# Lake Superior Brook Trout Conservation and Prioritization Report

Prepared for Ashland Fish and Wildlife Conservation Office

Downstream Strategies
Ideas That Sustain

# Contents

# 1. INTRODUCTION

This report describes an effort undertaken to prioritize regions within the Lake Superior basin of the United States for certain conservation and restoration activities for the benefit of brook trout (*Salvelinus fontinalis)*. The process described herein was executed by Downstream Strategies (DS) with significant input and participation from the U.S. Fish and Wildlife Service's Ashland Fish and Wildlife Conservation Office, of Ashland, Wisconsin.

This project was initiated within the context of Strategic Habitat Conservation (SHC), a framework developed to guide habitat restoration for priority species for the United States Fish and Wildlife Service (USFWS). Previous to this effort, many components of the SHC process had already been completed, such as the designation of priority species (brook trout), population delineation (Lake Superior Basin), and population objectives. The population objectives for brook trout in the Lake Superior Basin were defined in Newman et al. 2003, and are listed in Figure 1. Other key components (assessment of current population and identification of limiting factors) were previously addressed, but were also revisited in this project. The primary focus of this project is on the previously unaddressed component of the SHC framework, which seeks to designate priority focal areas.

**Figure 1. Population objectives as defined in Newman et al. 2003**

- Populations will be self-sustaining and capable of co-existing with populations of naturalized salmonines in the existing fish community.
- Populations will be geographically widespread, inhabiting the areas that historically held viable populations, provided that tributary and lake habitat conditions in these areas are still suitable, or that they can be restored.
- Populations will be comprised of six or more age-groups (ages 0-5), including at least two spawning year-classes of females; spawning populations will exhibit densities sufficient to ensure viable gene pools.
- Populations will exhibit genetic profiles consistent with those of populations currently existing in the Lake Superior basin.
- Essential habitat in tributaries will be protected and, where necessary, rehabilitated on a lakewide basis.

In order to identify and designate focal areas, we used a predictive model, anthropogenic stress and habitat quality indices, climate vulnerability assessment, and numerous other datasets. With these, we created several conservation scenarios to prioritize brook trout restoration and protection actions within the Lake Superior Basin. These results are summarized to designate priority focal areas for strategic brook trout habitat conservation actions.

# 2. PREDICTIVE MODEL

## 2.1 Objectives

A major component of the effort was the development of a predictive model of brook trout distributions both under current climate regimes and potential future climate regimes. This model helps to fill in the gaps of observation and survey data, which are, necessarily, specific to a small geography, and builds on existing assessments. Understanding the distribution of brook trout allows for the assessment of current conditions and is a vital element of any prioritization and assessment. This predictive model utilizes previously established methods.

Specifically, we:

1 – Constructed a boosted regression tree (BRT) model that could reliably estimate the probability of brook trout occurrence in 1:100K scale catchments throughout the Lake Superior Basin;

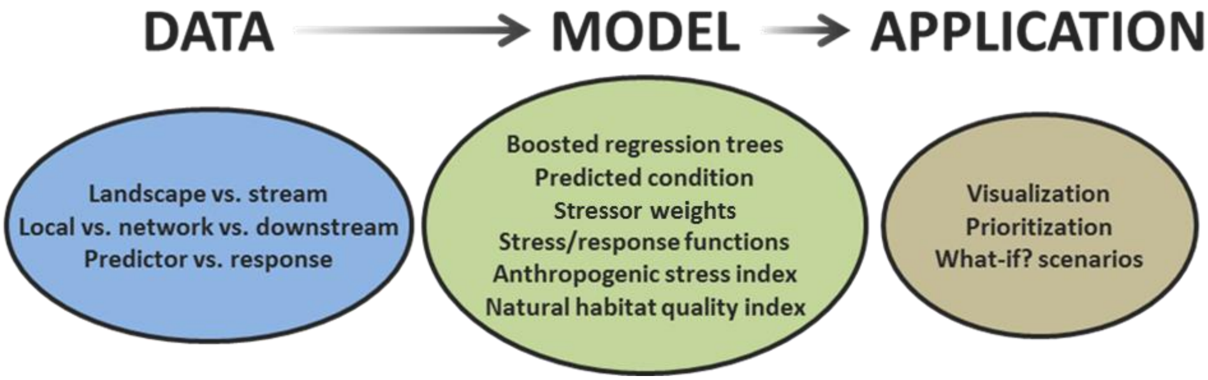
2 – Used BRT model outputs to calculate measures of underlying natural habitat quality and anthropogenic stress;

3 – Assessed future climate scenarios and the potential impact to brook trout populations (change in occupancy, stress, and natural habitat quality); and

4 – Created analytical tools to facilitate visualization of data and model results, prioritization of conservation actions.

A diagram of the general assessment process is outlined in Figure 2. DS acquired landscape and aquatic data from multiple sources to develop models and tools for visualizing expected current and potential future conditions and for prioritizing management actions.

**Figure 2: Diagram of the habitat assessment process**



## 2.2 Assessment Methodology

### 2.2.1 *Data*

The model utilized numerous predictor variables in order to generate a single response variable.

**Predictor Variables**

Predictor variables for this modeling methodology utilized landscape-level factors, such as land use or land cover classifications, soil type, and climatic factors. Many of these datasets were derived from geographic information systems (GIS) and reported as percentages. Examples include percent impervious surface area or road crossing density. The predictor variables were compiled at multiple scales, including the local scale (e.g., single 1:100k NHD stream catchment), and the network scale (e.g., all upstream catchments and the local catchment). A more detailed discussion about the predictor variables utilized for this model can be found in Section 2.3.1 and details on compilation and processing of this data can be found in Appendix C.

**Response Variable**

Boosted Regression Tree (BRT) models can produce response variables of three types: count data, continuous data, or binary data. The response variable for this project was binary type (1/0), indicating the presence or absence of brook trout. DS compiled fish sample data from known collections and then utilized the most recent sample within each catchment to create the final presence-absence response for modeling. This resulted in a single value of presence-absence for each catchment where a sample was taken. Although the predictor variables were compiled from datasets created at multiple scales, the response variable was always measured at the local scale (e.g., individual sample site on a stream).

### 2.2.2 *Boosted Regression Trees*

Previous fish habitat assessments completed by DS in conjunction with USFWS utilized boosted regression trees (BRT), a machine learning statistical method. DS staff and partners, along with the stakeholders of previously completed National Fish Habitat Partnership (FHP) assessments, decided upon BRT over competing methodologies after comparing and contrasting the strengths and weaknesses of each. BRT models combine decision trees and boosting methodologies, which often result in better cross-validated models than other methods (Elith et al., 2006), including classification and regression trees (CART). Decision trees are advantageous because (1) they can incorporate any type of predictor data (binary, numeric, categorical); (2) model outcomes are unaffected by differing scales of predictors; (3) irrelevant predictors are rarely selected; (4) they are insensitive to outliers and non-normalized data; (5) they can accommodate missing predictor data; (6) they can accommodate co-varying predictor variables; and (7) they can automatically handle interactions between predictors (Elith et al., 2008). The boosting algorithm used by BRT improves upon the accuracy of a basic regression tree approach by following the idea that averaging many models offers efficiency over finding a single prediction rule that is highly accurate (Elith et al., 2008). The software used to create the BRT models was R utilizing the 'gbm' package and source code from Elith et. al 2008 supplemental materials.

The modeling process results in a series of quantitative outcomes, including: predictions of expected current conditions of all catchments in the modeling area, measurement of prediction accuracy, a measure of each predictor's relative influence on the predictions (i.e., variable importance), and a series of plots illustrating the modeled functional relationship between each predictor and the response. The predictions of current conditions were created by extrapolating the BRT model to all catchments within the modeling area. The unit of the predicted current condition for this assessment is the probability of brook trout presence. These current conditions are useful for assessing habitats and mapping the expected range of species.

Predictive accuracy was quantified using an internal cross-validation (CV) method (Elith et al., 2008). The method consists of randomly splitting the input dataset into ten equally-sized subsets, developing a BRT model on a single subset and testing its performance on the remaining nine, and then repeating that process for the remaining nine subsets. Thus, the accuracy measures, such as the CV receiver operating characteristic (ROC) score and the CV correlation coefficient, are actually averages of ten separate ROC or correlation measurements. A standard error for the ten estimates is also provided. CV measures are designed to estimate how well the model will perform using independent data (i.e., data not used to build the model).

The BRT output includes a list of the predictor variables used in the model ordered and scored by their relative importance. The relative importance values are based on the number of times a variable is selected for splitting, weighted by the squared improvement to the model as a result of each split, and averaged over all trees (Friedman and Meulman, 2003). The relative influence score is scaled so that the sum of the scores for all variables is 100, where higher numbers indicate greater influence.

The BRT output also contains quantitative information on partial dependence functions that can be plotted to visualize the effect of each individual predictor variable on the response after accounting for all other variables in the model. Similar to the interpretation of traditional regression coefficients, the function plots are not always a perfect representation of the relationship for each variable, particularly if interactions are strong or predictors are strongly correlated. However, they do provide a useful and objective basis for interpretation (Friedman, 2001; Friedman and Meulman, 2003).

### 2.2.3 *Residual Analysis*

Analyzing patterns of omission and commission may highlight regions where the model is performing well or poorly or could suggest missing explanatory variables. Residuals are calculated by the BRT model and are used to assess misclassification, both false positive and false negative. The residuals are a measure of the difference in the measured and modeled values (measured value *minus* modeled value). Negative residuals indicate over-predictions (predicting higher values than are true, false positive), while positive residuals indicate under-predictions (predicting lower values than are true, false negative).

### 2.2.4 *Derivation of Anthropogenic Stress Index and Habitat Quality Index*

Characterizing anthropogenic stress and natural habitat quality of aquatic habitats is a necessary process for helping natural resource managers identify place-based conservation and restoration strategies. A post-modeling process was used to characterize anthropogenic stress and natural habitat quality for all catchments within the study area. Stress and natural habitat quality indices and metrics were identified and calculated based on BRT model outputs. Details of those calculations are below.

Once developed, these indices of stress and habitat quality can be used to generate and visualize restoration and protection priorities by analyzing how stress reduction can increase the probability of brook trout presence. For example, areas of high natural quality and low stress could represent protection priorities, whereas areas of high natural quality and high stress may represent restoration priorities. In addition, we can quantify how climate change may affect brook trout distributions through an effect on underlying natural habitat quality over time.

**Anthropogenic stress**

Stress indices are useful for evaluating anthropogenic landscape drivers—that is, **elements on the landscape of distinctly human origin** such as agriculture—that structure aquatic responses. Natural resource managers can use stress indices and metrics to assess how anthropogenic processes are impacting aquatic responses and can utilize this information to select site restoration projects in order to maximize efficiency. Individual stressors were identified by examining BRT model outputs, including both the variable influence table and the functional relationship between predictor variables and response variable. Any predictor variable significantly affected by anthropogenic disturbance was included as a potential stressor.

Individual stress metrics were calculated by determining the increase in probability of presence for each catchment when the statistical effect of that predictor variable was removed. A new predictor variable dataset was produced to calculate each individual stressor metric. The new predictor dataset contained the same values as the original predictor dataset except for a single anthropogenic variable for which a stress metric was calculated. For this variable, the values were all set to reflect “no stress.” This provided a hypothetical baseline that represented the removal of all stress from that predictor variable. The existing BRT model was then applied to the new hypothetical landscape data to provide an extrapolation of the current model assuming zero stress for that stressor.

All the stressors used had examples of "no stress" in the training dataset used to build the model, which ensures that calculations of stress were not derived by extrapolating the model beyond the range of the data. The difference between the current predicted probability of presence and the probability of presence under this "no stress" situation indicated change that could be attributed to stress. This process was repeated for each stressor to generate individual metrics of stress on a 0-1 scale. Higher stress values indicated a larger change in predicted probability of presence after removing stress, and lower stress values indicated that the catchment was relatively unaffected by removing stress (Table 1).

For each catchment, the individual stress metrics (e.g. agriculture stress and road crossing stress) were summed to produce an overall stress metric, the anthropogenic stress index (ASI). The generalized formulas for calculating individual stress metrics and ASI are as follows:

$$\begin{aligned} &\mathit{individual\ stress\ metric} \\ &\quad = \mathit{probability\ of\ presence}_{\mathit{no\ stress}} - \mathit{probability\ of\ presence}_{\mathit{current}} \end{aligned}$$

$$\mathit{anthropogenic\ stress\ index}\ (\mathit{ASI}) = \sum \mathit{individual\ stress\ metrics}$$

**Table 1: Example of stress calculations**

| Comid | Current Condition Predictions | Stressor 1 Predictions | Stressor 1 Metric | Stressor 2 Predictions | Stressor 2 Metric | Anthro. Stress Index (ASI) |
|---|---|---|---|---|---|---|
| **Catchment ID** | **Predicted probability of occurrence using current landscape data** | **Predicted probability of occurrence when stressor 1 removed** | **(Stressor 1 pred – Current Pred)** | **Predicted probability of occurrence when stressor 2 removed** | **(Stressor 2 pred – Current Pred)** | **Stressor 1 Metric + Stressor 2 Metric** |
| 1234567 | 0.80 | 0.90 | 0.10 | 0.80 | 0 | 0.10 |
| 1234568 | 0.25 | 0.50 | 0.25 | 0.35 | .10 | 0.35 |
| 1234569 | 0.5 | 0.7 | 0.2 | 0.55 | .05 | 0.25 |

### Natural habitat quality

Natural habitat quality metrics provide baseline information on the optimal potential condition of a catchment. We defined natural quality as the **maximum probability of presence under a zero-stress situation**; essentially, the highest attainable condition in the catchment. These metrics allow natural resource managers to understand the potential of each catchment and more intelligently target specific land-based conservation or restoration actions.

The natural habitat quality index (HQI) was calculated directly from the BRT output. Metrics for 'natural' predictor variables were calculated using a different approach than for the previously discussed stressor calculations. A single hypothetical 'no stress' dataset was created where all stressors were removed. The existing BRT model was then applied to this hypothetical predictor dataset, and the resulting probability of presence indicated the maximum condition attainable by removing all stress. This hypothetical situation where all stressors were zero was also represented in the training dataset, which ensures that these extrapolations are not outside of the range of the data used to build the model. The probability of presence calculated by the BRT model for this hypothetical 'no stress' dataset is the HQI and this value indicates the maximum condition expected in each catchment.

## 2.3 Model Details

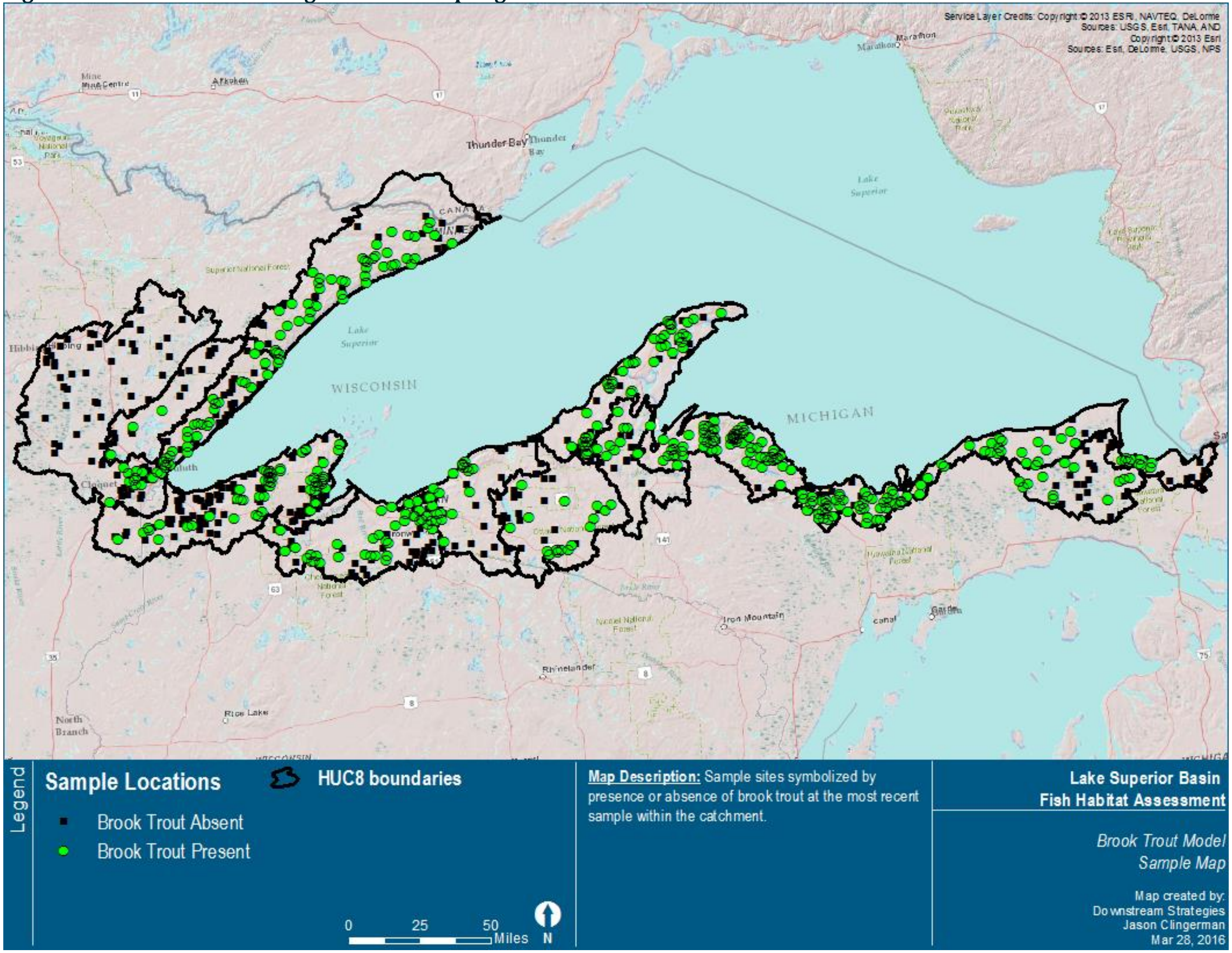
### 2.3.1 *Predictor Data*

DS, in cooperation with the project's Technical Review Team, arrived at a list of landscape-based habitat variables (Appendix A) used to predict brook trout throughout the region; those variables were also used to characterize habitat quality and anthropogenic stress. DS and the Review Team compiled a list of 85 predictors for evaluation. From that list, 66 variables were removed due to statistical redundancy ($r > 0.6$), logical redundancy, or because of a lack of model influence, resulting in a final list of 19 predictor variables (Table 2) for the BRT model and assessment. Most predictor variables were gathered from public sources, but modeled stream temperature from FishVis (USGS 2015) was acquired from Jana Stewart, USGS.

### 2.3.2 *Response Data*

DS compiled stream fish collection records from 1995 to 2015. This included data extracted from a fish sampling database provided by the Great Lakes Basin Fish Habitat Partnership as well as a sampling dataset provided by the Ashland FWCO specific to the Lake Superior Basin. DS processed those data to create a presence-absence dataset for brook trout. This dataset covers 835 catchments within the Lake Superior Basin. Figure 3 illustrates all of the sampling sites that were used to construct the model.

**Figure 3: Brook trout modeling area and sampling sites**



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**Map Description:** Sample sites symbolized by presence or absence of brook trout at the most recent sample within the catchment.

Map created by:
Downstream Strategies
Jason Clingerman
Mar 28, 2016

### 2.3.3 *Final BRT Model*

**Model Details**

Via BRT, we developed a predictive statistical model for brook trout at the 1:100k catchment scale throughout the Lake Superior Basin. We utilized the default settings for model building for most options, including using a 10-fold cross validation procedure and bag fraction = 0.75. Tree complexity (interaction depth) was set to 1 (this setting is necessary to ensure proper stress and natural quality calculations) and learning rate was set at 0.01. Learning rate was chosen after examination of holdout deviance plot produced from the BRT model, and ensuring the model did not come to resolution too quickly or too slowly. The final selected model was comprised of 2,650 trees.

Modeled stream temperature, a natural habitat quality variable, was the single most important predictor variable in the model with a relative influence of 10.5% (Table 2). Of the predictors important to brook trout occupancy, network percent agriculture and network road crossing density were deemed as anthropogenic stressors and had relative influences of 3.7% and 1.3%, respectively.

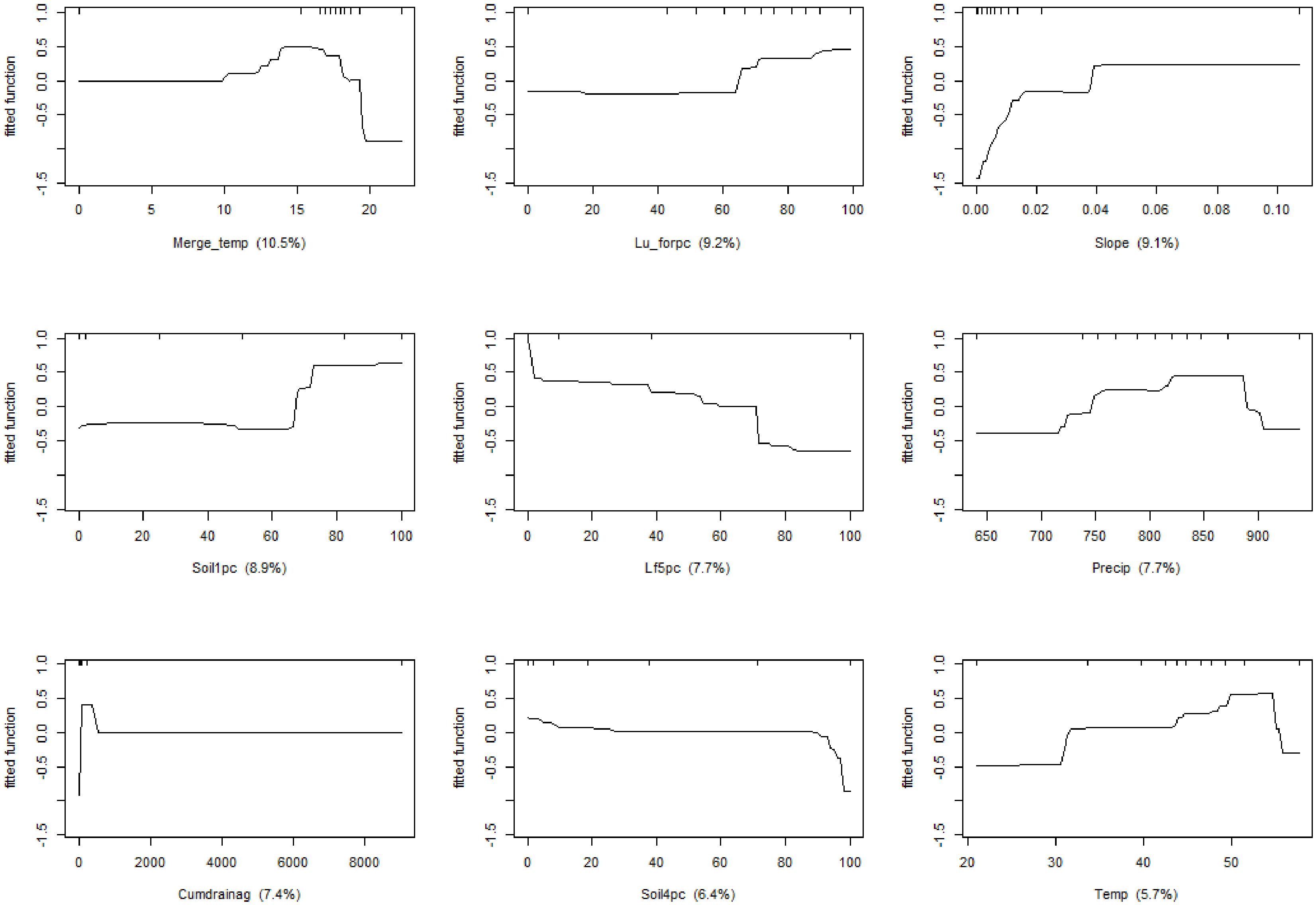
**Table 2: Relative influence of all variables in the final brook trout model**

| Variable Name | Variable Description | Relative Influence | Type of relationship |
|---|---|---|---|
| Merge_temp | Modeled Stream Temperature (predicted) | 10.52 | Negative |
| Lu_forpc | Network percent forest land cover | 9.17 | Positive |
| Slope | Slope of catchment flowline | 9.06 | Positive |
| Soil1pc | Network percent high infiltration soils | 8.86 | Positive |
| Lf5pc | Network percent lacustrine landform | 7.74 | Negative |
| Precip | Mean annual precipitation | 7.71 | Variable |
| Cumdrainag | Network drainage area | 7.39 | Variable |
| Soil4pc | Network percent very slow infiltration soils | 6.40 | Negative |
| Temp | Mean annual air temperature | 5.72 | Variable |
| Soil2pc | Network percent moderate infiltration soils | 5.10 | Variable |
| Lu_agpc | Network percent agriculture land cover | 3.70 | Negative |
| Lf4pc | Network percent ground moraine landform | 3.65 | Negative |
| Minelevraw | Minimum catchment elevation | 3.13 | Positive |
| Soil3pc | Network percent slow infiltration soils | 2.53 | Negative |
| Geol_maj | Majority geologic texture/type within catchment | 2.52 | Variable |
| Roadlen_den | Catchment road density | 2.18 | Variable |
| Lf1pc | Network percent outwash landform | 1.89 | Positive |
| Lu_devpc | Network percent developed land cover | 1.39 | Variable |
| Roadcrc_den | Network road/stream crossing density | 1.33 | Negative |

Note: Individual variables are highlighted according to whether they were determined to be anthropogenic (gray shading) or natural (no shading). Negative relationships indicate that general trends show that as the predictor increases, the likelihood of brook trout decrease. Positive relationships indicate the general trend is that likelihood of brook trout increases as the predictor variable value increases.

The function plots for the model, which illustrate the marginal effect on the response variable (logit(p)) (y-axis) as the predictor variable (x-axis) changes, are shown in Figure 4 for the nine most influential variables in the brook trout model (Table 2). The tick marks at the top of each function represent the deciles of the data used to build the model. The plots for all 19 variables are shown in Figure 4.

Figure 4: Functional responses of the dependent variable to individual predictors of brook trout



Note: Only the top nine predictors, based on relative influence are shown here. See **Error! Reference source not found.** for plots of all predictor variables.

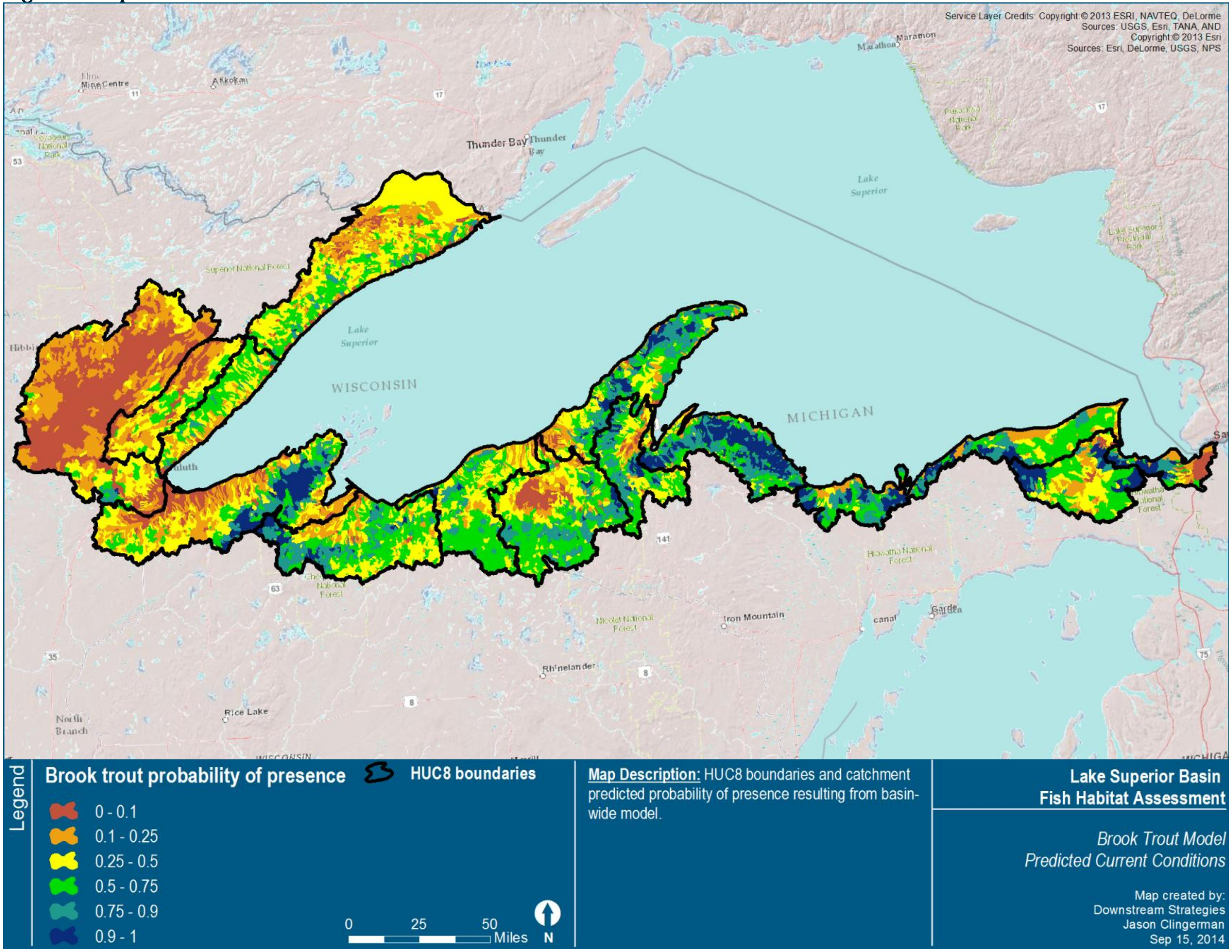
### Model Validation

We utilized a 10-fold cross validation procedure and bag fraction = 0.75 within the BRT model.  The model had a CV correlation statistic of 0.523±0.026 and a CV ROC score of 0.797±0.015 and it explained 38% of the deviance in the response data.

### Map of current brook trout occupancy

Brook trout probability of presence was calculated for all 1:100k stream catchments in the study area. The predicted probability of presence ranged from 0 to 1, where 0 = absent and 1 = 100% probability of presence. The mean predicted probability was 0.40, or 40% likelihood of presence. Of the 15,134 catchments in the Lake Superior Basin, there were 2,337 catchments with a predicted probability of presence greater than 0.75 and 3,141 catchments where the probability of presence was between 0.5 and 0.75. These results are mapped in Figure 5.

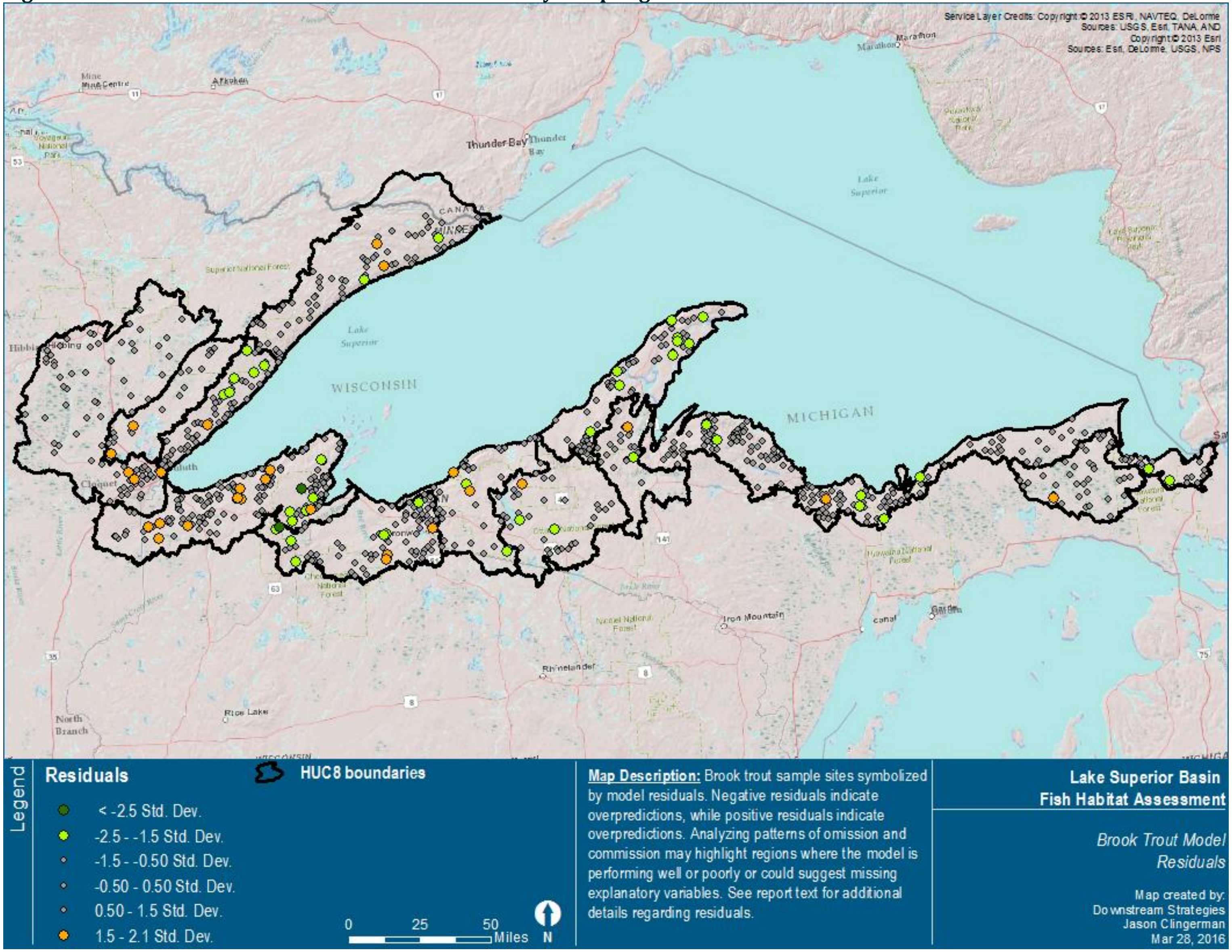
**Figure 5: Expected brook trout distribution**



### Spatial Residuals

The spatial distribution of residuals is shown in Figure 6. Brook trout sample sites are symbolized by model residuals. Negative residuals indicate over-predictions, while positive residuals indicate under-predictions. Analyzing patterns of omission and comission may highlight regions where the model is performing well or poorly or could suggest missing explanatory variables.

**Figure 6: Distribution of brook trout model residuals by sampling site**



**Map Description:** Brook trout sample sites symbolized by model residuals. Negative residuals indicate overpredictions, while positive residuals indicate overpredictions. Analyzing patterns of omission and commission may highlight regions where the model is performing well or poorly or could suggest missing explanatory variables. See report text for additional details regarding residuals.

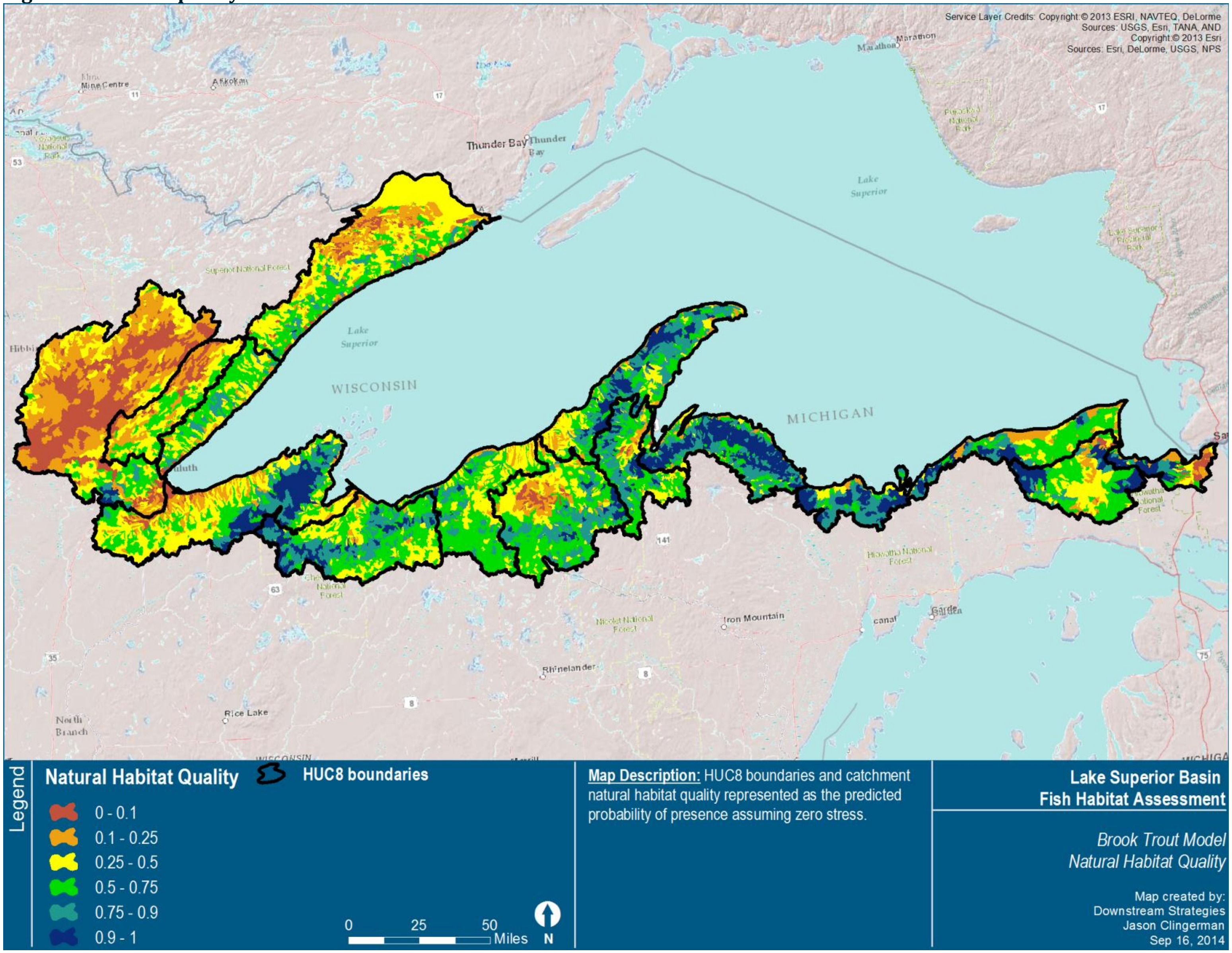
**Anthropogenic Stress and Natural Habitat Quality**

The variable importance table and partial dependence functions of the final BRT model were used to assess the potential stressors for the brook trout model. Two anthropogenic variables were included in the model (Table 2). These two stressors, network agriculture land cover (Lu_agpc) and network road crossing density (Roadcrc_den), were used to calculate ASI for the brook trout model. See Section 2.2.4 for details on how ASI and HQI were calculated for each model.

Maps of HQI and ASI illustrate the spatial distribution of natural habitat potential (i.e., HQI score) and anthropogenic stress (i.e., ASI score) in the Lake Superior Basin. HQI and ASI scores are mapped in Figure 7 and Figure 8, respectively. The two metrics contributing toward the calculation of ASI are mapped in Figure 9 and Figure 10. HQI, ASI, and their metrics are all scaled on a 0-1 scale. Higher HQI values indicate higher natural quality, while higher ASI values indicate higher levels of anthropogenic stress.

It is important to note that the stress values are not simply a measure of anthropogenic changes to the watershed, but also how much those changes are impacting brook trout. If an area was naturally unsuitable for brook trout (i.e. low natural quality index score), the stress index will also be low, even if stressors are present in the area. In other words, stress values can only be elevated if the natural habitat quality index is high. If natural habitat quality is so low that brook trout would likely be absent independent of stress, then the stress index is, necessarily, low. It is likely that, in general, stress on aquatic systems is much more widespread than is indicated in this model, which accounts specifically for brook trout. For all stress and natural quality indices, all catchments are shown, even in areas where the probability of presence is low. This is necessary and useful to consider areas outside of the current expected range where stress could have caused a historic population to be extirpated.

**Figure 7: Habitat quality index for brook trout**



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**Map Description:** HUC8 boundaries and catchment natural habitat quality represented as the predicted probability of presence assuming zero stress.

**Lake Superior Basin**
**Fish Habitat Assessment**

*Brook Trout Model*
*Natural Habitat Quality*

Map created by:
Downstream Strategies
Jason Clingerman
Sep 16, 2014

**Figure 8: Total anthropogenic stress index for brook trout**

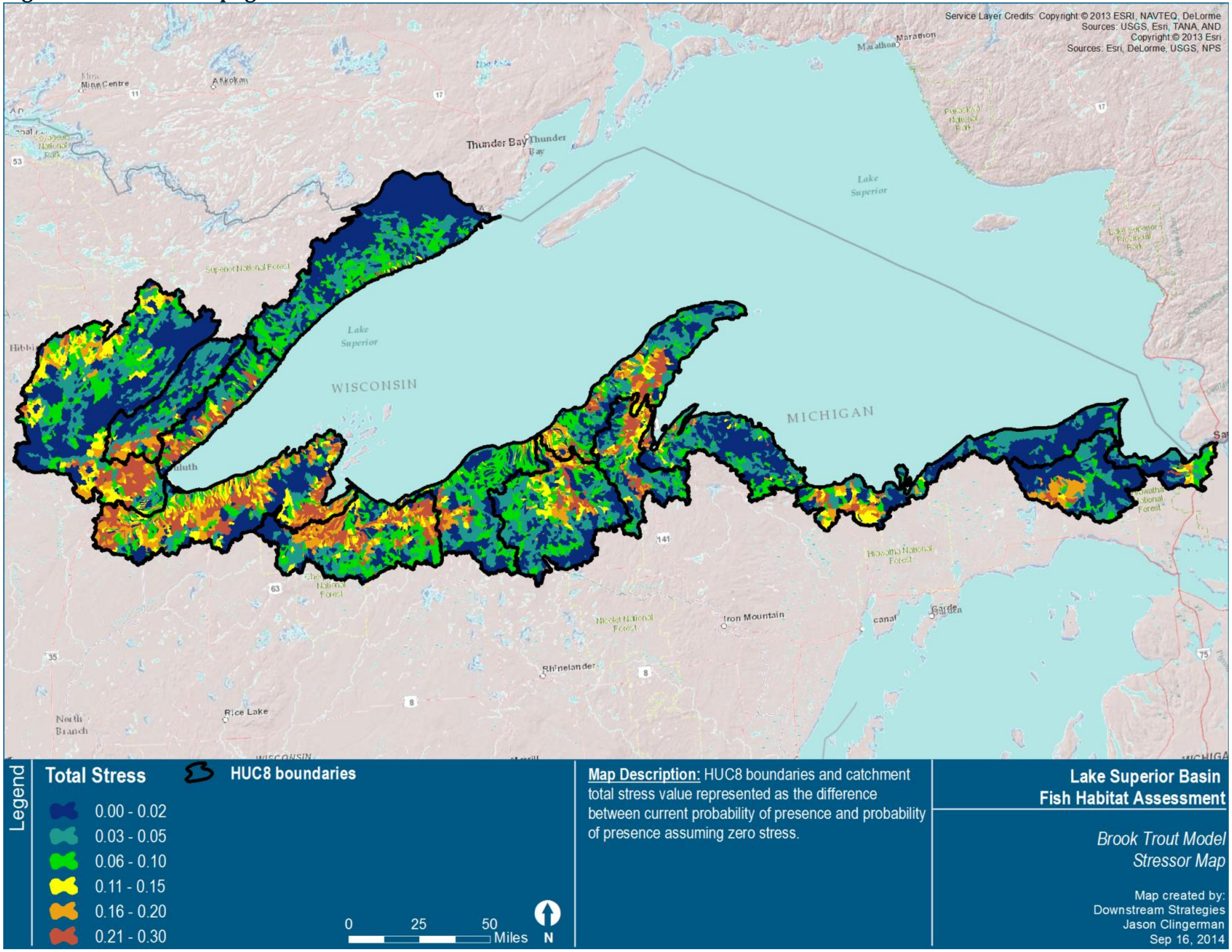
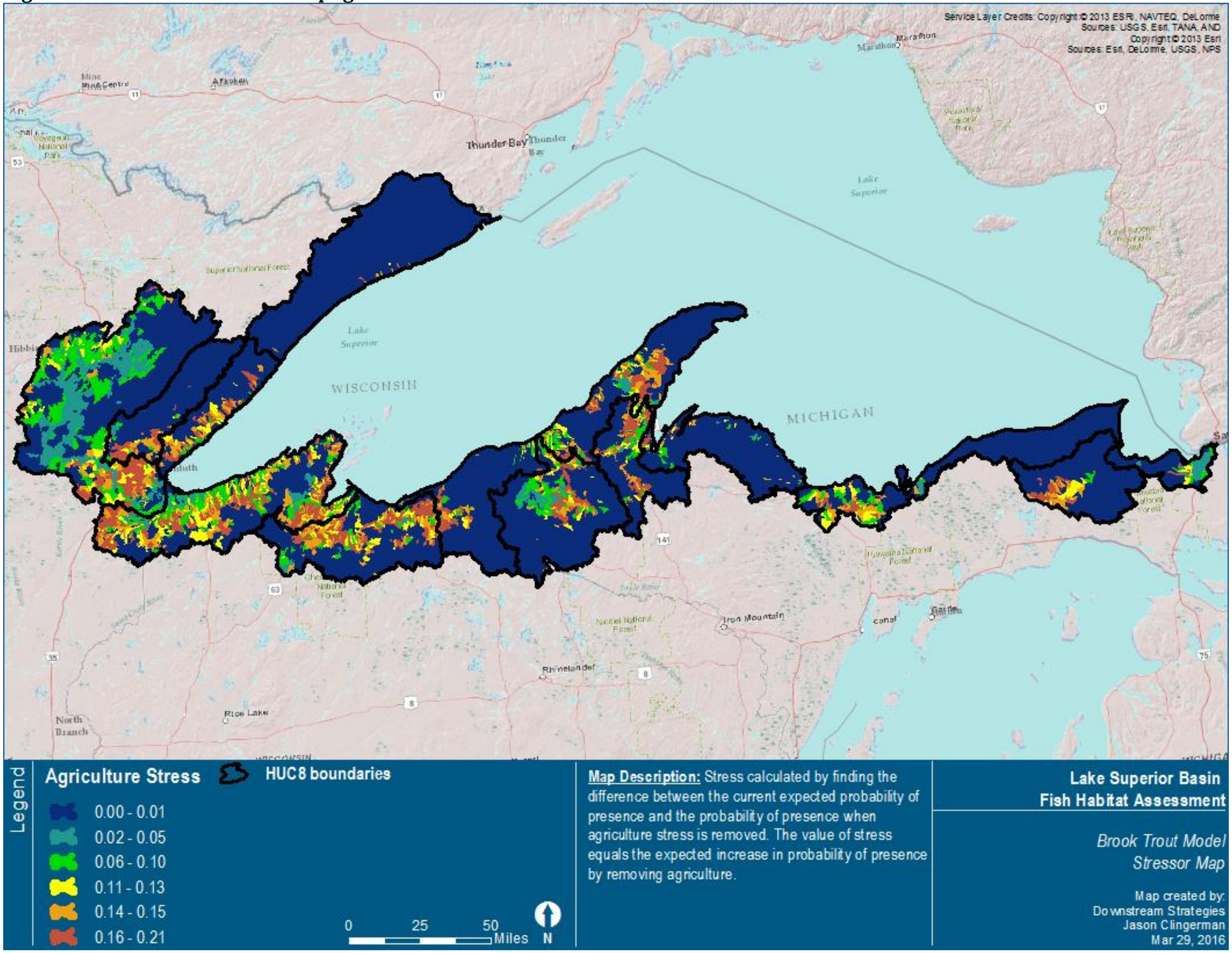


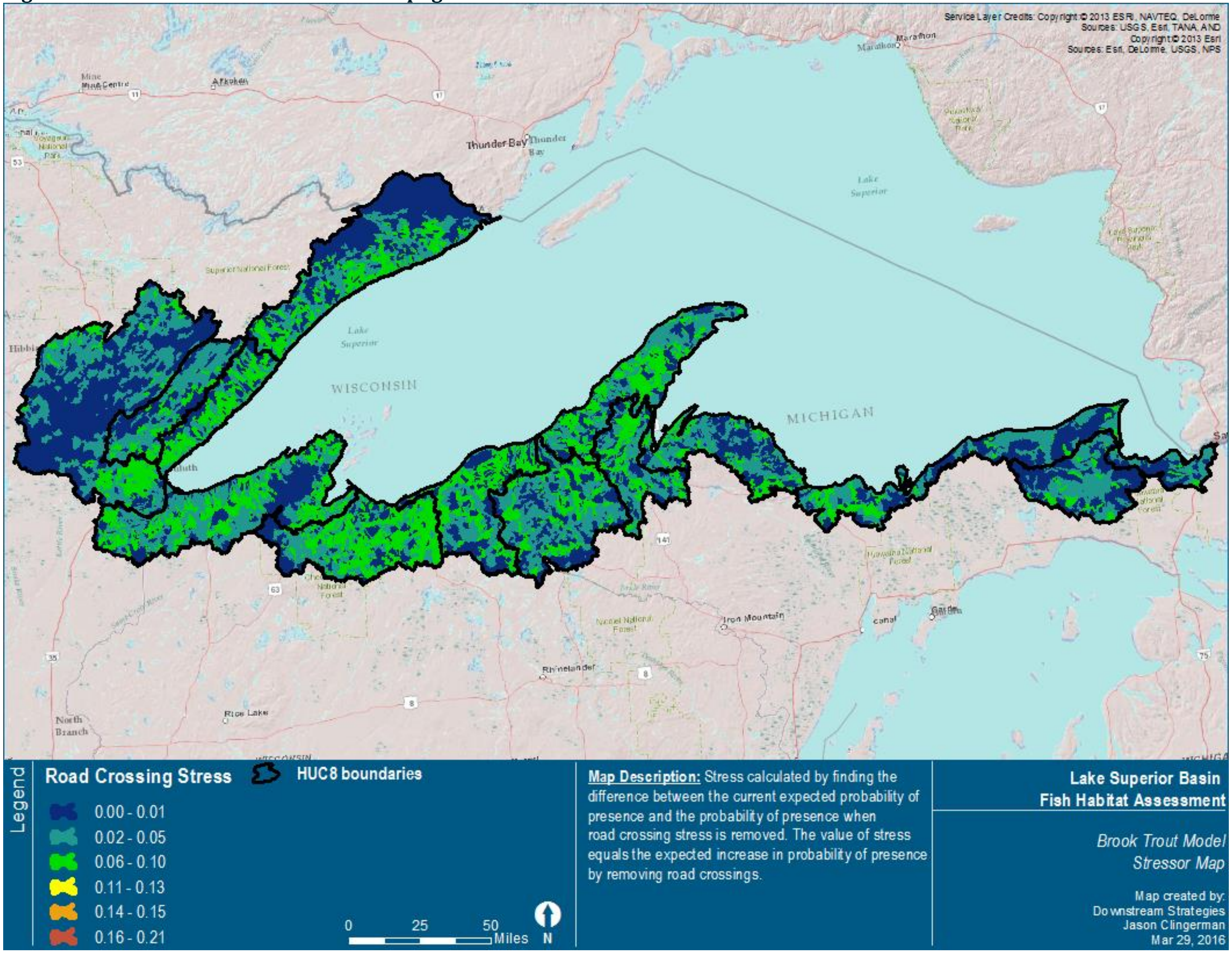
**Figure 9. Most influential anthropogenic index metric for brook trout**



**Map Description:** Stress calculated by finding the difference between the current expected probability of presence and the probability of presence when agriculture stress is removed. The value of stress equals the expected increase in probability of presence by removing agriculture.

Note: "most influential" references the relative influence scores from the BRT model output.

**Figure 10: Second most influential anthropogenic index metric for brook trout**



**Map Description:** Stress calculated by finding the difference between the current expected probability of presence and the probability of presence when road crossing stress is removed. The value of stress equals the expected increase in probability of presence by removing road crossings.

Note: "most influential" references the relative influence scores from the BRT model output.

# 3. CLIMATE ASSESSMENT

## 3.1 Objectives/Introduction

The impact of potential climate change on a coldwater obligate species such as brook trout is expected to manifest as an alteration/shift of their distribution across the landscape (Comte et al., 2013; Hickling et al., 2006). In this assessment, we quantified the anticipated resiliency and vulnerability to climate change for brook trout in the Lake Superior Basin. The results of these analyses will aid in the identification of future restoration and protection priorities for brook trout, especially when considered alongside other factors such as current stress and current habitat quality.

Our assessment is based on large-scale climatic factors, including mean annual precipitation and mean annual or seasonal temperatures, and assumes the current relationships between habitat and brook trout occurrence will persist into the future. Impacts resulting from changes in frequency or severity of individual storm events are beyond the scope of this assessment. It is also important to note the population parameter of interest in this analysis was brook trout occupancy. Impacts to population structure and dynamics resulting from climatic changes are also beyond the scope of this effort. An example of such an impact would be a severe localized flood event that does not change brook trout occupancy, but causes a shift in population structure because of high juvenile mortality.

## 3.2 Methods

### 3.2.1 *Data*

In our analysis, three predictor variables from the model described above were altered to capture potential future changes in climate: mean July stream temperature, mean annual air temperature, and mean annual precipitation.

Mean July stream temperatures were compiled from FishVis data (USGS, 2015). FishVis provided predictions of stream temperatures for current climate conditions as well as for future timeframes. The current mean July stream temperature conditions data were utilized for the predictive model described above and the projections for the 2046 to 2065 time frame were utilized for the future climate scenario. The predicted 2046 to 2065 FishVis models were created using the A1B emissions scenario (Intergovernmental Panel on Climate Change (IPCC). 2007) and an ensemble of 13 general circulation models (GCMs).

Mean annual precipitation and mean annual air temperature data as included in the NHD plus datasets (Horizon Systems, 2012) were used as predictor variables for the predictive model for each catchment. This data was originally sourced from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). Future mean annual precipitation and mean annual air temperature projections were collected from The Nature Conservancy's Climate Wizard for the 2040 to 2069 timeframe (The Nature Conservancy, 2009). These projections were based on the IPCC A2 scenario (IPCC, 2007) and 16 ensembled GCMs. While the timeframe and climate scenarios utilized are not exact matches to the FishVis data, they provided the best available match that could be accessed for this project.

### 3.2.2 *Future status, habitat quality and stress*

Predicted probability of presence for brook trout under future climate scenarios was calculated in a manner similar to the post-modeling methodology described above, where the predictor variables used in the model were manipulated—current climate data were replaced with projected future climate data. Probability of presence was calculated for each of the eight climate scenarios identified above.

Using the methodology described in Section 2.2.4, we also recalculated stress and natural quality under each potential climate scenario. This allowed us to calculate the differences between stress and natural quality between current and future conditions. For each climate scenario, the difference between current values and values calculated using future climate predictions are interpreted as an indicator of the potential effects of future climate scenarios.

### 3.2.3 *Defining resilience and vulnerability*

Climate resiliency and vulnerability were determined by analyzing predicted losses or gains in natural quality resulting from climate change. Underlying natural quality is directly impacted by changes in climate. Analyzing changes in modeled natural quality indicates the anticipated impacts on brook trout occupancy. Areas anticipated to have reduced natural habitat quality index scores were determined to be vulnerable to future climate change scenarios, while resilient areas were expected to remain unchanged or increase in natural quality under future climate scenarios.

## 3.3 Results/Discussion

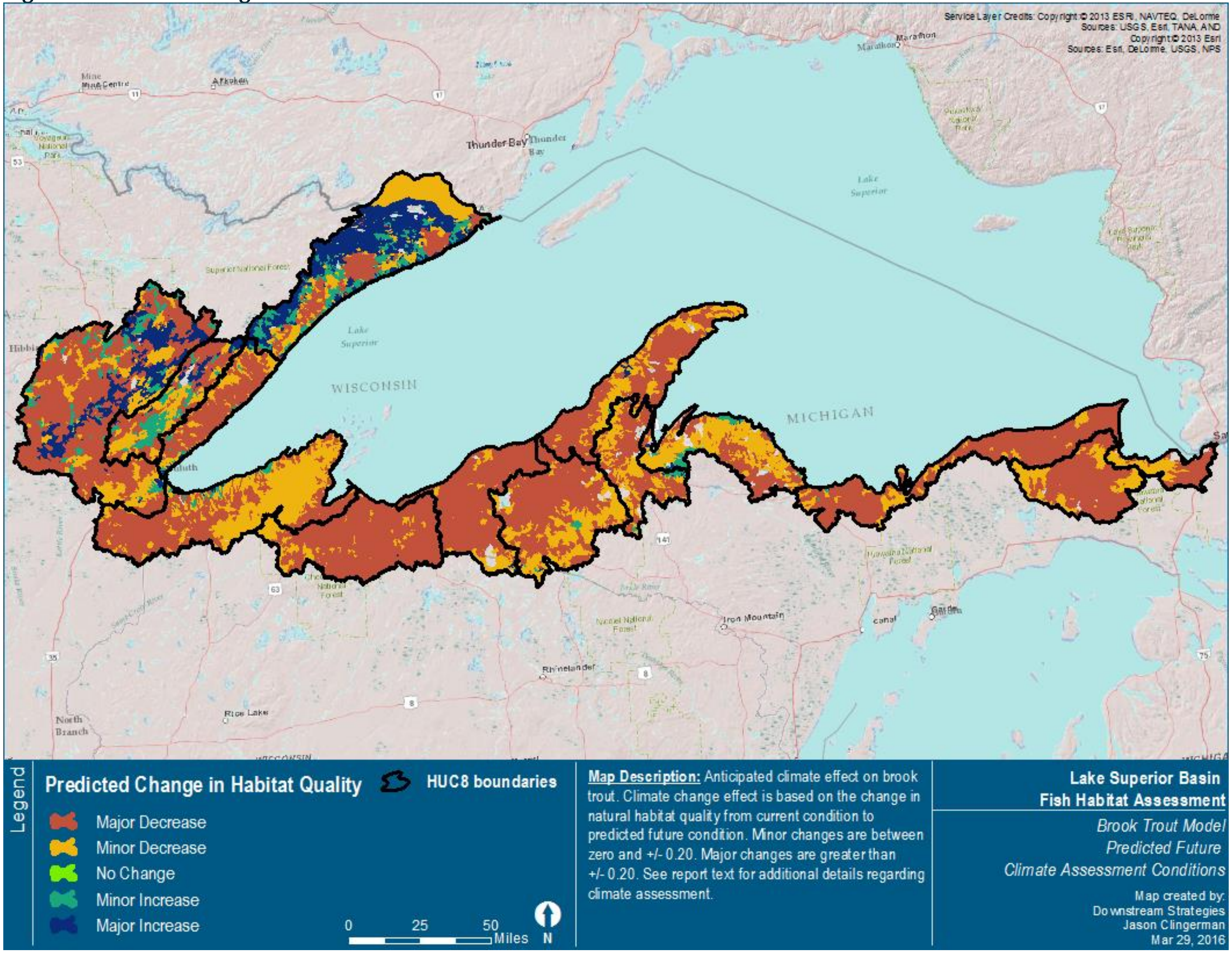
### 3.3.1 *Watershed-wide results*

This assessment produced a large volume of data, not all of which can be shown or discussed in a meaningful way within this report; all data produced will be made available as a deliverable. In this section, we focus on results from the 2055 time frame. This time frame is an actionable time frame, but is one far enough into the future that projected climate changes become more significant than projections at the earlier time frames.

The map below (Figure 11) illustrates changes in natural habitat quality, which is the measure of climate effect for every catchment within the Lake Superior Basin. For visualization purposes, we classified changes into five categories. These categories were major decrease, minor decrease, no change, minor increase, and major increase. The minor categories were defined as a change between 0 +/- 0.20, and the major categories were defined as a change greater than +/- 0.20.

While the overall effect of future climate scenarios is negative for brook trout, there are specific regions projected to be more resilient, and some areas may experience an improvement in natural habitat quality. An increase in projected precipitation rates is the primary driver for those areas identified to be resilient or improve. Increased precipitation may moderate higher projected air temperatures or ameliorate effects from seasonal low flow mortality. Appendix B (function plots from the original BRT model) illustrates the functional relationship between predicted probability of presence of brook trout and these two climatic factors, illustrating how increases in precipitation result in higher probabilities of occurrence.

Figure 11. Climate change effect for 2062 EH5 scenario.



**Map Description:** Anticipated climate effect on brook trout. Climate change effect is based on the change in natural habitat quality from current condition to predicted future condition. Minor changes are between zero and +/- 0.20. Major changes are greater than +/- 0.20. See report text for additional details regarding climate assessment.

### 3.3.2 *Using climate vulnerability and resilience to inform priority establishment*

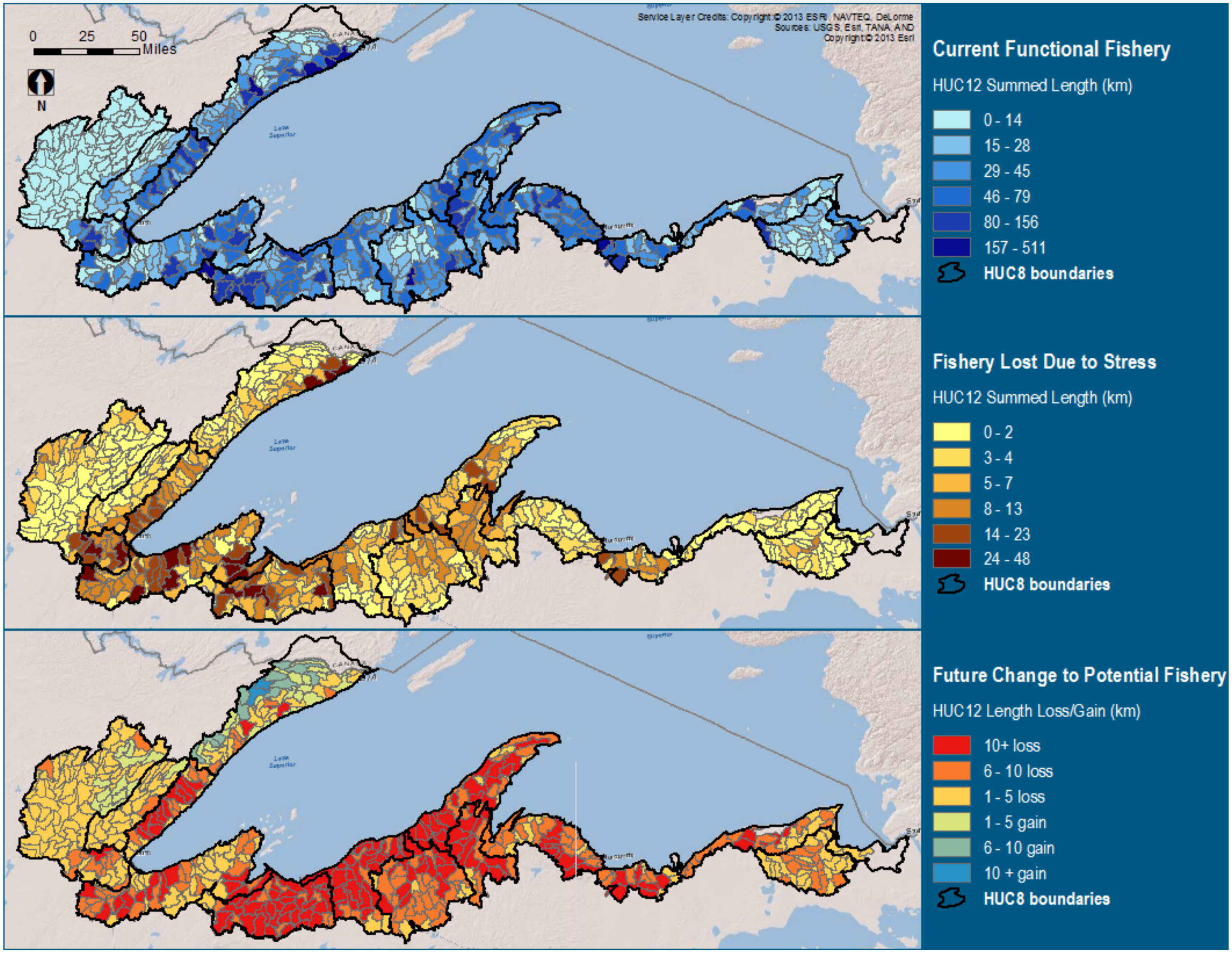
Future climate scenarios provide natural resource managers with key contextual information about current conditions as well as resiliency to impacts due to climate change, which can result in important refinements to decision making and prioritization of management actions. Areas identified as priorities for restoration can be established where the work is expected to persist. Conversely, areas indicated as vulnerable to future climate scenarios can be identified and prioritized for actions that may ameliorate the impacts of warmer water and/or less precipitation.

# 4. FISHERY VALUE CALCULATION

Here we apply a process for estimating functional stream length that was developed for identifying acid remediation priorities (Petty and Thorne, 2005) and culvert replacement priorities (Poplar-Jeffers et al., 2009).

To estimate the current functional value of a given stream segment as brook trout habitat, we multiplied the length of the segment (kilometer) by the current occupancy measure (ranges from 0-1). The final value can be interpreted as a function weighted length of ecological habitat. This value can then be summed across all stream segments within a HUC12 or HUC8 watershed to provide a relative measure of current fishery value in units of stream segment length (km) at the larger scales. We can derive a similar estimate of lost value for each segment by multiplying anthropogenic stress by the stream length. Once summed across segments within a watershed, this gives us a measure of the fishery value that has been lost due to anthropogenic stress on the landscape. Finally, we can multiply the change in natural habitat quality expected due to climate change by the stream length to get a measure of the potential lost fishery that may result from climate change. The combination of these three measures (current value, value lost due to stress, and potential value loss due to climate) provides important information for setting conservation priorities at hierarchical scales (e.g., segment, HUC12, HUC8). Figure 12, below, depicts the fishery values for the three measures noted above, shown at the HUC12 level.

**Figure 12. Fishery values by HUC12 watershed.**



# 5. DISCUSSION

## 5.1 Key Outcomes

Several of the outcomes from this modeling effort are of considerable value for brook trout conservation in the Lake Superior Basin. First, the new model provides an improved predictive model focused on the Lake Superior Basin, ensuring that relationships derived are relevant solely to the region, and that post-modeling techniques provide for improved understanding of stress, natural quality and their impact on the fishery.

Second, in addition to providing predictions of brook trout occupancy, we quantified the impacts that each anthropogenic stressor had on brook trout occurrence rates as well as the underlying potential of brook trout habitat in the absence of stress. These indices are critical in developing habitat restoration and protection priorities.

This assessment identified agriculture as a stressor to brook trout. Agricultural land cover was among the most important variables for the DeWeber and Wagner (2015) model predicting brook trout occupancy and for the model predicting brook trout population status for subwatersheds in Hudy et al. (2008). Predictive models created for brook trout in the Great Lakes (Downstream Strategies, 2015) and Driftless (Downstream Strategies, 2012) regions indicated that agriculture acted as a stressor in those regions as well. Road crossing density was also indicated as a stressor. Road crossing density may be acting as a coarse surrogate for barrier density and/or as a surrogate for development within this model, as areas with lower road density values are predicted to have higher likelihood of occurrence for brook trout.

Among natural factors, stream temperature was identified as the most important variable structuring brook trout occurrence. Stream temperature was also among the most important predictor variables in the DeWeber and Wagner (2015) model predicting brook trout occupancy range-wide in the eastern United States. While some factors influencing stream temperature could be considered anthropogenic in nature (e.g. riparian forest cover), we chose to consider stream temperature a natural habitat quality variable.

Finally, our analysis of future climate scenarios provides spatially explicit predictions of the potential impacts of future changes in precipitation and water temperature on brook trout habitats in the Lake Superior Basin. These predictions will allow natural resource managers to assess future conditions as well as current brook trout conditions when making decisions about restoration or management efforts. Although the degree of error in these predictions is unclear, they have value in identifying areas where brook trout populations may be at high risk or more resistant to changing climate.

The data and results compiled here provide improved understanding and ample data for prioritizing conservation action for brook trout for the Lake Superior Basin. Section Six outlines the prioritization process DS and Ashland FWCO utilized to create a suite of scenarios to identify areas for brook trout restoration and protection across the Lake Superior Basin.

## 5.2 Limitations and suggestion for future work

In general, while the estimates of probability of presence, index scores, HQI, and ASI generated through this assessment represent a useful and objective means for assessing aquatic habitat and prioritizing habitats for restoration or protection, there are some limitations that are important to consider.

While this model has been created for, and is highly accurate within the Lake Superior Basin, its use is limited to only that geographic region. Results and habitat relationships cannot be applied to areas outside the study area, which ultimately restricts widespread use of this assessment. One suggestion for future work regarding the impact of model extent and scale is the need to examine the balance between statistically valid, region-wide models (DeWeber and Wagner 2015) and within-region specific models such as our assessment. Each model has applicability, and a detailed analysis of the tradeoffs and benefits of each type of assessment would be useful for future efforts.

All results generated through the modeling process are ultimately limited by the quality and scale of data used in the model. The model can be improved by utilizing refined or higher quality predictor data. For example, many of the datasets used for predictor variables were based on a 30 meter grid cell (precipitation, land cover, impervious surfaces), and if resolution of those publically-available datasets improves to 10- or 1-meter grid cells, more accurate results should be possible. Additionally, some high quality or high resolution data was only available in a certain subset of the Lake Superior Basin, and thus had to be omitted. If such high quality datasets have more broad coverage in the future those should be included as predictor variables as well.

Including additional predictor variables that are deemed appropriate at structuring brook trout populations could also be beneficial to future efforts. While we feel confident that the major factors influencing brook trout in the Lake Superior Basin have been included in this analysis, if future study indicates additional variables of importance, those should also be included. Inclusion of more refined predictor variables or additional relevant predictor variables could improve both the precision of the BRT model predictions and post-modeling indices.

Another limitation is that the data and maps represent only a snapshot in time. Therefore, the models may not represent conditions before or after the data were collected or created. For example, any habitat lost or gained due to increased impervious surface cover since the 2006 National Land Cover Database (NLCD) was not considered in this assessment. Similarly, a portion of the uncertainty can be attributable to the temporal mismatches between the fish collection data and landscape data. As such, improving the temporal match between those datasets for future work would be beneficial.

Local habitat measures such as water quality (pH, alkalinity, and conductivity), physical habitat complexity, and substrate size are examples of local measures important to structuring fish communities. These measures could not be directly quantified in this analysis given the scope and scale of the project. However, since the analysis includes each catchment’s land cover and geology, some aspects of water quality were indirectly modeled. Likewise, habitat complexity and substrate size could be partially captured by the combination of stream slope and bedrock and surficial geology. Nonetheless, exclusion of detailed local measures of this sort likely accounts for some uncertainty in the model results. Thus, the results from this analysis should be combined with local expert knowledge and additional field data to arrive at the most accurate representation of habitat conditions.

## 5.3 Influence of non-native salmonids on brook trout occurrence

Previous studies have found that the presence of non-native salmonid species is a major threat to brook trout across their eastern range (EBTJV, 2006). The EBTJV (2006) report indicates that professionals deemed non-native salmonids to be a major stressor in some states, such as Pennsylvania and New York, but were not identified in all states as a major threat. Similarly, competitive interactions with brown trout have been shown to decrease the occupancy of brook trout (Wagner et al., 2013), so the inclusion of interactions with non-native salmonids in future models could improve the precision of the model and the ability to quantify its influence on the response variable, given the proper scope and scale of assessment.

In developing our predictive model for brook trout, for several reasons, we decided against the inclusion of predictor variables describing the presence of non-native salmonids. First and foremost, continuous information on non-native salmonid presence throughout the Lake Superior Basin does not exist. Consequently, a model that includes non-native salmonids cannot be used to predict brook trout occurrence continuously across the basin.

Additionally, because non-native salmonids and brook trout share similar habitat characteristics, it is likely that their distributions are highly correlated with similar landscape attributes (e.g., water temperature, forest cover, land use). Consequently, a model that includes non-native salmonids may influence underlying relationships between brook trout and natural habitat variables. The modeling completed by Wagner et al. (2013) assessed only conditions within streams that could support trout (brown or brook trout were sampled and the watershed size was less than 1,000 km$^2$), but when assessing all stream reaches, the relationship between non-native trout and brook trout is typically positive (Clingerman et al., 2015). By excluding non-trout streams, Wagner et al. (2013) was better able to isolate differences in brook trout occupancy related to changes in brown trout presence, rather than finding relationships in brook trout occupancy across a wider range of habitat conditions. In the latter situation, as in this assessment, the influence of non-native salmonids is muddled by other habitat factors.

Previously, DS attempted to quantify the potential effects of non-native salmonid presence on brook trout occupancy in the Chesapeake Bay watershed (Clingerman et al., 2015). Our analysis on non-native salmonids suggests that the absence of information on non-native salmonids does not systematically effect the explanatory / predictive power of our predictive model. This is not to say that non-native salmonids cannot, or are not, having negative effects brook trout populations. There may be effects of non-native salmonids on brook trout abundance, or there may be localized effects on brook trout occurrence. Nevertheless, there is little evidence that the effect on brook trout occurrence is so widespread as to undermine the application of the predictive model at the scale of a large watershed. Ultimately, the biological interactions between non-native salmonids may account for some local variability in model results that were beyond the scope of this project, but as shown in Elith and Leathwick (2009), this is a complex and difficult solution to implement in predictive models.

# 6. CONSERVATION SCENARIOS

## 6.1 Introduction

This section details the process utilized to pinpoint distinct watersheds that are best suited for conservation actions –both restoration and protection—for brook trout in the Lake Superior Basin. The details of this prioritization process were jointly agreed upon by DS and Ashland FWCO personnel during a face-to-face meeting in February, 2016. This process follows both the Strategic Habitat Conservation (SHC) framework developed by USFWS and the first steps in a hierarchical process to establish restoration and protection priorities described in Merovich et al. (2013).

## 6.2 Methods

From February 8 to February 10, 2016, DS and Ashland FWCO conducted an intensive workshop wherein we utilized a series of Tableau worksheets to interact with various datasets in real-time. Tableau is a software platform that allows users to create and run customized analytics on a wide range of data. We created Tableau worksheets pre-loaded with data attributes of the HUC12 watersheds and catchments. Prior to the workshop, Ashland FWCO identified several possible prioritizations, and in preparation, separate worksheets were utilized for each management scenario. A broad range of generalized data was populated into a separate worksheet to evaluate scenarios that did not specifically focus on a certain concern. We created filters and queries within these worksheets prior to the workshop and updated them during the workshop. This allowed us to perform real-time analysis of data which informed the prioritizations of watersheds and catchments, all of which was based on the feedback from Ashland FWCO biologists and staff. During the workshop, we ultimately used these worksheets to create seven scenarios, each of which pinpointed areas most likely to create ecological lift from restoration and/or protection activities.

## 6.3 Scenarios

Each of the following scenarios represents a distinct opportunity for Ashland FWCO to prioritize brook trout conservation within the Lake Superior Basin. These scenarios were largely driven by current and anticipated future restoration funding sources, but were also grounded in research regarding stressors and threats to brook trout populations. The criteria used for each scenario is discussed in detail, but factors included model results and indices described in the "Predictive Model" section of this report, Ashland FWCO brook trout status classifications, land cover, soils data, and information on potential aquatic barriers.

### 6.3.1 *"Best of the Best" Protection Scenario*

**Description**

The goal of this scenario was to identify the best, high quality habitats for brook trout in the Lake Superior Basin. The HUC12 watersheds pinpointed here are very likely to be strongholds of brook trout population. These watersheds are primarily areas where the overall population should be protected, but localized restoration opportunities may also exist.

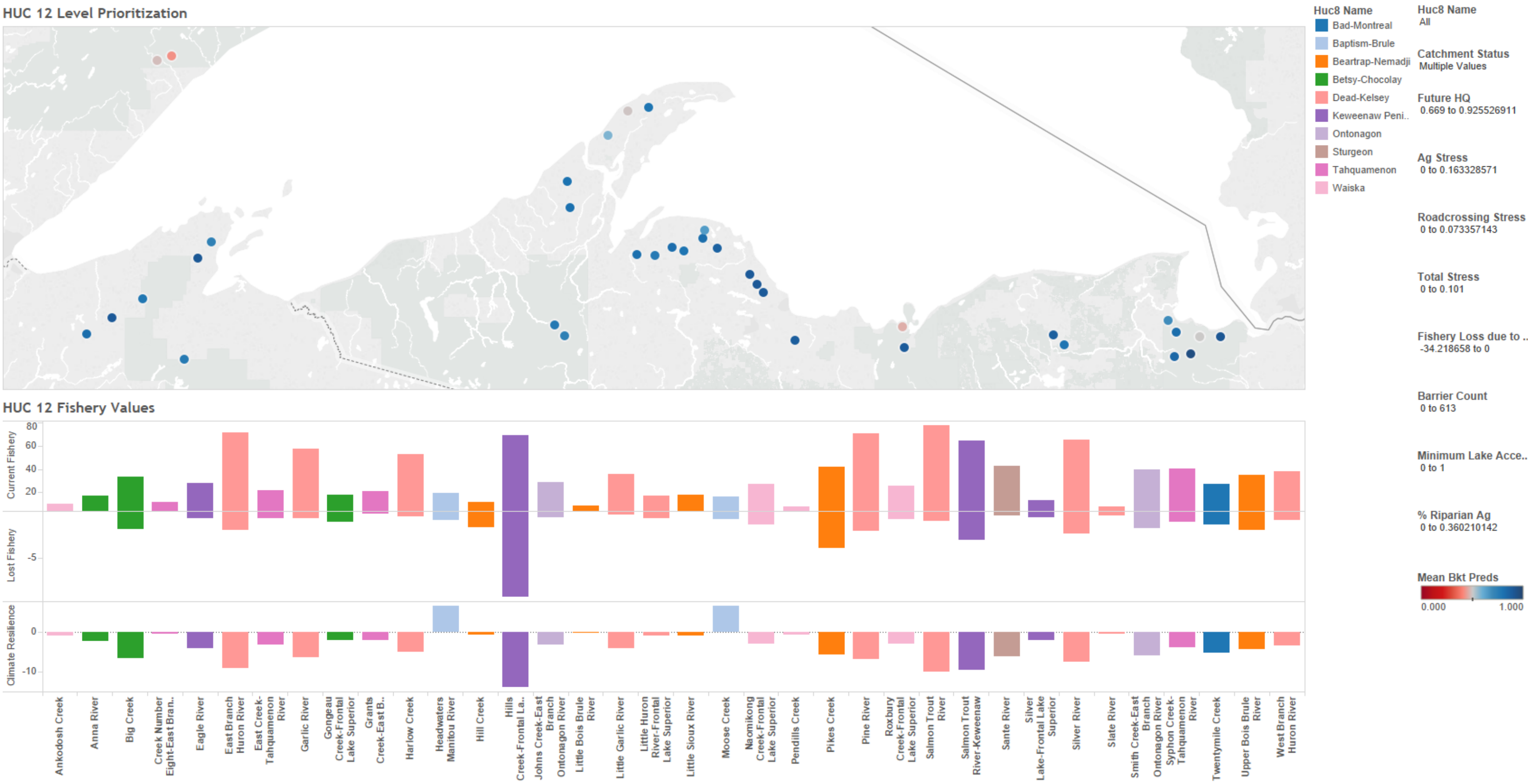
**Criteria**

We utilized three criteria to identify the HUC12 watersheds for this scenario. First, we used the Ashland FWCO HUC12 brook trout status classifications to identify those watershed identified as 'Intact' or 'Predicted Intact'. Next, we selected only HUC12 watersheds with high future habitat quality scores (mean score under future climate condition was greater than 0.67). This factor accounted for both underlying habitat quality score and the impact from future climate conditions. Lastly, we used the total stress score to remove watersheds that were highly stressed (mean stress score for identified HUC12s was less than 0.101).

**Results**

There are 36 HUC12 watersheds identified in this scenario distributed across the basin, within 10 distinct HUC8s. Figure 13 shows the Tableau interface used to evaluate this scenario. The evaluation criteria can be seen in the right hand column and a map of the identified watersheds (marked as HUC12 centroids) and bar charts of some of the relevant data of each identified watershed make up the remainder of the figure. Given that this is a protection-based scenario, the bar charts representing current fishery and climate resiliency are critical to further prioritize the identified watersheds. Current fishery values give an indication of how widespread and sound brook trout populations are within the HUC12, and the climate resiliency measure provides insight into the predicted relative impact of future climate scenarios.

**Figure 13. Tableau interface for protection initiative.**



Huc8 Name
All

Catchment Status
Multiple Values

Future HQ
0.669 to 0.925526911

Ag Stress
0 to 0.163328571

Roadcrossing Stress
0 to 0.073357143

Total Stress
0 to 0.101

Fishery Loss due to ..
-34.218658 to 0

Barrier Count
0 to 613

Minimum Lake Acce..
0 to 1

% Riparian Ag
0 to 0.360210142

### 6.3.2 *General Restoration Scenario (Agriculture/Barriers)*

**Description**

The goal of this scenario was to identify watersheds ideal for restoration. Both of the major stressors identified through modeling (agriculture and barriers to connectivity) were considered as part of the criteria for this scenario. This scenario was designed to find watersheds that have generally good habitat throughout, but that also exhibit localized stress, and could therefore provide opportunity for targeted restoration.

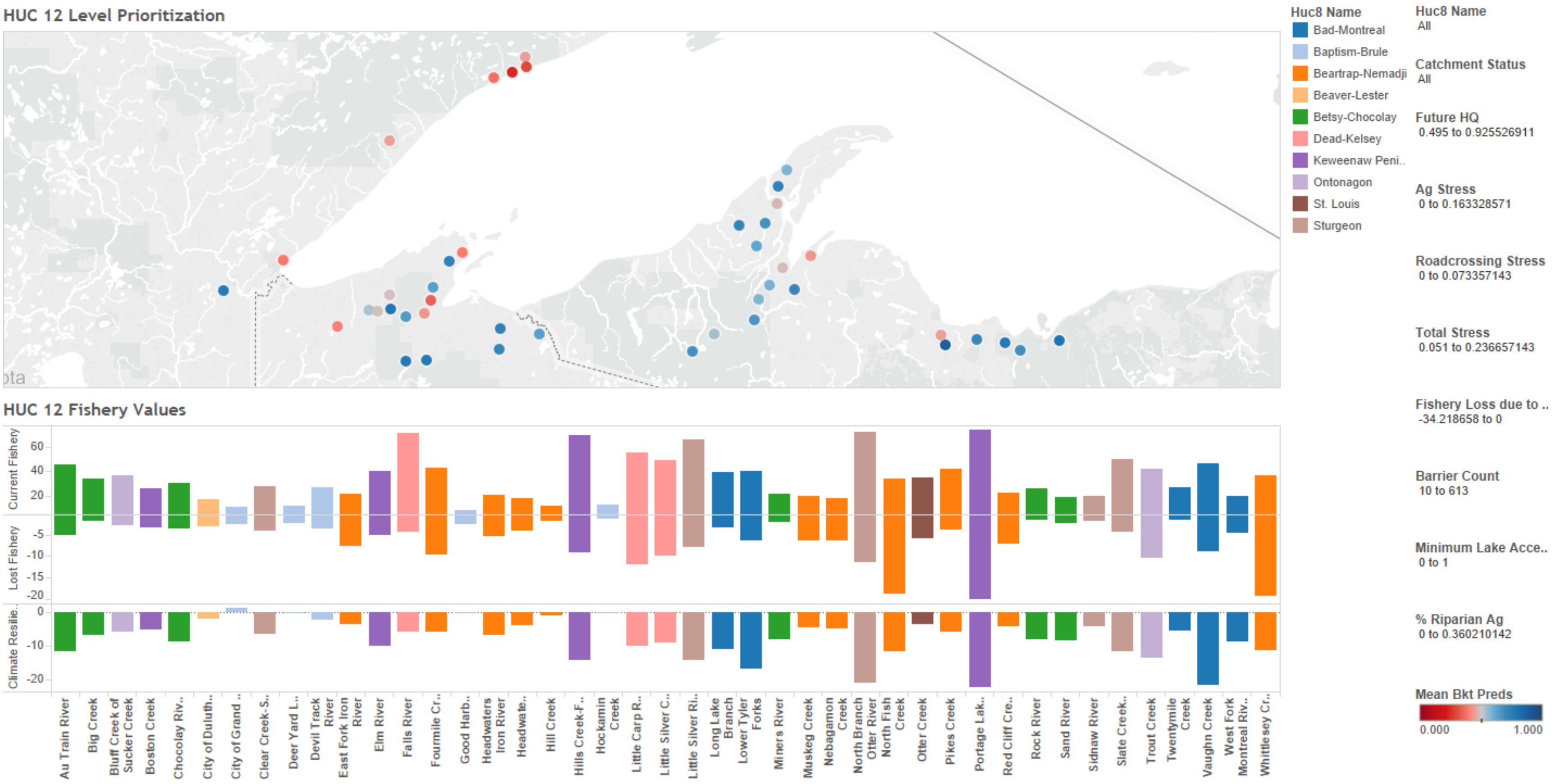
**Criteria**

We utilized three criteria to identify the HUC12 watersheds for this scenario. First, we selected only HUC12 watersheds that had high future habitat quality scores (mean score under future climate condition was greater than 0.495). This factor accounted for both underlying habitat quality score and the impact from future climate conditions. Next, we used the total stress score to ensure the identified watersheds had non-negligible stress (>0) that could be ameliorated by restorative actions. Lastly, to account for potential opportunity for connectivity restoration, we selected only watersheds that had 10 or more road/stream crossings or dams.

**Results**

There are 43 HUC12 watersheds identified in this scenario distributed across the basin and within 10 distinct HUC8s. Figure 14 shows the Tableau interface used to evaluate this scenario. The evaluation criteria can be seen in the right hand column and a map of the identified watersheds (marked as HUC12 centroids) and bar charts of some of the relevant data of each identified watershed make up the remainder of the figure. In this, a restoration scenario, evaluating the climate resiliency and lost fishery value is important for finding the best watersheds from within those identified. Larger lost fishery values indicate more gross potential for restoration, and more climate resiliency would indicate that benefits from restoration would not be undermined by habitat loss due to climate change.

**Figure 14. Tableau interface for general restoration scenario.**



Huc8 Name
All

Catchment Status
All

Future HQ
0.495 to 0.925526911

Ag Stress
0 to 0.163328571

Roadcrossing Stress
0 to 0.073357143

Total Stress
0.051 to 0.236657143

Fishery Loss due to ..
-34.218658 to 0

Barrier Count
10 to 613

Minimum Lake Acce..
0 to 1

% Riparian Ag
0 to 0.360210142

### 6.3.3 *Connectivity Scenario*

**Description**

The goal of this scenario was to identify watersheds with a significant number of potential barriers to connectivity that could be addressed in order to aid in reconnecting disparate sections of brook trout populations or habitat. This scenario seeks to aid in identifying prime project locations that are eligible for funding through the Fish Passage Program.

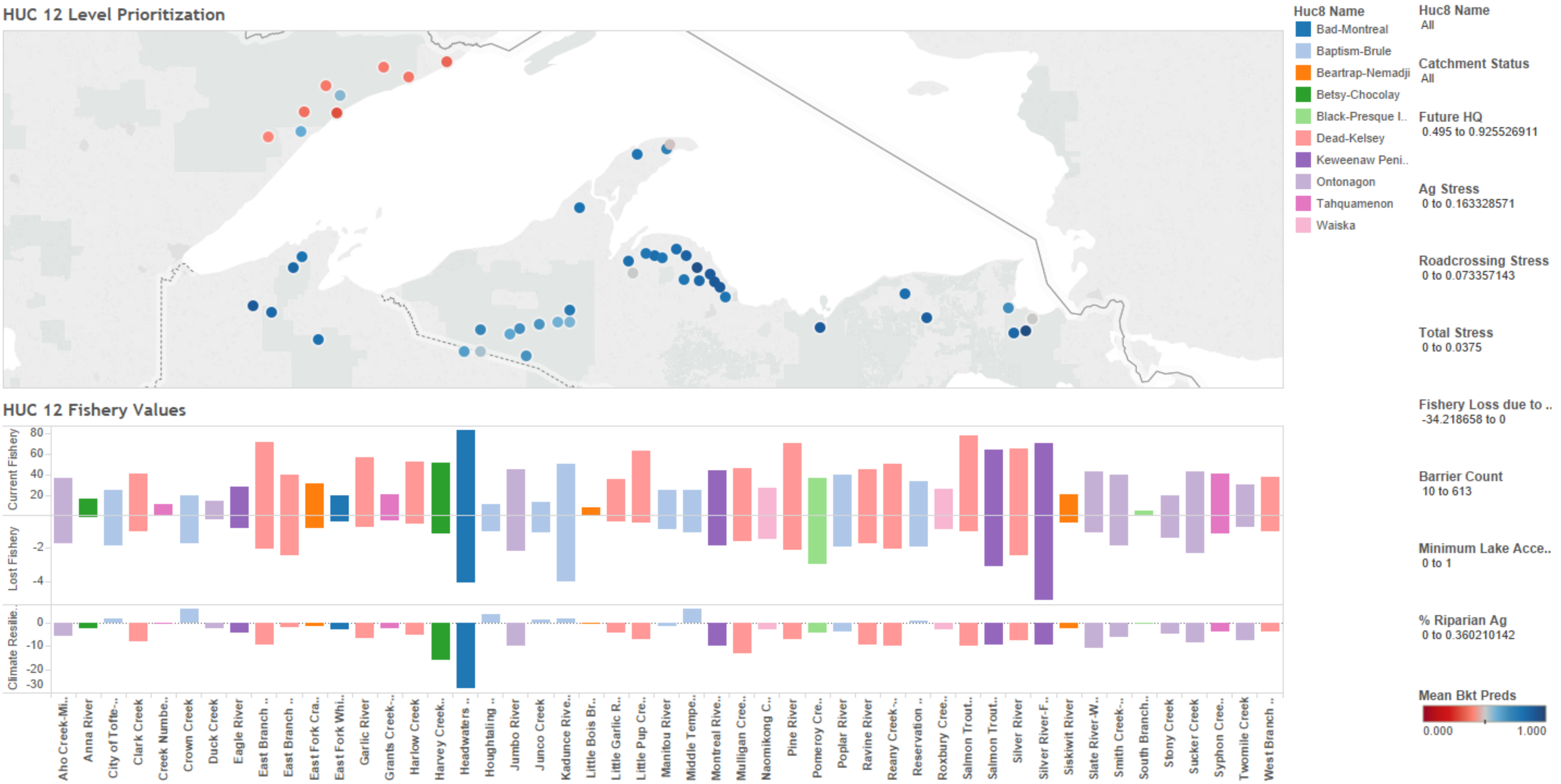
**Criteria**

We utilized three criteria to identify the HUC12 watersheds for this scenario. First, we selected only HUC12 watersheds that had high future habitat quality scores (mean score under future climate condition was greater than 0.495). This factor accounted for both underlying habitat quality score and the impact from future climate conditions. Next, we used the total stress score (<0.0375) to ensure the identified watersheds had very little overall stress, ensuring that the major limiting factor within the watershed was likely tied to connectivity alone. Lastly, to account for connectivity restoration, we selected only watersheds that had 10 or more road/stream crossings or dams.

**Results**

There are 49 HUC12 watersheds identified in this scenario distributed across the basin and within 10 distinct HUC8s. Figure 15 shows the Tableau interface used to evaluate this scenario. The evaluation criteria can be seen in the right hand column and a map of the identified watersheds (marked as HUC12 centroids) and bar charts of some of the relevant data of each identified watershed make up the remainder of the figure. For a restoration scenario, evaluating the climate resiliency and lost fishery value is important in finding the best watersheds from within those identified. Larger lost fishery values indicate more gross potential for restoration, and more climate resiliency would indicate that benefits from restoration would not be undermined by habitat loss due to climate change.

**Figure 15. Tableau interface for connectivity scenario.**



Huc8 Name
All

Catchment Status
All

Future HQ
0.495 to 0.925526911

Ag Stress
0 to 0.163328571

Roadcrossing Stress
0 to 0.073357143

Total Stress
0 to 0.0375

Fishery Loss due to ..
-34.218658 to 0

Barrier Count
10 to 613

Minimum Lake Acce..
0 to 1

% Riparian Ag
0 to 0.360210142

### 6.3.4 *Climate Change Resiliency Scenario*

**Description**

The goal of this scenario was to identify watersheds where brook trout populations are projected to be very resilient in the face of future climate scenarios. Given the overall negative implications of future climate projections on brook trout in the Lake Superior Basin, these resilient areas could be areas to focus resources for restoration to ensure those actions will not be undermined by relatively unavoidable future conditions.

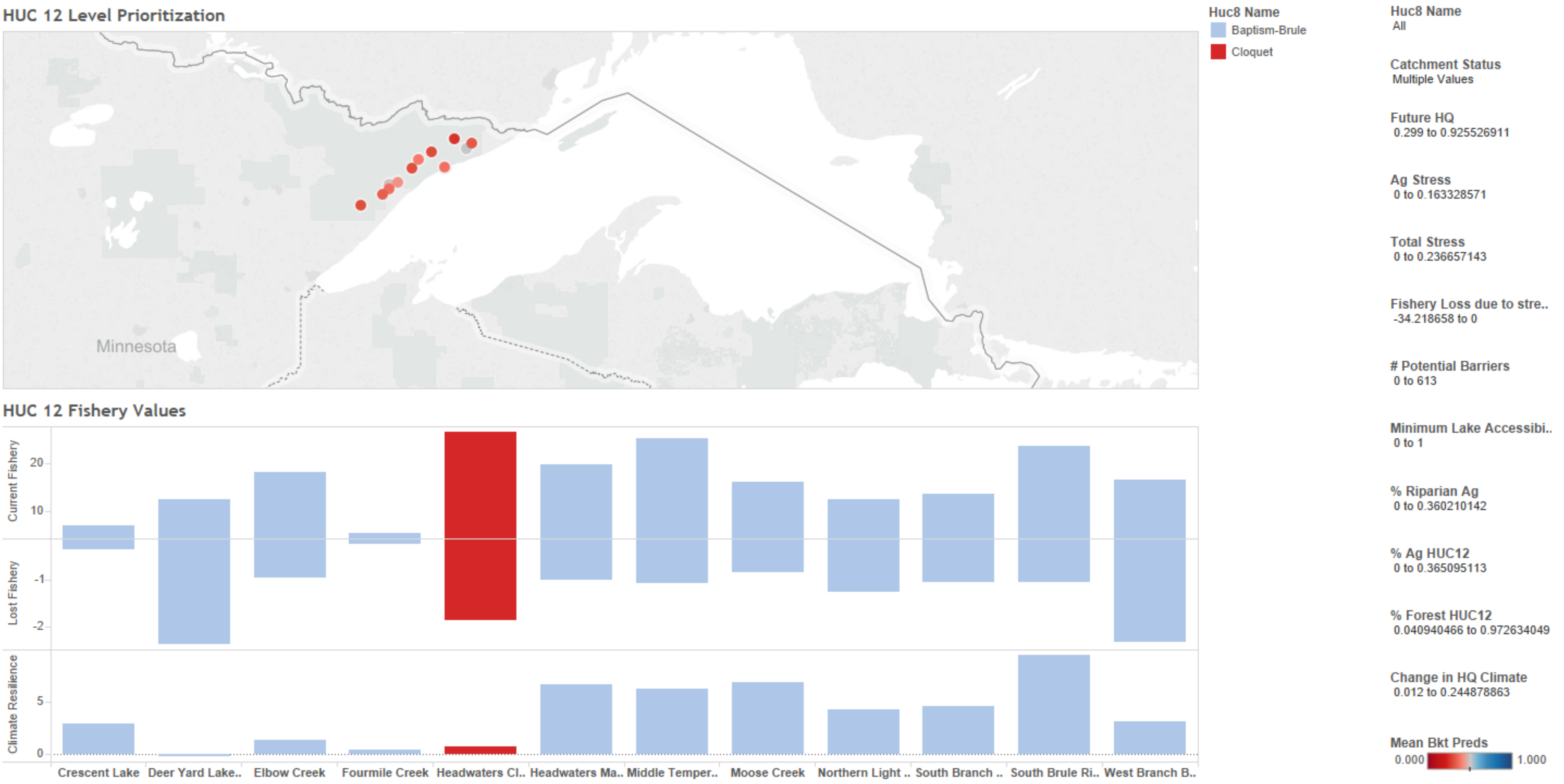
**Criteria**

We utilized three criteria to identify the HUC12 watersheds for this scenario. First, we selected only HUC12 watersheds that had high future habitat quality scores (mean score under future climate condition was greater than 0.299). This factor accounted for both underlying habitat quality score and the impact from future climate conditions. Next, we used the habitat quality change under future climate conditions ( > 0.012 positive change). Lastly, we selected on those HUC12 watersheds that were considered intact in the Ashland FWCO brook trout classification.

**Results**

There are 12 HUC12 watersheds identified in this scenario, all of which were within two distinct HUC8s, on Minnesota's northern shore. Figure 16 shows the Tableau interface used to evaluate this scenario. The evaluation criteria can be seen in the right hand column and a map of the identified watersheds (marked as HUC12 centroids) and bar charts of some of the relevant data of each identified watershed make up the remainder of the figure. These watersheds are all predicted to have high resistance to future climate scenarios, and increased precipitation could even improve brook trout habitat in limited areas. Given the strong future projected for brook trout in these areas, work within these watersheds to otherwise improve brook trout can be done with confidence that the positive effects will perpetuate into the future.

**Figure 16. Tableau interface for climate resiliency scenario.**



Huc8 Name
All

Catchment Status
Multiple Values

Future HQ
0.299 to 0.925526911

Ag Stress
0 to 0.163328571

Total Stress
0 to 0.236657143

Fishery Loss due to stre..
-34.218658 to 0

# Potential Barriers
0 to 613

Minimum Lake Accessibi..
0 to 1

% Riparian Ag
0 to 0.360210142

% Ag HUC12
0 to 0.365095113

% Forest HUC12
0.040940466 to 0.972634049

Change in HQ Climate
0.012 to 0.244878863

Mean Bkt Preds
0.000 1.000

### 6.3.5 *Climate Change Vulnerability Scenario*

**Description**

This goal of this scenario was to identify watersheds where brook trout populations are projected to be the most at risk of losing brook trout populations in the face of future climate scenarios. These watersheds are areas where restoration could be focused to ameliorate potential negative impacts of future climate scenarios by focusing on restoration of riparian forest cover in order to shade and cool streams as a way to ameliorate for the effects of higher temperatures.

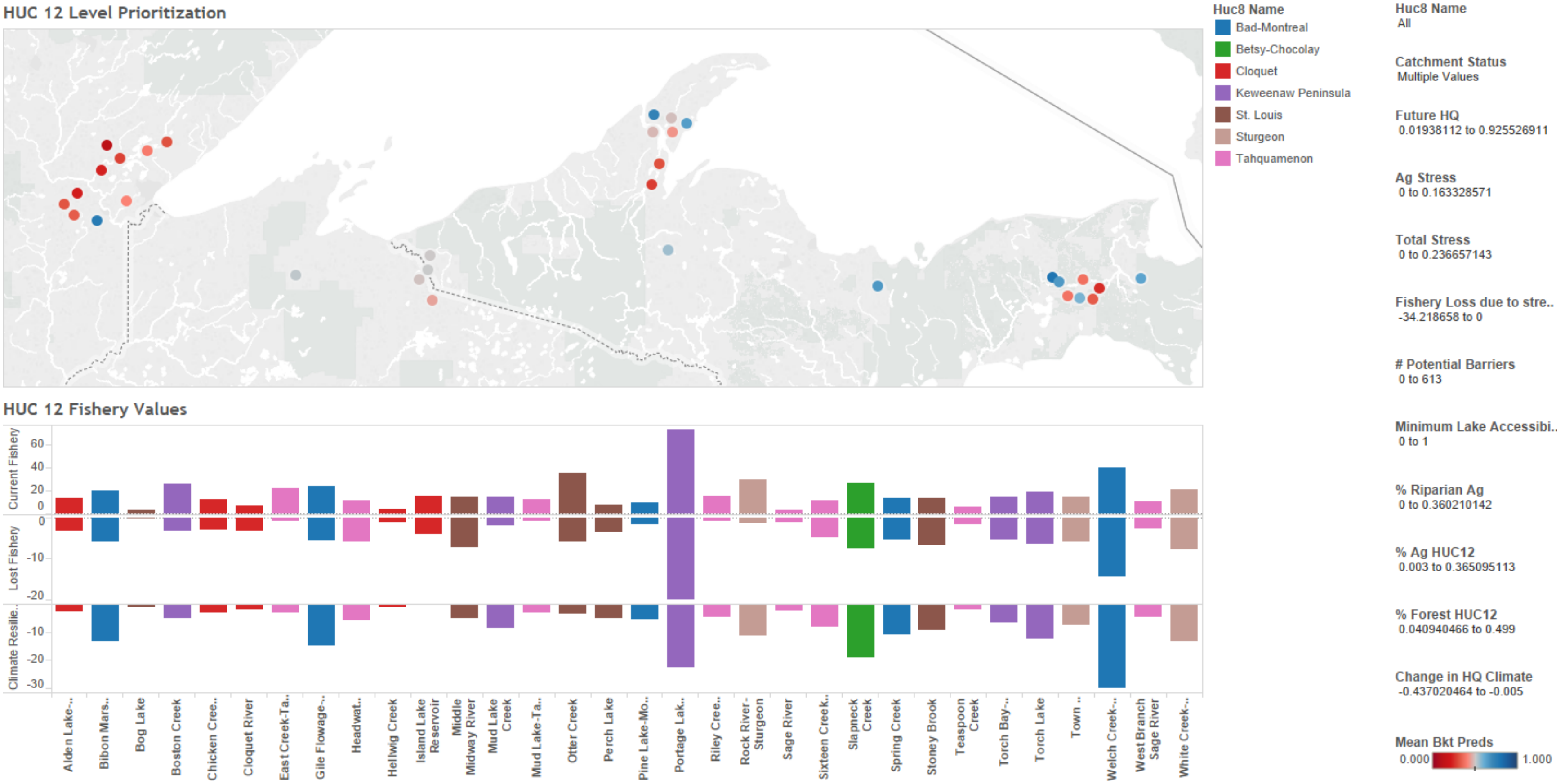
**Criteria**

We utilized four criteria to identify the HUC12 watersheds for this scenario. First, we used the Ashland FWCO HUC12 classifications to find those watershed identified as 'Intact' or 'Predicted Intact'. Next, we selected only HUC12 watersheds that had a reduction in habitat score under future climate scenarios. Next, we used land cover for the watershed to further refine this scenario. We selected watersheds where agriculture cover was greater than zero, and where forest cover was less than 50% of the entire HUC12. Together, these criteria select watersheds vulnerable to climate change that provide realistic opportunity for restoration of forest cover in order to ameliorate for increased temperatures under projected future climates.

**Results**

There are 32 HUC12 watersheds identified in this scenario distributed across the basin and within seven distinct HUC8s. Figure 17 shows the Tableau interface used to evaluate this scenario. The evaluation criteria can be seen in the right hand column and a map of the identified watersheds (marked as HUC12 centroids) and bar charts of some of the relevant data of each identified watershed make up the remainder of the figure. These watersheds are those that are expected to potentially lose the most brook trout habitat as a result of projected climate change. Additionally, because of the selection criteria, these are all areas where ample opportunity for riparian plantings to shade stream channels could be useful in ameliorating potential increased stream temperatures. Analyzing the climate resiliency bar chart can provide more information on the amount of habitat loss expected from future climate conditions, and those expected to have the most loss (Portage Lake, Welch Creek) could be prioritized even higher for this specific scenario.

**Figure 17. Tableau interface for climate vulnerbility scenario.**



**Huc8 Name**
All

**Catchment Status**
Multiple Values

**Future HQ**
0.01938112 to 0.925526911

**Ag Stress**
0 to 0.163328571

**Total Stress**
0 to 0.236657143

**Fishery Loss due to stre..**
-34.218658 to 0

**# Potential Barriers**
0 to 613

**Minimum Lake Accessibi..**
0 to 1

**% Riparian Ag**
0 to 0.360210142

**% Ag HUC12**
0.003 to 0.365095113

**% Forest HUC12**
0.040940466 to 0.499

**Change in HQ Climate**
-0.437020464 to -0.005

### 6.3.6 *Riparian Agriculture Scenario*

**Description**

The goal of this scenario was to identify watersheds where brook trout populations would most benefit from riparian agriculture restoration. Agricultural practices in the riparian corridor can stress brook trout in various ways including sedimentation, nutrient inputs, and loss of streamside canopy. Riparian forest restoration could ameliorate or reduce these sources of stress.

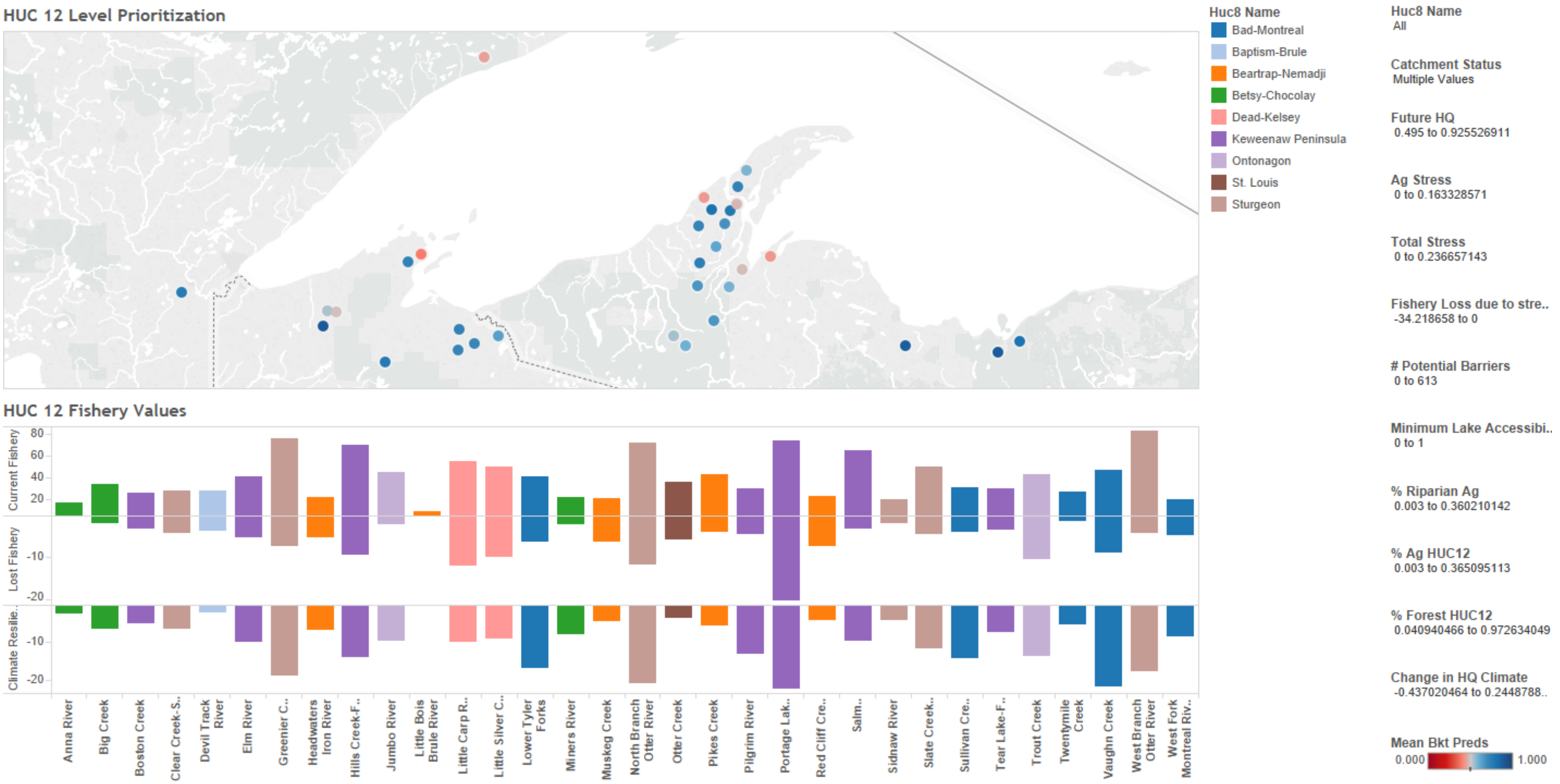
**Criteria**

We utilized four criteria to identify the HUC12 watersheds for this scenario. First, we used the Ashland FWCO HUC12 brook trout status classifications to refine our query to those watersheds that had a particular population status, and we used this criterion to create two separate sub-scenarios; one scenario focused on "Intact" populations, and one focused on "Reduced" populations. Next, we selected watersheds where HUC12 agriculture cover was greater than zero, and also where the HUC12 percent riparian agriculture greater than zero. Finally, we selected only HUC12 watersheds that had high future habitat quality scores. This factor accounted for both underlying habitat quality score and the impact from future climate conditions. We selected only those watersheds with a mean habitat quality score under future climate condition of greater than 0.495 (intact populations) or greater than 0.397 (reduced populations).

**Results**

There are 52 total HUC12 watersheds identified in this scenario (32 intact, 20 reduced) distributed across the basin and within 10 distinct HUC8s. Figure 18 and Figure 19 show the Tableau interfaces used to evaluate these scenarios. The evaluation criteria can be seen in the right hand column and a map of the identified watersheds (marked as HUC12 centroids) and bar charts of some of the relevant data of each identified watershed make up the remainder of the figure. For a restoration scenario, evaluating the climate resiliency and lost fishery value would be important in finding the best watersheds from within those identified. Larger lost fishery values indicate more gross potential for restoration, and more climate resiliency would indicate that benefits from restoration would not be undermined by habitat loss due to climate change.

**Figure 18. Tableau interface for riparian agriculture intact scenario.**



Huc8 Name
All

Catchment Status
Multiple Values

Future HQ
0.495 to 0.925526911

Ag Stress
0 to 0.163328571

Total Stress
0 to 0.236657143

Fishery Loss due to stre..
-34.218658 to 0

# Potential Barriers
0 to 613

Minimum Lake Accessibi..
0 to 1

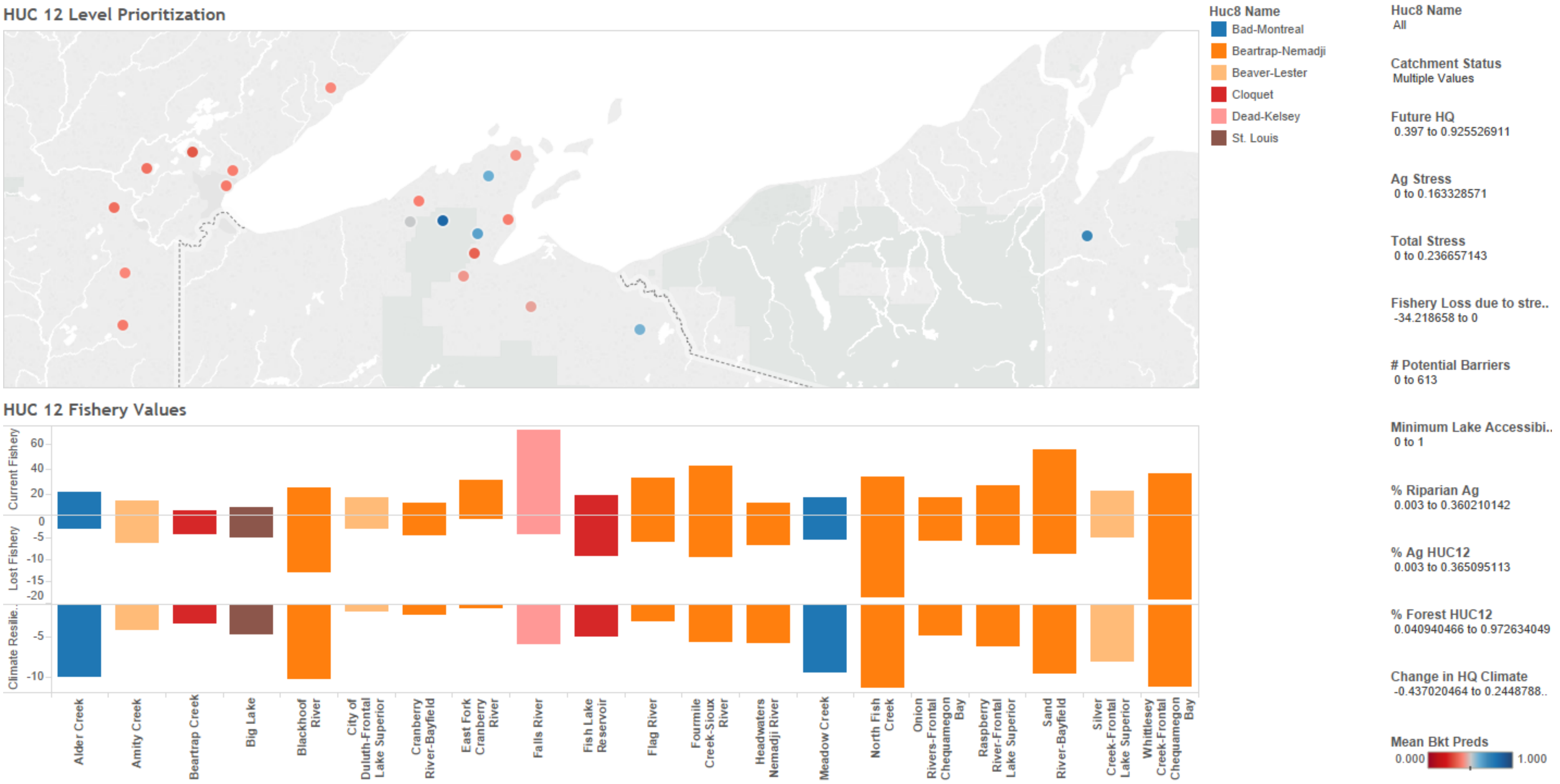
% Riparian Ag
0.003 to 0.360210142

% Ag HUC12
0.003 to 0.365095113

% Forest HUC12
0.040940466 to 0.972634049

Change in HQ Climate
-0.437020464 to 0.2448788..

Figure 19. Tableau interface for riparian agriculture reduced scenario.



Huc8 Name
All

Catchment Status
Multiple Values

Future HQ
0.397 to 0.925526911

Ag Stress
0 to 0.163328571

Total Stress
0 to 0.236657143

Fishery Loss due to stre..
-34.218658 to 0

# Potential Barriers
0 to 613

Minimum Lake Accessibi..
0 to 1

% Riparian Ag
0.003 to 0.360210142

% Ag HUC12
0.003 to 0.365095113

% Forest HUC12
0.040940466 to 0.972634049

Change in HQ Climate
-0.437020464 to 0.2448788..

Mean Bkt Preds
0.000 1.000

### 6.3.7 *Slow-The-Flow Catchment Scenario*

**Description**

The goal of this scenario was to identify segment level watersheds (catchments) within the HUC12s identified in the Riparian Agriculture Scenario where brook trout populations would most benefit from riparian agriculture restoration as advocated for by “Slow the Flow” Initiative. This effort was developed in the Lake Superior Basin and provides funding for restorative actions that slow overland runoff in order to reduce sedimentation within stream channels. Examples of management actions include riparian and upland tree planting, improved agricultural and livestock practices, wetland restoration and protection, increased stream channel complexity, and restored floodplain connectivity.

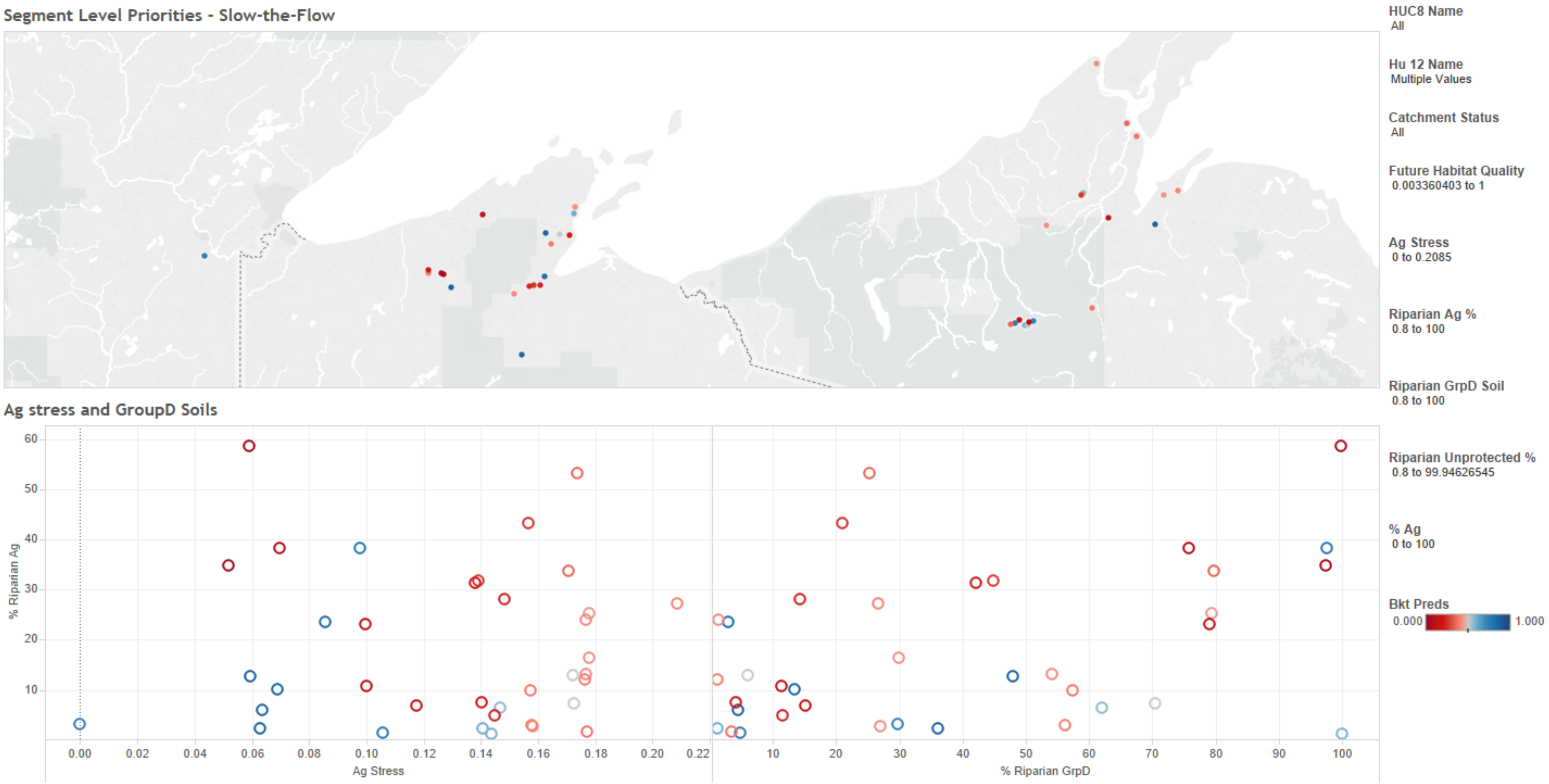
**Criteria**

We utilized four criteria to identify the HUC12 watersheds for this scenario. First, we queried catchments in watersheds that were identified in the Riparian Agriculture Scenario. Next, we selected catchments that had percent riparian agriculture values greater than zero to ensure areas identified could benefit from riparian agricultural restoration. Next we selected only catchments that had riparian lands that were currently “unprotected” as defined by the USGS Protected Area Database. One source of funds used to address “slowing the flow” is only available for use on private lands; this criterion ensured that selected catchments did not fall entirely within protected state or federal lands. Lastly, we used soil hydrologic data to find only catchments with very low infiltration rates (typically clay soils) where runoff would likely be high. Specifically, this criterion was to find catchments where percent soil hydrologic group D within the catchment was greater than zero.

**Results**

There are 37 catchments identified in this scenario distributed across the basin and within 20 different HUC12 watersheds and seven distinct HUC8s. Figure 20 shows the Tableau interface used to evaluate this scenario. The evaluation criteria can be seen in the right hand column and a map of the identified watersheds (marked as HUC12 centroids) and bar charts of some of the relevant data of each identified watershed make up the remainder of the figure.  The catchments identified here are high priorities for targeted restoration through the Slow the Flow Initiative. They are reasonably well distributed throughout the watershed, providing potential locations across all three of the Lake Superior Basin states. Targeted restoration of the noted catchments should provide ecological lift locally and downstream of the focal catchment.

**Figure 20. Tableau interface for Slow the Flow catchment scenario.**



Segment Level Priorities - Slow-the-Flow

Ag stress and GroupD Soils

HUC8 Name: All

Hu 12 Name: Multiple Values

Catchment Status: All

Future Habitat Quality: 0.003360403 to 1

Ag Stress: 0 to 0.2085

Riparian Ag %: 0.8 to 100

Riparian GrpD Soil: 0.8 to 100

Riparian Unprotected %: 0.8 to 99.94626545

% Ag: 0 to 100

Bkt Preds: 0.000 to 1.000

## 6.4 Watershed Prioritization

We utilized the results of the previous eight scenarios to establish HUC12 watershed prioritizations. This was a straight forward process where we counted the number of scenarios in which each HUC12 watershed was identified. We then ranked watersheds based on the number of scenarios they matched, and also by the calculated lost fishery value within the HUC12 watershed. Lost fishery is a length weighted measure of brook trout habitat lost due to stressors.

In total, 161 HUC12 watersheds were identified as matching at least one scenario. Figure 21 shows the number of instances a HUC12 was identified in a scenario, broken down by containing HUC8. The map in Figure 22 shows the spatial distribution of HUC12s identified within the prioritization scenarios, symbolized by how many scenarios within each HUC12 was pinpointed.

**Figure 21. HUC8 distribution of scenario results.**

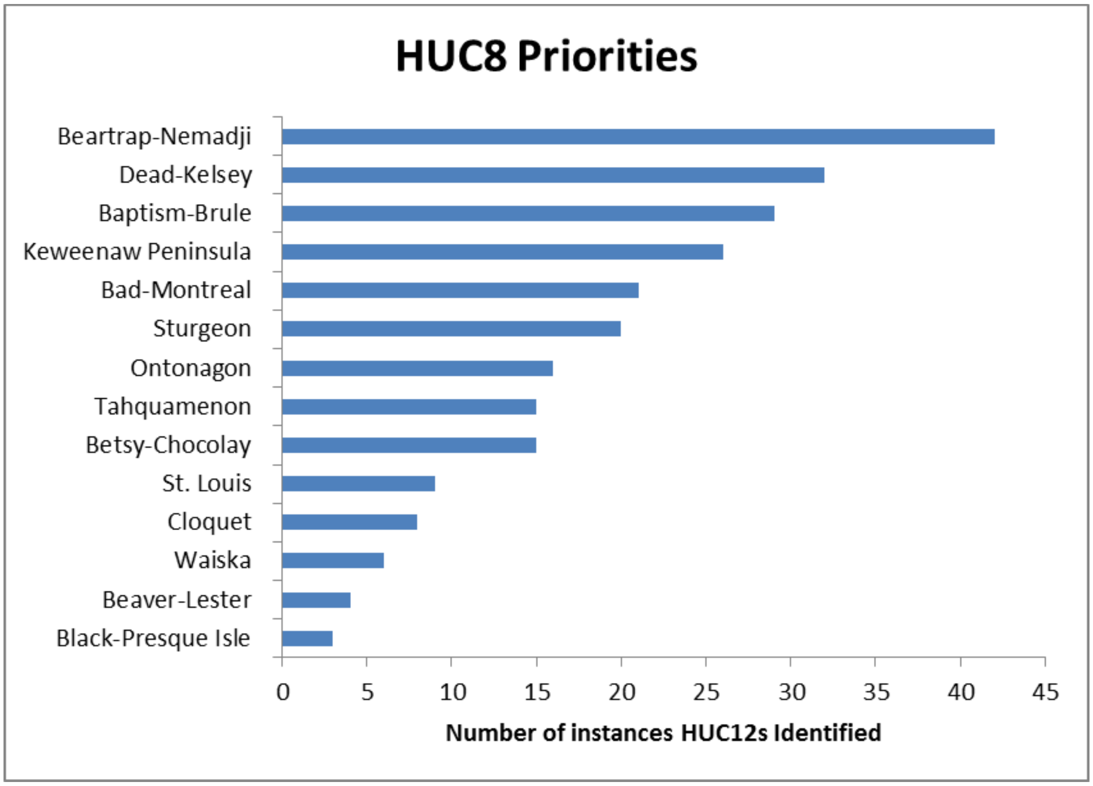
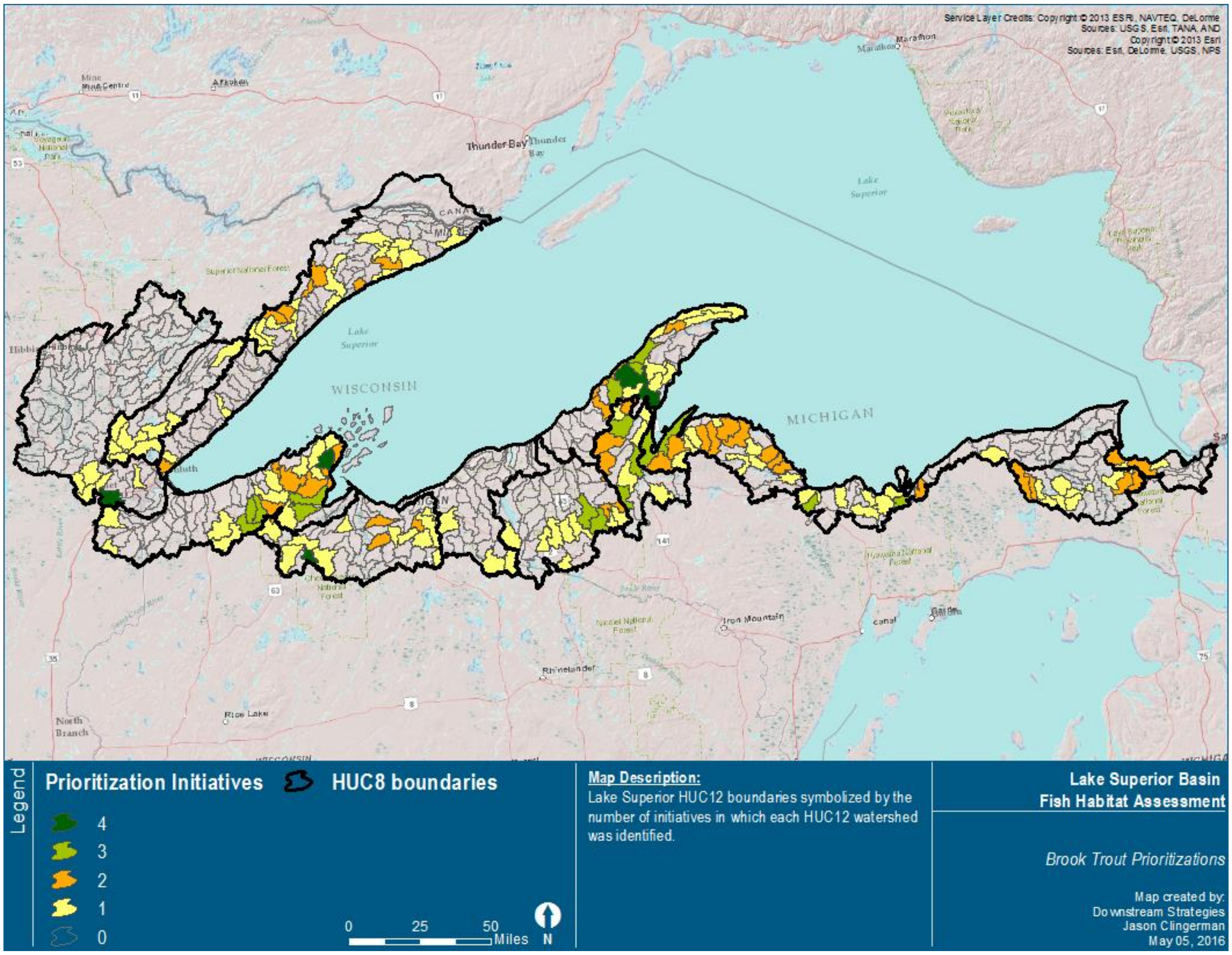


**Figure 22. Distribution and frequency of priority HUC12s.**



A total of 21 HUC12 watersheds were identified within three or more scenarios (Table 3). These 21 HUC12 watersheds were found within eight of the 14 HUC8 watersheds that make up the Lake Superior Basin. We sorted these HUC12 watersheds by lost fishery value in order to rank the watersheds by the total recovery and restoration potential within each. Detailed watershed profiles for some of these watersheds can be found in a separate document prepared for Ashland FWCO.

**Table 3. Top ranked prioritized HUC12s**

| HUC12 Name | HUC8 Name | Lost Fishery Value | Best of the best | Climate Resil. | Climate Vuln. | Connectivity | General Restoration | Riparian Agriculture Intact | Riparian Agriculture Reduced | Slow The Flow Catchment | Scenario Count |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Portage Lake-Portage River | Keweenaw Peninsula | -20.2 | | | X | | X | X | | X | 4 |
| Whittlesey Creek-Frontal Chequamegon Bay | Beartrap-Nemadji | -19.3 | | | | | X | | X | X | 3 |
| North Fish Creek | Beartrap-Nemadji | -18.8 | | | | | X | | X | X | 3 |
| Little Carp River-Frontal Keweenaw Bay | Dead-Kelsey | -12.0 | | | | | X | X | | X | 3 |
| North Branch Otter River | Sturgeon | -11.6 | | | | | X | X | | X | 3 |
| Trout Creek | Ontonagon | -10.5 | | | | | X | X | | X | 3 |
| Little Silver Creek-Frontal Keweenaw Bay | Dead-Kelsey | -9.9 | | | | | X | X | | X | 3 |
| Hills Creek-Frontal Lake Superior | Keweenaw Peninsula | -9.2 | X | | | | X | X | | | 3 |
| Muskeg Creek | Beartrap-Nemadji | -6.3 | | | | | X | X | | X | 3 |
| Otter Creek | St. Louis | -5.8 | | | X | | X | X | | X | 4 |
| Headwaters Iron River | Beartrap-Nemadji | -5.3 | | | | | X | X | | X | 3 |
| Clear Creek-Sturgeon Creek | Sturgeon | -4.1 | | | | | X | X | | X | 3 |
| Pikes Creek | Beartrap-Nemadji | -4.0 | X | | | | X | X | | X | 4 |
| Boston Creek | Keweenaw Peninsula | -3.3 | | | X | | X | X | | | 3 |
| Salmon Trout River-Keweenaw | Keweenaw Peninsula | -3.1 | X | | | X | | X | | | 3 |
| Jumbo River | Ontonagon | -2.2 | | | | X | | X | | X | 3 |
| Big Creek | Betsy-Chocolay | -1.9 | X | | | | X | X | | | 3 |
| Sidnaw River | Sturgeon | -1.8 | | | | | X | X | | X | 3 |
| Twentymile Creek | Bad-Montreal | -1.5 | X | | | | X | X | | X | 4 |
| Anna River | Betsy-Chocolay | -0.1 | X | | | X | | X | | | 3 |
| Little Bois Brule River | Beartrap-Nemadji | -0.1 | X | | | X | | X | | | 3 |

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# APPENDIX A: DATA DICTIONARY

| Attribute Name | Description | Source |
|---|---|---|
| FEATUREID | Catchment Identifier | NHD+, Horizon Systems |
| AreaSqKM | Catchment area | NHD+, Horizon Systems |
| TotDASqKM | Network basin area | NHD+, Horizon Systems |
| StreamOrde | Strahler stream order | NHD+, Horizon Systems |
| MINELEVRAW | Minimum catchment elevation | NHD+, Horizon Systems |
| SLOPE | Slope of catchment flowline | NHD+, Horizon Systems |
| hJXnow | Current predicted stream temperature | FishVis (USGS) |
| TempV | Mean annual air temperature, catchment | NHD+, Horizon Systems |
| TempVC | Mean annual air temperature, network | NHD+, Horizon Systems |
| PrecipV | Mean annual precipitation, catchment | NHD+, Horizon Systems |
| PrecipVC | Mean annual precipitation, network | NHD+, Horizon Systems |
| JXF1 | Future predicted stream temperature | FishVis (USGS) |
| fut_precV | Future predicted mean annual air temperature, catchment | TNC Climate Wizard |
| fut_tempV | Future predicted mean annual air temperature, network | TNC Climate Wizard |
| RunOffV | Mean annual runoff, catchment | NHD+, Horizon Systems |
| RunOffVC | Mean annual runoff, network | NHD+, Horizon Systems |
| water_p | Surface water percentage, catchment | NLCD |
| dev_p | Developed percentage, catchment | NLCD |
| bar_p | Barren percentage, catchment | NLCD |
| for_p | Forest percentage, catchment | NLCD |
| shrub_p | Shrub/scrub percentage, catchment | NLCD |
| grass_p | Grassland percentage, catchment | NLCD |
| past_p | Pasture percentage, catchment | NLCD |
| crop_p | Cropland percentage, catchment | NLCD |
| ag_p | Agriculture percentage, catchment | NLCD |

| Attribute Name | Description | Source |
|---|---|---|
| wet_p | Wetland percentage, catchment | NLCD |
| water_pc | Surface water percentage, network | NLCD |
| dev_pc | Developed percentage, network | NLCD |
| bar_pc | Barren percentage, network | NLCD |
| for_pc | Forest percentage, network | NLCD |
| shrub_pc | Shrub/scrub percentage, network | NLCD |
| grass_pc | Grassland percentage, network | NLCD |
| past_pc | Pasture percentage, network | NLCD |
| crop_pc | Cropland percentage, network | NLCD |
| ag_pc | Agriculture percentage, network | NLCD |
| wet_pc | Wetland percentage, network | NLCD |
| nwi_wetp | Wetland percentage, catchment | NWI |
| nwi_wet_emerp | Emergent wetland percentage, catchment | NWI |
| nwi_wet_forp | Forested wetland percentage, catchment | NWI |
| nwi_wet_lakep | Lake wetland percentage, catchment | NWI |
| nwi_wet_otherp | Other wetland percentage, catchment | NWI |
| nwi_wet_pondp | Pond wetland percentage, catchment | NWI |
| nwi_wet_riverp | Riverine wetland percentage, catchment | NWI |
| nwi_wetpc | Wetland percentage, network | NWI |
| nwi_wet_emerpc | Emergent wetland percentage, network | NWI |
| nwi_wet_forpc | Forested wetland percentage, network | NWI |
| nwi_wet_lakepc | Lake wetland percentage, network | NWI |
| nwi_wet_otherpc | Other wetland percentage, network | NWI |
| nwi_wet_pondpc | Pond wetland percentage, network | NWI |
| nwi_wet_riverpc | Riverine wetland percentage, network | NWI |
| imp_pctV | Mean imperviousness, catchment | NLCD |
| imp_pctVC | Mean imperviousness, network | NLCD |
| changeP | Percent landcover change, catchment | NLCD |
| changePC | Percent landcover change, network | NLCD |

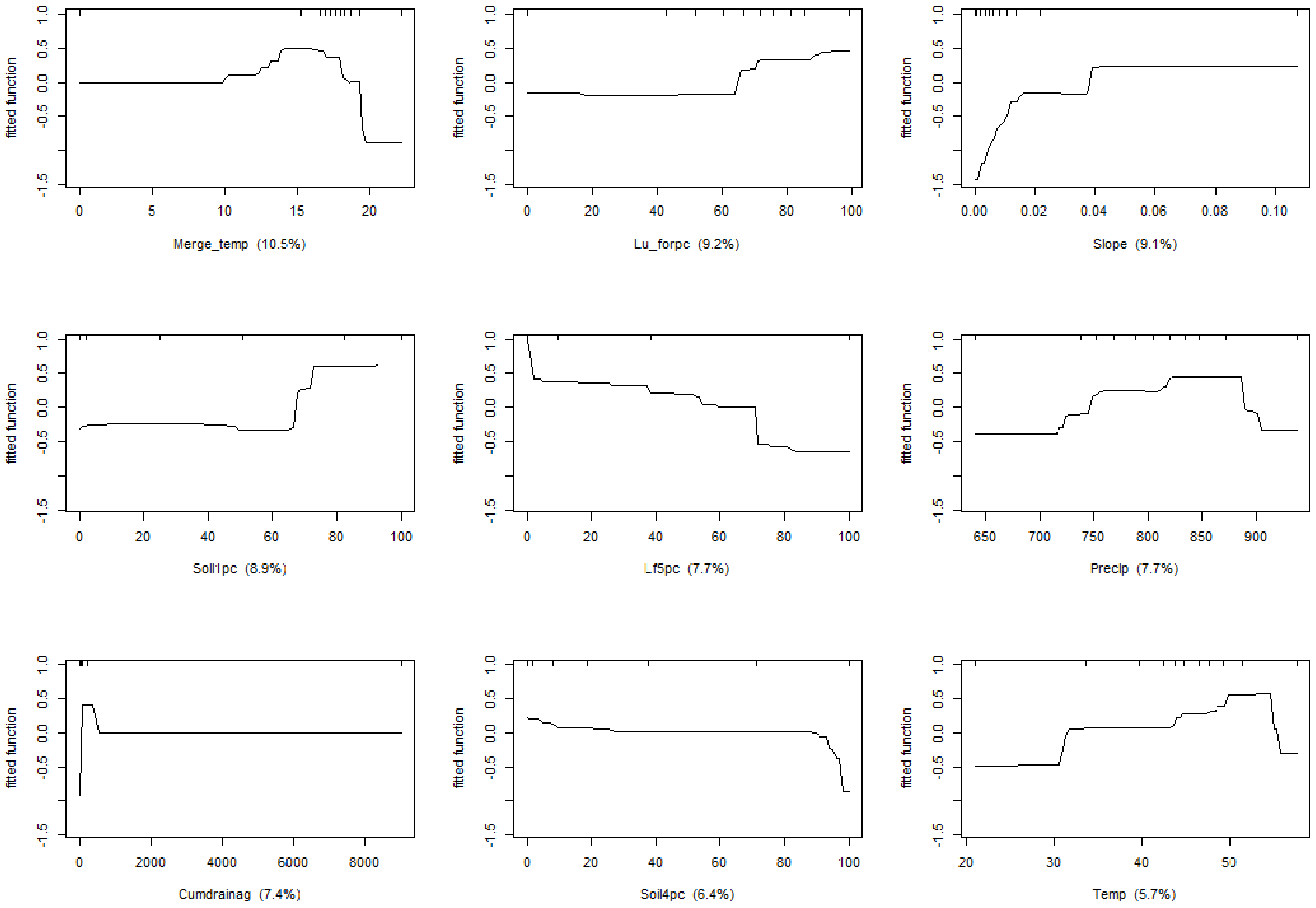
| Attribute Name | Description | Source |
|---|---|---|
| nochangeP | Percent landcover unchanged, catchment | NLCD |
| nochangePC | Percent landcover unchanged, network | NLCD |
| neg_chgP | Percent negative landcover change, catchment | NLCD |
| neg_chgPC | Percent negative landcover change, network | NLCD |
| neut_chgP | Percent neutral landcover change, catchment | NLCD |
| neut_chgPC | Percent neutral landcover change, network | NLCD |
| pos_chgP | Percent positive landcover change, catchment | NLCD |
| pos_chgPC | Percent positive landcover change, network | NLCD |
| min_bed_depth | Depth to bedrock, minimum, catchment | SSURGO |
| mean_bed_depth | Depth to bedrock, mean, catchment | SSURGO |
| max_bed_depth | Depth to bedrock, maximum, catchment | SSURGO |
| min_bed_depthC | Depth to bedrock, minimum, network | SSURGO |
| mean_bed_depthC | Depth to bedrock, mean, network | SSURGO |
| max_bed_depthC | Depth to bedrock, maximum, network | SSURGO |
| min_h20_depth | Depth to water table, minimum, catchment | SSURGO |
| mean_h20_depth | Depth to water table, mean, catchment | SSURGO |
| max_h20_depth | Depth to water table, maximum, catchment | SSURGO |
| min_h20_depthC | Depth to water table, minimum, network | SSURGO |
| mean_h20_depthC | Depth to water table, mean, network | SSURGO |
| max_h20_depthC | Depth to water table, maximum, network | SSURGO |
| Grp_ADP | Percent soil hydrologic group AD, catchment | SSURGO |
| Grp_AP | Percent soil hydrologic group A, catchment | SSURGO |
| Grp_BDP | Percent soil hydrologic group BD, catchment | SSURGO |
| Grp_BP | Percent soil hydrologic group B, catchment | SSURGO |
| Grp_CDP | Percent soil hydrologic group CD, catchment | SSURGO |
| Grp_CP | Percent soil hydrologic group C, catchment | SSURGO |
| Grp_DP | Percent soil hydrologic group D, catchment | SSURGO |
| Grp_ADPC | Percent soil hydrologic group AD, network | SSURGO |
| Grp_APC | Percent soil hydrologic group A, network | SSURGO |

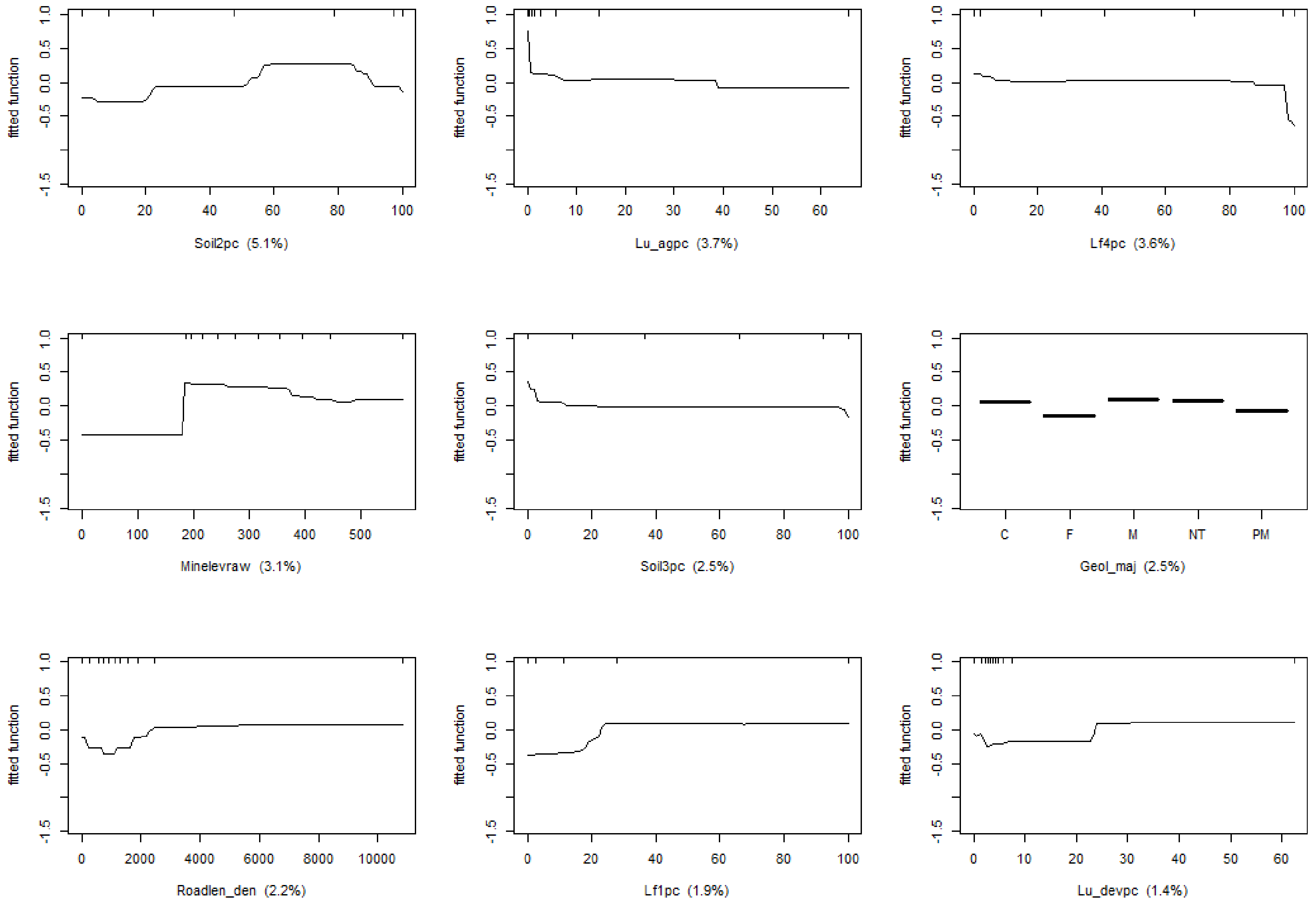
| Attribute Name | Description | Source |
|---|---|---|
| Grp_BDPC | Percent soil hydrologic group BD, network | SSURGO |
| Grp_BPC | Percent soil hydrologic group B, network | SSURGO |
| Grp_CDPC | Percent soil hydrologic group CD, network | SSURGO |
| Grp_CPC | Percent soil hydrologic group C, network | SSURGO |
| Grp_DPC | Percent soil hydrologic group D, network | SSURGO |
| Rip_area | Riparian area, catchment | DS |
| Rip_catchp | Percent riparian area, catchment | NLCD |
| Rip_barp | Percent barren riparian area, catchment | NLCD |
| Rip_devp | Percent developed riparian area, catchment | NLCD |
| Rip_forp | Percent forested riparian area, catchment | NLCD |
| Rip_grassp | Percent grassland riparian area, catchment | NLCD |
| Rip_cropp | Percent cropland riparian area, catchment | NLCD |
| Rip_pastp | Percent pasture riparian area, catchment | NLCD |
| Rip_agp | Percent agricultural riparian area, catchment | NLCD |
| Rip_scrubp | Percent scrub/shrub riparian area, catchment | NLCD |
| Rip_wetp | Percent wetland riparian area, catchment | NLCD |
| Rip_distp | Percent disturbed riparian area, catchment | NLCD |
| Rip_undp | Percent undisturbed riparian area, catchment | NLCD |
| Rip_areac | Riparian area, network | DS |
| Rip_catchpc | Percent riparian area, network | NLCD |
| Rip_barpc | Percent barren riparian area, network | NLCD |
| Rip_devpc | Percent developed riparian area, network | NLCD |
| Rip_forpc | Percent forested riparian area, network | NLCD |
| Rip_grasspc | Percent grassland riparian area, network | NLCD |
| Rip_croppc | Percent cropland riparian area, network | NLCD |
| Rip_pastpc | Percent pasture riparian area, network | NLCD |
| Rip_agpc | Percent agricultural riparian area, network | NLCD |
| Rip_scrubpc | Percent scrub/shrub riparian area, network | NLCD |
| Rip_wetpc | Percent wetland riparian area, network | NLCD |

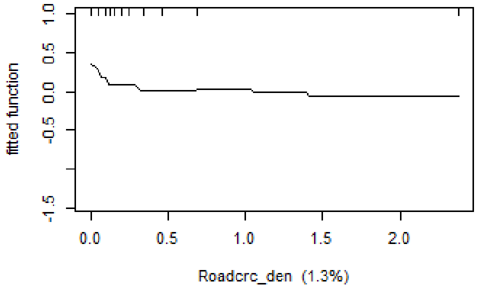
| Attribute Name | Description | Source |
|---|---|---|
| Rip_distpc | Percent disturbed riparian area, network | NLCD |
| Rip_undpc | Percent undisturbed riparian area, network | NLCD |
| Ripsl_AP | Riparian percent soil hydrologic group AD, catchment | SSURGO |
| Ripsl_ADP | Riparian percent soil hydrologic group A, catchment | SSURGO |
| Ripsl_BP | Riparian percent soil hydrologic group BD, catchment | SSURGO |
| Ripsl_BDP | Riparian percent soil hydrologic group B, catchment | SSURGO |
| Ripsl_CP | Riparian percent soil hydrologic group CD, catchment | SSURGO |
| Ripsl_CDP | Riparian percent soil hydrologic group C, catchment | SSURGO |
| Ripsl_DP | Riparian percent soil hydrologic group D, catchment | SSURGO |
| Ripsl_APC | Riparian percent soil hydrologic group AD, network | SSURGO |
| Ripsl_ADPC | Riparian percent soil hydrologic group A, network | SSURGO |
| Ripsl_BPC | Riparian percent soil hydrologic group BD, network | SSURGO |
| Ripsl_BDPC | Riparian percent soil hydrologic group B, network | SSURGO |
| Ripsl_CPC | Riparian percent soil hydrologic group CD, network | SSURGO |
| Ripsl_CDPC | Riparian percent soil hydrologic group C, network | SSURGO |
| Ripsl_DPC | Riparian percent soil hydrologic group D, network | SSURGO |
| Sum_toCoun | Number of barriers within catchment | FishWerks |
| Min_COST | Minimum cost of barrier replacement within catchment | FishWerks |
| Max_COST | Maximum cost of barrier replacement within catchment | FishWerks |
| Ave_COST | Mean cost of barrier replacement within catchment | FishWerks |
| Sum_COST | Sum of cost of barrier replacement within catchment | FishWerks |
| Min_PASS10 | Minimum passibility value for strong swimming species for all barriers within catchment | FishWerks |
| Max_PASS10 | Maximum passibility value for strong swimming species for all barriers within catchment | FishWerks |
| Ave_PASS10 | Mean passibility value for strong swimming species for all barriers within catchment | FishWerks |
| multiVal | Multiplied passibility value for strong swimming species for all barriers within catchment | FishWerks/DS |
| dsBarr | Number of barriers between catchment and Lake Superior along downstream | FishWerks/DS |

| Attribute Name | Description | Source |
|---|---|---|
|  | flowpath |  |
| dsMinP10 | Minimum passibility value between catchment and Lake Superior along downstream flowpath for strong swimming species | FishWerks/DS |
| dsMulP10 | Multiplied passibility value between catchment and Lake Superior along downstream flowpath  for strong swimming species | FishWerks/DS |

# APPENDIX B: FUNCTION PLOTS




fitted function
1.0
0.5
0.0
-0.5
-1.5
0
20
40
60
80
100
Soil2pc (5.1%)
0
10
20
30
40
50
60
Lu_agpc (3.7%)
Lf4pc (3.6%)
0
100
200
300
400
500
Minelevraw (3.1%)
Soil3pc (2.5%)
C
F
M
NT
PM
Geol_maj (2.5%)
0
2000
4000
6000
8000
10000
Roadlen_den (2.2%)
Lf1pc (1.9%)
Lu_devpc (1.4%)


fitted function
-1.5
-0.5
0.0
0.5
1.0
0.0
0.5
1.0
1.5
2.0
Roadcrc_den (1.3%)

# APPENDIX C: DATA PROCESSING DETAILS

### Data Set-Up

NHDPlus Version 2 datasets were used to update all predictor data within the Lake Superior Basin that were able to be associated to catchments. We used the CA3TV2 Tool to allocate and accumulate variables to catchments. This provided data on the local catchment conditions as well and the condition of the entire upstream drainage area for each catchment.

### NLCD 2011 Landcover

1. Downloaded NLCD 2011 Land Cover Grid.
2. Clipped raster to study area.
3. Utilized CA3TV2 tool to allocate/accumulate area of each land cover class.
4. Within Microsoft Access/Excel, calculated percentages of land cover types, using the following table to reclassify the original categories into more generalized categories.

| NLCD 2011 Grid Code | Description | Reclassified Category |
|---|---|---|
| 11 | Open water | N/A |
| 21 | Developed, open space | Developed |
| 22 | Developed, low intensity | Developed |
| 23 | Developed, medium intensity | Developed |
| 24 | Developed, high intensity | Developed |
| 31 | Barren land | Barren |
| 41 | Deciduous forest | Forest |
| 42 | Evergreen forest | Forest |
| 43 | Mixed forest | Forest |
| 52 | Shrub/scrub | Shrub/scrub |

| | | |
|---|---|---|
| 71 | Grassland/herbaceous | Grassland/herbaceous |
| 81 | Pasture/hay | Agriculture |
| 82 | Cultivated crops | Agriculture |
| 90 | Woody wetlands | Wetland |
| 95 | Emergent herbaceous wetlands | Wetland |

**NLCD 2011 Imperviousness**

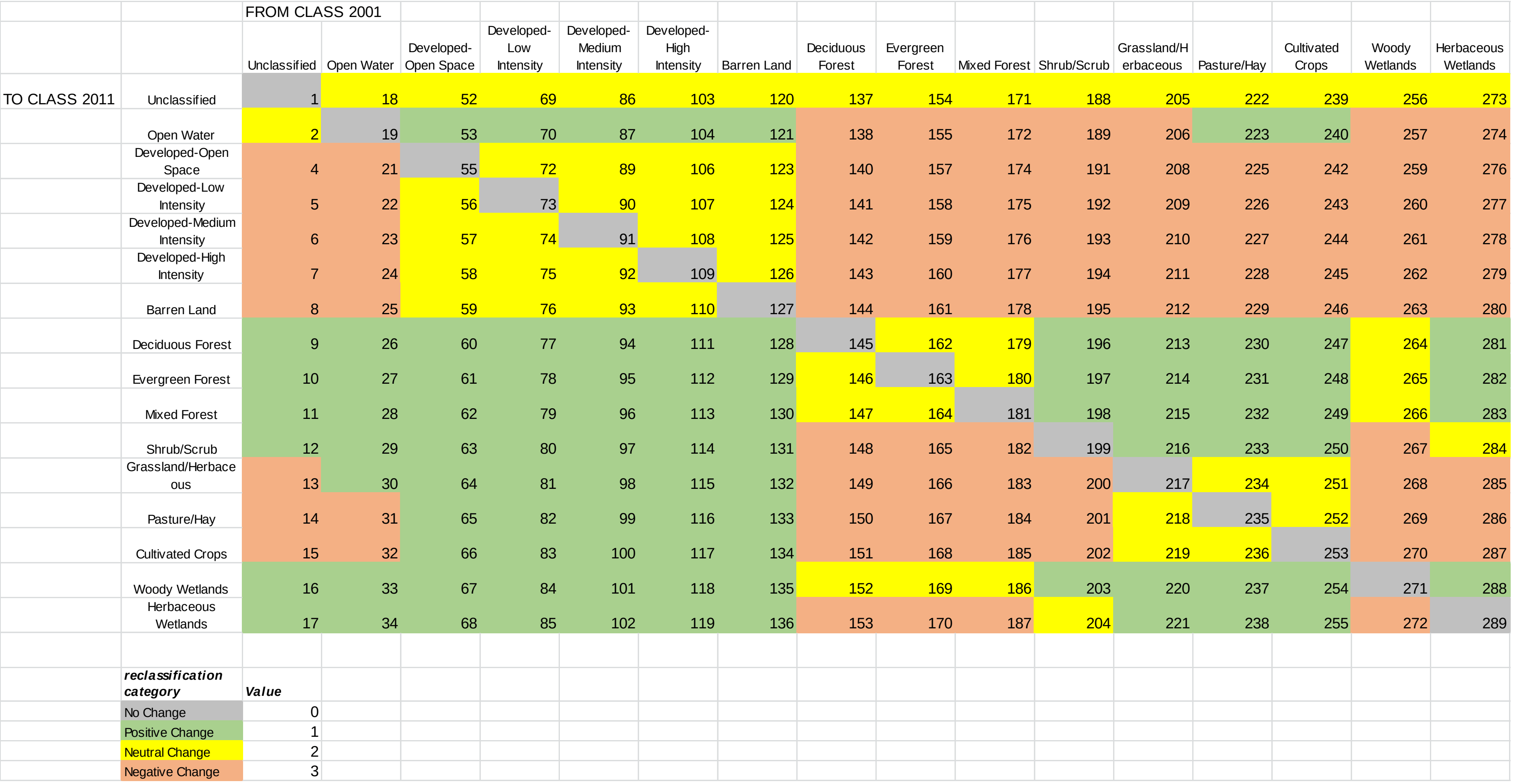
1. Downloaded NLCD 2011 Percent Developed Imperviousness
2. Clipped raster to study area.
3. Used CA3TV2 tool to allocate/accumulate mean area-weighted imperviousness for each catchment.

**NWI Wetlands**

1. Downloaded NWI state datasets in geodatabase format for Wisconsin, Minnesota, and Michigan.
2. Clipped state datasets to study area, exported as shapefiles.
3. Merged state shapefiles into a single polygon shapefile that covered the Lake Superior Basin study area.
4. Used polygon to raster tool to create a grid of wetlands based on wetland type.
    a. Wetland Types:
        i. Emergent wetland
        ii. Forested/shrub wetland
        iii. Freshwater pond
        iv. Lake
        v. Riverine
        vi. Other
5. Used CA3TV2 tool to allocate/accumulate area of each wetland type for each catchment.
6. Used Access/Excel to calculate total wetland area percentage and total upstream wetland area percentage for each catchment.

**Land Use Change NLCD 2011**

1. Downloaded NLCD 2001 to 2011 Land Cover Change
2. Clipped raster to study area.
3. Reclassified raster to indicate areas of change/no change.
4. Used CA3TV2 tool to allocate/accumulate areas of change.
5. Reclassified raster created in step #2 to indicate types of change
    a. Change Types
        i. No Change
        ii. Neutral Change – from a “bad” to “bad”, or from “good” to “good”
        iii. Positive Change – from a “bad” classification to a “good” classification
        iv. Negative Change – from a “good” classification to a “bad” classification
    b. Always considered “good” – forest and woody wetlands
    c. Always considered “bad” – developed, barren, grassland, pasture, crops
    d. “Good/Bad” dependent on change type – open water, shrub/scrub, herbaceous wetland
    e. Full change matrix is below



| | | FROM CLASS 2001 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Unclassified | Open Water | Developed-Open Space | Developed-Low Intensity | Developed-Medium Intensity | Developed-High Intensity | Barren Land | Deciduous Forest | Evergreen Forest | Mixed Forest | Shrub/Scrub | Grassland/Herbaceous | Pasture/Hay | Cultivated Crops | Woody Wetlands | Herbaceous Wetlands |
| TO CLASS 2011 | Unclassified | 1 | 18 | 52 | 69 | 86 | 103 | 120 | 137 | 154 | 171 | 188 | 205 | 222 | 239 | 256 | 273 |
| | Open Water | 2 | 19 | 53 | 70 | 87 | 104 | 121 | 138 | 155 | 172 | 189 | 206 | 223 | 240 | 257 | 274 |
| | Developed-Open Space | 4 | 21 | 55 | 72 | 89 | 106 | 123 | 140 | 157 | 174 | 191 | 208 | 225 | 242 | 259 | 276 |
| | Developed-Low Intensity | 5 | 22 | 56 | 73 | 90 | 107 | 124 | 141 | 158 | 175 | 192 | 209 | 226 | 243 | 260 | 277 |
| | Developed-Medium Intensity | 6 | 23 | 57 | 74 | 91 | 108 | 125 | 142 | 159 | 176 | 193 | 210 | 227 | 244 | 261 | 278 |
| | Developed-High Intensity | 7 | 24 | 58 | 75 | 92 | 109 | 126 | 143 | 160 | 177 | 194 | 211 | 228 | 245 | 262 | 279 |
| | Barren Land | 8 | 25 | 59 | 76 | 93 | 110 | 127 | 144 | 161 | 178 | 195 | 212 | 229 | 246 | 263 | 280 |
| | Deciduous Forest | 9 | 26 | 60 | 77 | 94 | 111 | 128 | 145 | 162 | 179 | 196 | 213 | 230 | 247 | 264 | 281 |
| | Evergreen Forest | 10 | 27 | 61 | 78 | 95 | 112 | 129 | 146 | 163 | 180 | 197 | 214 | 231 | 248 | 265 | 282 |
| | Mixed Forest | 11 | 28 | 62 | 79 | 96 | 113 | 130 | 147 | 164 | 181 | 198 | 215 | 232 | 249 | 266 | 283 |
| | Shrub/Scrub | 12 | 29 | 63 | 80 | 97 | 114 | 131 | 148 | 165 | 182 | 199 | 216 | 233 | 250 | 267 | 284 |
| | Grassland/Herbaceous | 13 | 30 | 64 | 81 | 98 | 115 | 132 | 149 | 166 | 183 | 200 | 217 | 234 | 251 | 268 | 285 |
| | Pasture/Hay | 14 | 31 | 65 | 82 | 99 | 116 | 133 | 150 | 167 | 184 | 201 | 218 | 235 | 252 | 269 | 286 |
| | Cultivated Crops | 15 | 32 | 66 | 83 | 100 | 117 | 134 | 151 | 168 | 185 | 202 | 219 | 236 | 253 | 270 | 287 |
| | Woody Wetlands | 16 | 33 | 67 | 84 | 101 | 118 | 135 | 152 | 169 | 186 | 203 | 220 | 237 | 254 | 271 | 288 |
| | Herbaceous Wetlands | 17 | 34 | 68 | 85 | 102 | 119 | 136 | 153 | 170 | 187 | 204 | 221 | 238 | 255 | 272 | 289 |

| ***reclassification category*** | ***Value*** |
|---|---|
| No Change | 0 |
| Positive Change | 1 |
| Neutral Change | 2 |
| Negative Change | 3 |

### Barrier data

1. Received barrier/road crossing data from AFWS.
2. Created 30 meter buffer around 1:100k NHD+ flowlines.
3. Removed barriers/road crossings not within the 30 meter buffer.
4. Used CA3TV2 tool to allocate/accumulate number of barriers and road crossing within each catchment and within the entire upstream drainage area for each catchment.
5. Used Access/Excel to calculate densities of barriers and road crossings for the local and upstream drainage areas for each catchment.

### Soils data

1. Downloaded soils data from NRCS Geospatial Data Gateway in Geodatabase format for each state.
2. Joined Map Unit Polygon feature to muaggatt table using the mukey field in each table.
3. Exported feature with attached data table for each state.
4. Merged state files into a single shapefile.
5. Used polygon to raster tool to create rasters for the following attributes:
    a. Depth to bedrock (attribute name beddepth) – continuous variable
    b. Depth to water table (attribute name H2otabdepth) – continuous variable
    c. Hydrologic soil type (attribute name Hydrosoil) – categorical
6. Used CA3TV2 tool to allocate/accumulate the above variables and categories within each catchment and within the entire upstream drainage area for each catchment. For continuous variables, means were used within each area. For continuous variables, we calculated area of each categorical classification.
6. Used Access/Excel to calculate percentages from areas of categorical classifications

### Variable width riparian delineation

1. After reviewing a multitude of references oriented around methods and pros/coins of variable width riparian area delineation, we settled on a tool/method utilized by the Sustainable Futures Institute of Michigan Technological University. That tool and the supporting information were retrieved from here: http://www.sfi.mtu.edu/muses/GIS_Riparian.htm and via personal communication with the tool's author.

2. Source data for the tool included the National Elevation Dataset, National Wetlands Inventory, and 100K scale NHD stream lines and waterbody polygons.
3. Per methods described in Bedient (2002), utilized data for all stream gauges in study region to find 50 year flood depths. Of 13 gauges, 3 provided statistically significant results. We utilized an average of that value for 50 year flood height value of 1.8 meters as a primary input into the tool.
4. Per 8 digit watershed, we assembled data and ran tool per watershed with the following parameters: 200 meter sample distance, process artificial paths (owing to several observed errors of feature type categories where stream/rivers were classified as artificial paths) and stream/river line features, waterbody features from NHD with default buffer distance, and all NWI feature types.
5. Used CA3TV2 tool to allocate/accumulate area of each NLCD land cover class, imperviousness, and wetland types within the defined riparian zone for each catchment
6. Used Access/Excel to calculate total area percentages and total upstream area percentages for each catchment land cover class and each wetland type within the defined riparian zone.

References:

Mason, Lacey and Maclean Ann L. “GIS Modeling of Riparian Zones Utilizing Digital Elevation Models and Flood Height Data: An Intelligent Approach.” *Proceedings of ASPRS 2007 Annual Conference.* 2007.

Abood, Sinan A., Maclean, Ann L. and Mason, Lacey A. “Modeling Riparian Zones Utilizing DEMs and Flood Height Data.” *Photogrammetric Engineering & Remote Sensing.* Vol. 78, No. 3, March 2012, pp. 259-269.

Bedient, P.B., and W.C. Huber, 2002. *Hydrology and Floodplain Analysis*, Third edition, Prentice Hall, New Jersey, 763 p.

*USGS Surface Water Annual Statistics*. Version 0.34. http://waterdata.usgs.gov/nwis/annual/ Website. Accessed 5/2015.

**NHDPlus Compiled Datasets**

1. We pulled the following tables from the NHDPlus Attributes
   a. CumulativeArea
   b. Elevslope
2. We pulled the following tables from the NHDPlus VPUAttributesExtensions

   a. CumTotPrecipMA
   b. CumTotROMA
   c. CumTotTempMA
   d. IncrTempMA
   e. IncrPrecipMA
   f. ROMA

3. Used Access to join pertinent data from each catchment.

**Predicted Stream Temperature**

1. Used Access to join table provided by GLBFHP to each catchment.
2. Used fieldname ‘hJXnow’ as predicted current mean July stream temperature
3. Used fieldname ‘JXF1’ as predicted mean July stream temperature (2046-2065)

**Future Climate Data**

1. Downloaded BCDS-CMIP3-Climate-monthly data, 1/8 degree BCSD projections for Jan. 2046 – Dec. 2065.
2. Selected one run for each climate model
3. Selected precipitation rate and average surface air temperature
4. Selected period mean
5. Selected ASCII output format
6. Compiled each model run period data into a single Excel Workbook for each parameter (precip/temp).
7. Used formulas within Excel to find the average value for each cell within the lat/long matrix.
8. Used formula to convert from daily precipitation rate to mean annual precipitation total.
9. Manually reordered rows from bottom to top (necessary for proper spatial projection in step 12).
10. Exported table of values as .txt file
11. Added relevant header information to allow the ASCII to Raster Arc tool to run properly.
12. Created raster using the ASCII to Raster tool.
13. Set projection as geographic, NAD83.

14. Used CA3TV2 tool allocate each value to each catchment.

**Future Brook Trout Scenarios**

1. Use future stream temperature, precipitation, and air temperature predictions to replace current values in the predictor database.
2. Ascertain future land use data (if available) or manually manipulate development levels of current data based on published figures to provide an estimation of future land use.
3. Extrapolate current basin-wide model for provide predictions of current brook trout occupancy.
4. Calculate vulnerability/resiliency for each catchment or watershed based on difference between current and future occupancy and natural habitat quality.