terms that are used in the SQT and the debit calculator. These include restoration potential, catchment assessment, and function-based goals and objectives. It is strongly recommended that users of the debit calculator described below first read and understand the SQT Spreadsheet User Manual and the Data Collection and Analysis Manual.

3.0 Introduction to Debit Methodology and Calculator

This section provides step-by-step instructions on how to calculate the functional loss caused by a permitted impact to stream ecosystems. The calculations are shown in the text, however, spreadsheet tools (SQT and debit calculator) are provided to perform most of the calculations. The existing condition score and functional-foot calculations in the debit tool follow the same form as functional-lift determinations in the SQT so that a direct comparison can be made between functional loss and lift. This process helps ensure that the credits provided by mitigation equal or exceed the functional loss (debits) caused by the permitted impact.

3.1 Functional Loss Calculations

The SQT determines functional loss and functional lift in units of functional feet (FF) calculated using the stream length and a stream reach condition score (CS) as follows.

$$Existing\ Stream\ FFS = Existing\ CS * Existing\ Stream\ Length \quad (1)$$

$$Proposed\ Stream\ FFS = Proposed\ CS * Proposed\ Stream\ Length \quad (2)$$

$$FF = Proposed\ FF - Existing\ FF \quad (3)$$

Functional loss is generated when the proposed condition score is lower than the existing condition, and the third equation above yields a negative value (a debit).

This paper provides four options to calculate functional loss, each is listed in Table 1. Option 1 is for permit applicants who do not want to perform an assessment of the project reach prior to the impact, nor use the SQT or debit calculator to determine the proposed after-impact score. This is the fastest and easiest method for determining functional loss and debits. Option 2 is to use the SQT to calculate the existing and proposed functional-foot scores. This method requires the user to quantitatively assess the existing condition and have detailed knowledge from project reports and watershed data to accurately estimate the proposed condition.

Option 3 is for those who choose to complete an existing condition assessment and use the debit calculator to estimate the proposed condition. This method is best suited for applicants who have the capability to monitor the existing condition, but do not have accurate data and information to model the proposed condition within the SQT. Finally, Option 4 is for those applicants who do NOT want to perform an assessment of the project reach prior to impact, but DO choose to use the debit calculator for the proposed condition score. Each method is described below with the most detail provided for the third option because it explains how the debit tool is used. Note, the proposed condition steps in option 3 are also used in option 4.

Option Number	**Existing Condition Score (ECS)**	**Proposed Condition Score (PCS)**
1	Assume a value of 1	Assume a value of 0
2	Use SQT	Use SQT
3	Use SQT	Use Debit Tool
4	Assume a value of 1	Use Debit Tool

Table 1: Options for determining functional loss at a permitted impact site.

3.1.1 Option 1: No Assessment

Permit applicants may choose to not perform an existing condition assessment, nor use the debit tool to calculate functional loss. In this case, the applicant simply assumes that the existing condition score is a 1.0, and the proposed condition score is a 0. The functional-foot calculation would yield a debit equal to the existing stream length. This is a simple approach that requires the permit applicant to only measure the existing stream length. This approach is probably best suited to small impacts, but could be used by anyone needing to provide mitigation. Since this approach assumes that the existing condition is undisturbed and the proposed (after impact) condition causes a total loss of stream function, it assures that the credits will equal or exceed the functional loss.

3.1.2 Option 2: Use the SQT for the Existing and Proposed Conditions

Permit applicants that have detailed information about the proposed impact condition may choose to use the SQT to model the existing and proposed condition. This option is best suited for companies or organizations with large impacts and professionals who understand fluvial geomorphology, stream restoration science and application, and biology.

If the SQT is used to model the proposed condition score, the debit tool described in Option 3 is not needed. However, this option requires two key elements. First, the applicant must complete an existing condition assessment as described below in Option 3. Second, the applicant must be able to accurately predict the functional loss through the geomorphology category of the SFPF using project design reports, drawings, field investigations, etc. Then, the applicant must be able to reasonably predict how these lower-level impacts will affect physicochemical and biology functions. This is why the professionals listed above are needed.

Before completing this option or the other options below, the following resources are needed. These spreadsheet tools and user manuals for the North Carolina version of the SQT can be downloaded from https://stream-mechanics.com/stream-functions-pyramid-framework/. These are provided as example templates that can be modified to fit the unique needs of each state or Corps District.

1. Stream Quantification Tool.
2. *Functional Lift Quantification Tool for Stream Restoration Projects in North Carolina*: *Spreadsheet User Manual*
3. *Functional Lift Quantification Tool for Stream Restoration Projects in North Carolina*: *Data Collection and Analysis Manual*
4. The Debit Calculator. This is used to predict the proposed condition score and calculate functional loss for Option 3 below.

3.1.3 Option 3: Perform Existing Condition Assessment and Use Debit Calculator

Option 3 requires the user to perform an existing condition assessment of the proposed impact reach in the same way as Option 2, using the SQT. Then, the applicant will use the debit calculator to estimate the proposed (after-impact) condition score and calculate functional loss. Detailed steps on using this option are provided below.

Step 1: Determine Existing and Proposed Stream Lengths

Existing Stream Length. Calculate the length of the stream that will be directly impacted by the permitted activity. Stream length should be measured along the centerline of the channel. For example, the channel length before a culvert is installed.

Proposed Stream Length. Calculate the length of stream channel after the impact has occurred. For pipes, the proposed length is the length of the pipe at a minimum. If the stream will be straightened by the permitted activity, the proposed length will be less than the existing length.

Step 2: Determine the Existing Condition Score and Complete the Catchment Assessment Form

A function-based assessment must be completed on the reach of stream that is proposed to be impacted. This will yield an existing condition score once the data are entered into the SQT. Most users will apply a rapid-based assessment method; however, detailed methods may be required for certain projects. Detailed- and rapid-based assessment methods that accompany the NC version of the SQT are described in the SQT Data Collection and Analysis Manual. These are provided as example templates that can be modified to fit the unique needs of each state or Corps District.

The applicant must also complete the catchment assessment form provided in the SQT spreadsheet. This form is used to provide an overall condition determination (good, fair, or poor) of the upstream watershed. This information can help inform some of the hydrologic, physicochemical and biological existing conditions, which are part of the rapid-based assessment.

Once the field and desktop data have been gathered, the SQT can be used to calculate an existing condition score. Note, the user is only completing the existing condition assessment within the SQT and not a proposed condition assessment. Once completed, the user will enter the existing condition score into the Debit Calculator and begin working on the Proposed Condition score.

Step 3: Determine the Impact Severity Tier

Determination of an impact severity tier is needed in order to calculate a Proposed Condition Score using the Debit Calculator. The impact severity tier is a categorical determination of the adverse impact to stream functions, ranging from no loss to total loss. Tier 0 represents no loss of stream functions and therefore would not require mitigation activities, i.e., there is no reason to use the debit tool if the impact severity tier is 0. Table 2 lists the impact severity tiers from 0 to 6 along with a description of impacts to key function-based parameters and example activities that may lead to those impacts.

Some activities could be in multiple tiers depending on the magnitude of the impact. For example, a small bank stabilization project may equate to a Tier 1 if only riparian vegetation and/or lateral stability parameters are impacted. However, if the project is large enough to impact physicochemical and/or biological functions, then the project would be a Tier 4 impact. The activities are only examples, and the tiers are selected based on predictions to the function-based parameters.

Tier	Description (Impacts to function-based parameters)	Example Activities
0	No impact	Bio-engineering of streambanks
1	Impacts to riparian vegetation and/or lateral stability.	Bank stabilization and utility crossings.
2	Impacts to riparian vegetation, lateral stability, and bed form diversity.	Utility crossings, bridges, bottomless arch culverts
3	Impacts to riparian vegetation, lateral stability, bed form diversity, and floodplain connectivity	Bottomless arch culverts, small channelization/grading projects
4	Impacts to riparian vegetation, lateral stability, bed form diversity, and floodplain connectivity. Potential impacts to temperature, processing of organic matter, macroinvertebrate and fish communities.	Channelization, Arch culverts, weirs/impoundments
5	Removal of all aquatic functions except for hydrology	Pipes
6	Removal of all aquatic functions	Complete Fill / Channel Relocation

Table 2: Impact severity tiers and example activities

The following is a description of each impact tier.

Tier 0. If the proposed activity does not impact any of the key function-based parameters, then the impact severity tier is 0 and the user does not need to continue with the debit tool.

Tiers 1 – 4. The applicant selects the tier that best fits the proposed activity. This information can come from project plans and documents, permit applications, discussions between the permit applicant and the regulatory agencies, etc.

Tier 5. This tier is exclusive to enclosed pipes. Any pipe that is installed into a stream channel will automatically be included in this tier.

Tier 6. This tier is exclusive to projects that completely fill the stream channel, so that the channel is eliminated. This will typically be channel relocation projects where the existing channel is totally filled or eliminated from the drainage network.

Hypothetical examples for each impact tier are provided in Appendix A to demonstrate how certain activities could be categorized by an impact tier.

Step 4: Calculate the Proposed Condition Score

Once the Impact Severity Tier has been selected, the Proposed Condition Score can be calculated. There are unique methods for determining the Proposed Condition Scores for tiers 5 and 6. The same method is used for tiers 1 through 4. Each is described below, starting with Tier 6.

<u>Tier 6</u>

There are three ways that the proposed condition score (PCS) may be determined. Activities that completely fill the channel remove all aquatic functions and are assigned to tier 6. Their PCS is an automatic 0, meaning that all aquatic functions have been eliminated.

<u>Tier 5</u>

Piping activities are assigned to tier 5, and the proposed condition score is calculated using the catchment hydrology and reach runoff function-based parameters within the hydrology functional category. During the existing condition assessment, the overall catchment health was determined along with an overall estimate of hydrologic condition using a good, fair, or poor designation. For the proposed condition score, the same existing condition score for catchment hydrology is used. The reach runoff parameter is scored as a 0.0 since natural runoff processes within the impacted reach are eliminated. The user enters the catchment hydrology parameter score into the debit tool and an overall hydrology score is calculated. This number is multiplied by 0.2 to determine an overall reach score. This process is consistent with how the overall score is calculated in the SQT. In this case, zero function is shown for hydraulics, geomorphology, physicochemical and biology. An example calculation is provided below.

1. Catchment hydrology score from catchment assessment equals an index value of 0.5, representing a fair hydrologic watershed condition.
2. A reach runoff score of 0.0 is used.
3. The hydrology functional category score is the average of the results from steps 1 and 2. For example, the average of 0.5 and 0.0 is 0.25.
4. The overall proposed condition score equals 0.25 X 0.2 = 0.05.
   Note, the calculation in number 4 represents zero scores in hydraulics, geomorphology, physicochemical, and biology.

<u>Tiers 1-4</u>

This method of calculating a proposed condition score is specific to activities that are assigned to tiers 1 through 4. The existing condition score and the impact tier are used to calculate the proposed condition using the multipliers shown in table 2 below. For example, if a proposed activity has an impact severity tier of 3 and an Existing Condition Score of 0.52, the proposed condition equation is 0.6 * 0.52 = 0.31. This means that the proposed condition is 60% of the existing condition. The inverse is also true; that there was a 40% loss in stream function.

These multipliers were developed from linear regression equations of modeled impact scenarios using a simplified version of the SQT. A detailed description of this process is provided in Appendix B.

Impact Severity Tier	PCS Equation	Percent Loss
1	PCS = 0.9 * ECS	10%
2	PCS = 0.8 * ECS	20%
3	PCS = 0.6 * ECS	40%
4	PCS = 0.3 * ECS	70%

Table 2: PCS Equations.

Step 5: Calculate the Existing Functional Foot (EFF) using the following equation.

EFF = Existing Condition Score X Existing Stream Length

Step 6: Calculate the Proposed Functional Foot (PFF) using the following equation.

PFF = Proposed Condition Score X Proposed Stream Length

Step 7: Calculate functional loss (debit) using the following equation.

Debit = PFF – EFF

If the debit score is zero or a positive number, then mitigation would not be required. If the number is negative, then the absolute value of the debit is required as credits to equal no net loss of aquatic stream function.

Hypothetical Example of Functional Loss Calculation

A local government is proposing to channelize 3,000 linear feet of perennial stream to increase flood protection for adjacent landowners. The existing channel is enlarged to accommodate the 100-year flood event. The streambanks are rip rapped and woody riparian vegetation is replaced with grass. The bed of the channel remains natural, but all wood is removed and the channel is straightened.

The following shows how results from the first three steps can be used to calculate a debit.

Step 1: Existing Stream Length = 3,000 feet
Proposed Stream Length = 2,700 feet

Step 2: Existing Condition Score = 0.45

Step 3: Impact Severity Tier = Tier 4

Step 4: Proposed Condition Score equation for Tier 4
PCS = 0.3 * ECS

PCS = 0.3* 0.45
PCS = 0.14

Step 5: Existing Functional Foot Score
EFF = Existing Condition Score X Existing Stream Length
EFF = 0.45 * 3,000
EFF = 1,350

Step 6: Proposed Functional Foot Score
PFF = Proposed Condition Score X Proposed Stream Length
PFF = 0.14 *2,700
PFF = 378

Step 7: Debit = PFF – EFF
Debit = 378 – 1,350
Debit = -972 or 972 credits needed

3.1.3 Option 4: No Existing Condition Assessment, but Use Debit Calculator

Option 4 is for applicants choosing to not assess the impact reach using the SQT (existing condition), and choosing to use the debit calculator to estimate the proposed condition score. This option assumes that the existing condition score is a 1.0 since an assessment is not completed. However, instead of assuming the proposed condition score is a 0, the debit calculator is used to predict the proposed condition score using the impact tiers and PCS multipliers as described in option 3.

4.0 Conclusion

This paper introduces a methodology to calculate the functional loss (debit) of permitted impacts to stream ecosystems. The purpose is to provide Interagency Review Teams (IRTs) with a conceptual model for calculating functional loss (debits) that can complement the existing Stream Quantification Tool (SQT) that calculates functional lift (credits). The debit represents the amount of credits required to mitigate for the permitted loss to stream functions. The functional loss calculation uses the same logic and math as the SQT to ensure that the functional gain from mitigation equals or exceeds the functional loss from the permitted impact. A debit calculator is needed to determine the functional loss at permitted impact sites when sufficient information is not available to model the proposed condition in the SQT.

The concepts and ideas shared in this paper may need to be adapted and refined to fit the regulatory requirements and needs for a given state or Corps District. Likewise, the regression equations used in the Debit Calculator can be improved with local data from impacted streams.

The functional loss calculation does not consider temporal loss or make any adjustments based on the proximity of the mitigation to the impact, watershed need, or other factors that may be important to an overall debiting/crediting program. Regulatory agencies may consider creating "add on" debits or credits that deal with these issues.

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Appendix A
Hypothetical Examples of Impacts by Impact Severity Tier

The following hypothetical examples illustrate how a proposed project description can be used to match an activity to an impact severity tier. In real-world scenarios, the permit applicant would use project reports, discussions with regulators, and available site-specific data to make these determinations. The key is to link the activity to the function-based parameters being impacted. Note, any of the following examples could yield a higher-level tier if the scale of the impact negatively effects more function-based parameters than what is described in the current-level tier.

Impact Tier 1: Power Line Crossing

__Project Description.__ A utility company proposes to install large power lines parallel to a perennial stream. To complete the project, the company must remove the riparian vegetation within the stream corridor and along the left streambank for 600 linear feet of channel. The power poles are located a short distance from the top of the streambank. The maintenance plan calls for the treatment of riparian vegetation that exceeds a certain height. Rip rap is used to stabilize streambanks; it is placed from the bottom edge of the stream channel to the top of the bank.

__Function-Based Parameters Impacted.__ Riparian vegetation will be removed and therefore impacted. Lateral stability may be impacted by the removal of vegetation; installation of rip rap may disrupt natural lateral stability (migration) rates. Therefore, the two parameters impacted are riparian vegetation and lateral stability.

Impact Tier 2: Sewer Crossing

__Project Description.__ A utility company proposes to install a new sewer line across a perennial stream. The elevation of the pipe will be below the streambed. To install the pipe, riparian and streambank vegetation will be removed for a certain length of the stream. The streambank vegetation will be replaced with rip rap. The bed of the channel will be excavated to install the pipe. Natural bed material will be replaced with rip rap to protect the pipe. The rip rap will not cause backwater conditions upstream of the crossing, i.e. the rip rap elevation will equal the bed elevation prior to pipe installation.

__Function-based Parameters Impacted.__ Riparian vegetation will be removed and therefore impacted. Lateral stability will be impacted by the removal of vegetation and the installation of rip rap. The bed form diversity will be impacted by the removal of a natural bed feature (riffle and/or pool) and replacement with a rip rapped streambed. Note: If the rock placed in the streambed creates significant backwater conditions, additional function-based parameters (such as temperature, macroinvertebrates, and fish) could be negatively affected and the severity tier could increase to Tier 4. Conversely, if the applicant chooses to bury the pipe well below the bed elevation so that rip rap is not needed and bedforms are not impaired, then the impact severity tier may be reduced to a Tier 1 because lateral stability and riparian vegetation are the only function-based parameters affected.

Impact Tier 3: Bottomless-Arch Culvert

Project Description. A residential development is being proposed and a new road needs to cross an intermittent stream. The developer is proposing to install a bottomless-arch culvert that spans the channel, plus another percentage of the channel width. The bottom width of the channel will be widened to match the arch-culvert dimensions. The stream will be straightened to provide proper alignment with the arch culvert, decreasing the stream length by a certain percentage. Riparian vegetation will be removed on both sides of the stream to accommodate the new road.

Function-based Parameters Impacted. Riparian vegetation will be removed and therefore impacted. The bedform diversity will be impacted because the channel is being widened to accommodate the arch-culvert, and the arch-culvert will disrupt the riffle-pool sequence within the culvert, but not upstream or downstream. Floodplain connectivity will be negatively impacted because the channel is being enlarged (widened). Higher-order functions in physicochemical and biology are not affected in this example. However, if higher-order function-based parameters are affected, the impact severity tier would increase to tier 4.

Impact Tier 4: Channelization

Project Description. A local government is proposing to channelize a long stretch of perennial stream to increase flood protection for adjacent landowners. The existing channel is enlarged to accommodate the 100-year flood event. The streambanks are rip rapped and woody riparian vegetation is replaced with grass. The bed of the channel remains natural, but all wood is removed and the channel is straightened.

Function-based Parameters Impacted. Woody riparian vegetation will be removed replaced with grass, and therefore negatively impacted. Bedform diversity will be impacted because the channel will be straightened and wood removed, thus eliminating pool-forming processes. The channel will be enlarged to carry the 100-year flood, which negatively impacts floodplain connectivity by reducing floodplain inundation and storage. These same activities, decrease the stream's ability to retain and process organic matter and regulate temperature. The increase in channel width increases the risk of bed aggradation. Since bed forms (habitat) have been removed and the project is large enough to increase temperatures and decrease organic processing, there will be a negative impact to macroinvertebrate and fish communities.

Appendix B
Proposed Condition Score Modeling

Development of PCS Equations

The following information is not needed to use the debit calculator, but is provided for those who are interested in knowing how the equations shown in Table 2 were developed. The multipliers shown in Table 2 are the slope values from the regression equations shown in Figure A1. The y-intercepts equal zero for each regression line and have no influence on the final answer; therefore, the y-intercept values were removed leaving the slope as the multiplier. This simplifies the math and improves communication. For example, the multiplier can also be expressed as a percent of functional loss, which may be more intuitive than a multiplier.

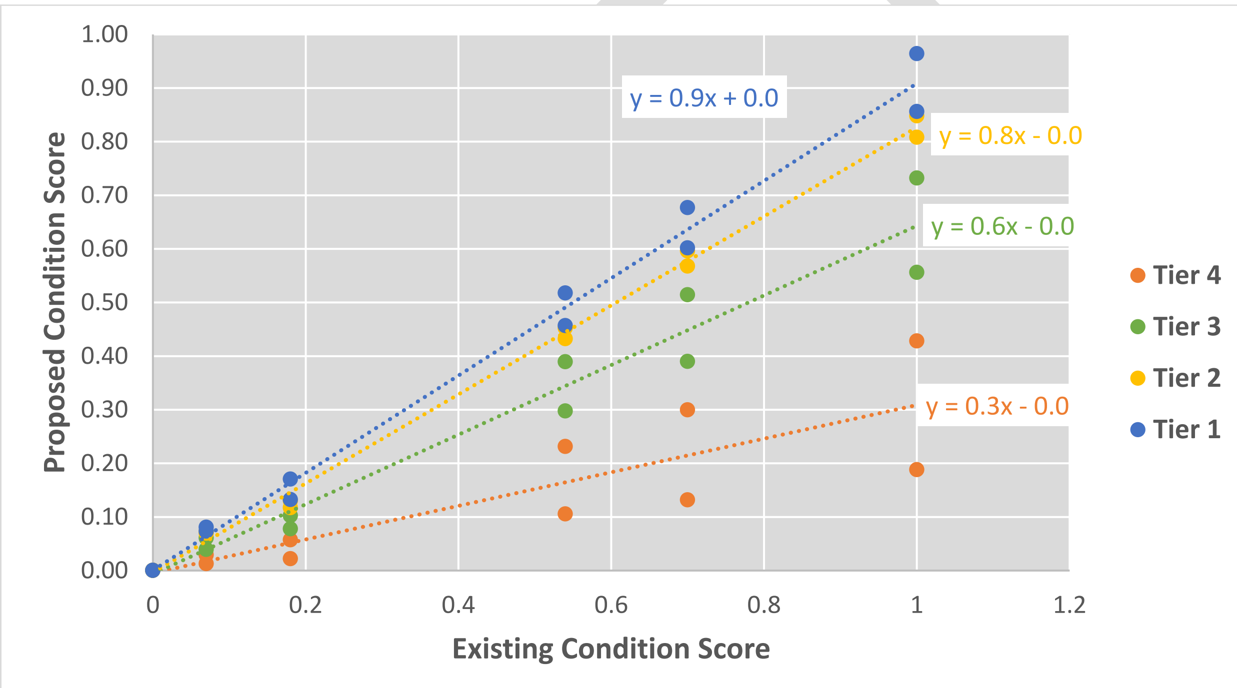

Figure A1: Proposed Condition Scores based on Existing Condition Score and Impact Severity Tier

The regression lines in Figure A1 were created by modeling impacts to function-based parameters as defined by the impact severity tiers (Shown in Table 1). In order to describe impacts to channels that span a range of possible existing conditions, values were assigned to parameters to yield existing condition scores of 0.08, 0.18, 0.54, 0.70 and 1.00. These overall scores are used to create the x-axis in Figure A1. The results by parameter are shown in Table A1.

Function-Based Parameters	Existing Condition				
Existing Condition Score (ECS)	**1**	**0.70**	**0.54**	**0.18**	**0.08**
Catchment Hydrology	1	0.70	0.58	0.1	0.05
Reach Runoff	1	0.70	0.67	0.36	0.08
Floodplain Connectivity	1	0.71	0.50	0.16	0.10
Large Woody Debris	1	0.70	0.47	0.16	0.07
Lateral Stability	1	0.67	0.40	0.25	0.05
Riparian Vegetation	1	0.70	0.46	0.44	0.06
Bed Form Diversity	1	0.72	0.55	0.30	0.10
Sinuosity	1	0.70	0.70	0.00	0.30
Temperature	1	0.67	0.53	0.20	0.07
Organic Matter	1	0.67	0.48	0.24	0.08
Nitrogen	1	0.74	0.50	0.20	0.08
Phosphorus	1	0.74	0.50	0.20	0.03
Macroinvertebrates	1	0.69	0.60	0.17	0.06
Fish	1	0.70	0.49	0.00	0.08

Table A1: Modeled Existing Condition Parameter Scores.

Next, a matrix was created showing how each function-based parameter could be impacted for each impact severity tier. This matrix is shown on Table A2 and illustrates how impacts to function-based parameter increase with increasing tier number. Using best professional judgement and scores from existing case studies, each function-based parameter under each impact severity tier was assigned a functional loss value, ranging from no impact to 100% functional loss (see the descriptions in Table A2). For many function-based parameters, a more moderate range of loss was modeled. For example, impacts to bedform diversity under a tier 2 impact severity yields a range of loss from 20 to 80% depending on impacts to the riffle-pool sequence. Using a range acknowledges the uncertainty in matching a given activity to the impact of a specific function.

Therefore, the actual model runs included a minimum and maximum score for each existing condition score. The minimum proposed condition score and the maximum proposed condition score are plotted on Figure A1 for each existing condition score. For example, the existing condition score of 1.0 for Tier 4 yields a minimum proposed condition score of 0.19 and a max of 0.43 (Refer to Figure A1). Each modeled scenario by existing condition score is provided in tables A3 through A7.

Once the graphs were created, linear regression equations were used to create best-fit lines through the minimum and maximum points. The regression is intended to represent the typical proposed condition score per impact severity tier. These equations produced the multipliers shown in Table 2 (see main body of report).

Function-Based Parameter	Tier 1	Tier 2	Tier 3	Tier 4
Catchment Hydrology	No impact	No impact	No impact	No impact
Reach Runoff	Minimal impact to lateral drainage and compaction. (20 – 80% functional loss)	Minimal impact to lateral drainage and compaction. (80% functional loss)	Significant impact to lateral drainage and compaction. (100% functional loss)	Significant impact to lateral drainage and compaction. (100% functional loss)
Floodplain Connectivity	No impact	No impact	Connection to the natural floodplain is impacted. (20 – 80% functional loss)	Connection to the natural floodplain is impacted. (100% functional loss)
Large Woody Debris	No impact	No impact	Woody debris is removed and regularly cleared from the channel. (20 – 100% functional loss)	Woody debris is removed and regularly cleared from the channel. (100% functional loss)
Lateral Stability	Natural migration rates are impacted. (20 – 80% functional loss)	Natural migration rates are impacted. (80 – 100% functional loss)	Natural migration rates are impacted. (100% functional loss)	Natural migration rates are impacted. (100% functional loss)
Riparian Vegetation	Natural vegetation is removed or not allowed to grow. (20 – 80% functional loss)	Natural vegetation is removed or not allowed to grow. (80 – 100% functional loss)	Natural vegetation is removed or not allowed to grow. (100% functional loss)	Natural vegetation is removed or not allowed to grow. (100% functional loss)
Bed form diversity	No impact	Impacts to riffle-pool sequence and/or heterogeneity. (20 – 80% functional loss)	Impacts to riffle-pool sequence and/or heterogeneity. (80% functional loss)	Impacts to riffle-pool sequence and/or heterogeneity. (80% functional loss)
Sinuosity	No impact	No impact	Minimal Impacts (20 – 80% functional loss)	Channel is straightened (80% functional loss)
Temperature	No impact	No impact	No impact	Moderate impacts (20 – 80% functional loss)
Nitrogen	No impact	No impact	No impact	Moderate impacts (20 – 80% functional loss)
Phosphorus	No impact	No impact	No impact	Moderate impacts (20 – 80% functional loss)
Organic Matter	No impact	No impact	No impact	Moderate impacts (20 – 80% functional loss)
Macroinvertebrates	No impact	No impact	No impact	Moderate impacts (20 – 80% functional loss)
Fish Communities	No impact	No impact	No impact	Moderate impacts (20 – 80% functional loss)

Table A2. Modeled function-based parameters for each impact severity tier.

Table A3: Model with An Existing Condition Score of 1.0

Function-Based Parameters	Existing Condition	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
		Tier 1	**Tier 1**	**Tier 2**	**Tier 2**	**Tier 3**	**Tier 3**	**Tier 4**	**Tier 4**
Catchment Hydrology	1	1	1	1	1	1	1	1	1
Reach Runoff	1	0.8	0.2	0.2	0.2	0	0	0	0
Floodplain Connectivity	1	1	1	1	1	0.8	0.2	0	0
Large Woody Debris	1	1	1	1	1	0.8	0	0	0
Lateral Stability	1	0.8	0.2	0.2	0	0	0	0	0
Riparian Vegetation	1	0.8	0.2	0.2	0	0	0	0	0
Bed Form Diversity	1	1	1	0.8	0.2	0.2	0.2	0	0
Sinuosity	1	1	1	1	1	0.8	0.2	0.2	0.2
Temperature	1	1	1	1	1	1	1	0.8	0.2
Organic Matter	1	1	1	1	1	1	1	0.8	0.2
Nitrogen	1	1	1	1	1	1	1	0.8	0.2
Phosphorus	1	1	1	1	1	1	1	0.8	0.2
Macros	1	1	1	1	1	1	1	0.8	0.2
Fish	1	1	1	1	1	1	1	0.8	0.2
Hydrology	1.00	0.90	0.60	0.60	0.60	0.50	0.50	0.50	0.50
Hydraulics	1.00	1.00	1.00	1.00	1.00	0.80	0.20	0.00	0.00
Geomorphology	1.00	0.92	0.68	0.64	0.44	0.36	0.08	0.04	0.04
Physicochemical	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.20
Biology	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.20
Existing Condition Score (ECS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Proposed Condition Score (PCS)		0.96	0.86	0.85	0.81	0.73	0.56	0.43	0.19
Functional Loss Score		-0.04	-0.14	-0.15	-0.19	-0.27	-0.44	-0.57	-0.81
Percent Condition Loss		-4%	-14%	-15%	-19%	-27%	-44%	-57%	-81%

Table A4: Model with Existing Condition Score of 0.70

Function-Based Parameters	Existing Condition	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
		Tier 1	Tier 1	Tier 2	Tier 2	Tier 3	Tier 3	Tier 4	Tier 4
Catchment Hydrology	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Reach Runoff	0.7	0.56	0.14	0.14	0.14	0	0	0	0
Floodplain Connectivity	0.71	0.71	0.71	0.71	0.71	0.568	0.142	0	0
Large Woody Debris	0.7	0.7	0.7	0.7	0.7	0.56	0	0	0
Lateral Stability	0.67	0.536	0.134	0.134	0	0	0	0	0
Riparian Vegetation	0.7	0.56	0.14	0.14	0	0	0	0	0
Bed Form Diversity	0.72	0.72	0.72	0.576	0.144	0.144	0.144	0	0
Sinuosity	0.7	0.7	0.7	0.7	0.7	0.56	0.14	0.14	0.14
Temperature	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.536	0.134
Organic Matter	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.536	0.134
Nitrogen	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.592	0.148
Phosphorus	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.592	0.148
Macros	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.552	0.138
Fish	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.56	0.14
Hydrology	0.70	0.63	0.42	0.42	0.42	0.35	0.35	0.35	0.35
Hydraulics	0.71	0.71	0.71	0.71	0.71	0.57	0.14	0.00	0.00
Geomorphology	0.70	0.64	0.48	0.45	0.31	0.25	0.06	0.03	0.03
Physicochemical	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.56	0.14
Biology	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.56	0.14
Existing Condition Score (ECS)	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Proposed Condition Score (PCS)		0.68	0.60	0.60	0.57	0.51	0.39	0.30	0.13
Functional Loss Score		-0.02	-0.10	-0.11	-0.13	-0.19	-0.31	-0.40	-0.57
Percent Condition Loss		-4%	-14%	-15%	-19%	-27%	-44%	-57%	-81%

Table A5: Model with an Existing Condition Score of 0.54

Function-Based Parameters	Existing Condition	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
		Tier 1	Tier 1	Tier 2	Tier 2	Tier 3	Tier 3	Tier 4	Tier 4
Catchment Hydrology	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Reach Runoff	0.67	0.536	0.134	0.134	0.134	0	0	0	0
Floodplain Connectivity	0.5	0.5	0.5	0.5	0.5	0.4	0.1	0	0
Large Woody Debris	0.47	0.47	0.47	0.47	0.47	0.376	0	0	0
Lateral Stability	0.4	0.32	0.08	0.08	0	0	0	0	0
Riparian Vegetation	0.46	0.368	0.092	0.092	0	0	0	0	0
Bed Form Diversity	0.55	0.55	0.55	0.44	0.11	0.11	0.11	0	0
Sinuosity	0.7	0.7	0.7	0.7	0.7	0.56	0.14	0.14	0.14
Temperature	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.424	0.106
Organic Matter	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.384	0.096
Nitrogen	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.1
Phosphorus	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.1
Macros	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.48	0.12
Fish	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.392	0.098

Hydrology	0.63	0.56	0.36	0.36	0.36	0.29	0.29	0.29	0.29
Hydraulics	0.50	0.50	0.50	0.50	0.50	0.40	0.10	0.00	0.00
Geomorphology	0.52	0.48	0.38	0.36	0.26	0.21	0.05	0.03	0.03
Physicochemical	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.10
Biology	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.11

Existing Condition Score (ECS)	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Proposed Condition Score (PCS)		0.52	0.46	0.45	0.43	0.39	0.30	0.23	0.11
Functional Loss Score		-0.02	-0.08	-0.09	-0.11	-0.15	-0.24	-0.31	-0.43
Percent Condition Loss		-4%	-15%	-16%	-20%	-28%	-45%	-57%	-80%

Table A6: Model with an Existing Condition Score of 0.18

Function-Based Parameters	Existing Condition	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
		Tier 1	Tier 1	Tier 2	Tier 2	Tier 3	Tier 3	Tier 4	Tier 4
Catchment Hydrology	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Reach Runoff	0.36	0.288	0.072	0.072	0.072	0	0	0	0
Floodplain Connectivity	0.16	0.16	0.16	0.16	0.16	0.128	0.032	0	0
Large Woody Debris	0.16	0.16	0.16	0.16	0.16	0.128	0	0	0
Lateral Stability	0.25	0.2	0.05	0.05	0	0	0	0	0
Riparian Vegetation	0.44	0.352	0.088	0.088	0	0	0	0	0
Bed Form Diversity	0.3	0.3	0.3	0.24	0.06	0.06	0.06	0	0
Sinuosity	0	0	0	0	0	0	0	0	0
Temperature	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.16	0.04
Organic Matter	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.192	0.048
Nitrogen	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.16	0.04
Phosphorus	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.16	0.04
Macros	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.136	0.034
Fish	0	0	0	0	0	0	0	0	0

Hydrology	0.23	0.19	0.09	0.09	0.09	0.05	0.05	0.05	0.05
Hydraulics	0.16	0.16	0.16	0.16	0.16	0.13	0.03	0.00	0.00
Geomorphology	0.23	0.20	0.12	0.11	0.04	0.04	0.01	0.00	0.00
Physicochemical	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.17	0.04
Biology	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.07	0.02

Existing Condition Score (ECS)	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Proposed Condition Score (PCS)		0.17	0.13	0.13	0.12	0.10	0.08	0.06	0.02
Functional Loss Score		-0.01	-0.05	-0.05	-0.07	-0.08	-0.11	-0.13	-0.16
Percent Condition Loss		-7%	-28%	-29%	-36%	-44%	-57%	-69%	-88%

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Existing Condition Score (ECS)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Proposed Condition Score (PCS)		0.11	0.07	0.07	0.06	0.04	0.02	0.01	0.01
Functional Loss Score		-0.01	-0.05	-0.05	-0.07	-0.08	-0.11	-0.11	-0.11
Percent Condition Loss		-10%	-41%	-43%	-53%	-65%	-85%	-92%	-92%

Table A7: Model with an Existing Condition Score of 0.07

Function-Based Parameters	Existing Condition	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
		Tier 1	Tier 1	Tier 2	Tier 2	Tier 3	Tier 3	Tier 4	Tier 4
Catchment Hydrology	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Reach Runoff	0.08	0.064	0.016	0.016	0.016	0	0	0	0
Floodplain Connectivity	0.1	0.1	0.1	0.1	0.1	0.08	0.02	0	0
Large Woody Debris	0.07	0.07	0.07	0.07	0.07	0.056	0	0	0
Lateral Stability	0.05	0.04	0.01	0.01	0	0	0	0	0
Riparian Vegetation	0.06	0.048	0.012	0.012	0	0	0	0	0
Bed Form Diversity	0.1	0.1	0.1	0.08	0.02	0.02	0.02	0	0
Sinuosity	0.3	0.3	0.3	0.3	0.3	0.24	0.06	0.06	0.06
Temperature	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.056	0.014
Organic Matter	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.064	0.016
Nitrogen	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.064	0.016
Phosphorus	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.024	0.006
Macros	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.048	0.012
Fish	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.064	0.016
Hydrology	0.07	0.06	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Hydraulics	0.10	0.10	0.10	0.10	0.10	0.08	0.02	0.00	0.00
Geomorphology	0.12	0.11	0.10	0.09	0.08	0.06	0.02	0.01	0.01
Physicochemical	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.01
Biology	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.01
Existing Condition Score (ECS)	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Proposed Condition Score (PCS)		0.08	0.07	0.07	0.07	0.06	0.04	0.03	0.01
Functional Loss Score		0.00	-0.01	-0.01	-0.01	-0.02	-0.04	-0.05	-0.07
Percent Condition Loss		-3%	-12%	-13%	-17%	-27%	-53%	-65%	-85%