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# Validation of and Enhancements to an Assessment Framework for Impounded Wetlands of Great Salt Lake

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# 1. Introduction

## 1.1 Background

Located downstream of urban areas, framed by berms, weirs, and culverts, and largely managed to optimize habitat for waterfowl, the water quality of impounded wetlands (IWs) of Great Salt Lake (GSL) has been a significant challenge to understand, assess, and manage. Not only are IWs complex and dynamic, but the unique nature of these wetlands make it extremely difficult to assess their condition using typical criteria.

The Utah Division of Water Quality (UDWQ) and its partners initiated research in 2004 to characterize these wetland resources and develop defensible assessment methods that would enable UDWQ to manage IW water quality and protect their beneficial uses. Miller and Hoven (2007) provided a review of research completed through 2007 and included recommendations for potential metrics to assess the condition of IWs. UDWQ updated this effort and incorporated new data into a draft assessment framework specifically developed for the GSL IWs (Utah Department of Environmental Quality [UDEQ], 2009). This draft assessment framework outlined an approach for assessing the condition of IWs with the intent that it would be validated and improved for use in UDWQ's watershed approach toward the GSL wetlands (see UDEQ, 2009 for a discussion of this watershed approach). The objective of this project is to validate and improve this draft assessment framework for GSL IWs.

## 1.2 Draft Assessment Framework for GSL IWs

The 2009 Draft Assessment Framework for GSL IWs is composed of multi-metric indices (MMIs) that relate the physical, chemical (water chemistry), and biological conditions of the IWs of GSL. These MMIs integrate measures of water chemistry (Chemistry MMI) and the condition of submerged aquatic vegetation (SAV MMI), surface algal mats (Surface Mat MMI), and benthic macroinvertebrates (Macroinvertebrate MMI) with the beneficial uses of the wetlands to present an overall score card of the physical, chemical, and biological condition of wetland sites. The SAV, Surface Mat, and Macroinvertebrate MMIs are used to represent biological responses related to variations in the Chemistry MMI, and as such, serve as an integrated measure of ecosystem health. While the 2009 Draft Assessment Framework (hereafter referred to as Draft MMI) was known to have limitations, it provided UDWQ with a foundation by which it could move its efforts forward to assess the condition of these wetlands (UDEQ, 2009).

## 1.3 Key Objective

UDWQ's objective is to develop an assessment framework for GSL IWs that can be used to report the biological condition of IWs and evaluate the effectiveness of management activities with respect to wetland water quality. Using the Draft MMI, UDWQ worked with the U.S. Environmental Protection Agency (EPA) to develop a Sampling and Analysis Plan (SAP) (UDEQ, 2012) with the goal of developing an independent dataset that could be used to validate and improve the Draft MMI. UDWQ implemented the SAP in 2012 and began evaluation of the dataset in January 2013.

The objective of this study is to validate and improve the Draft MMI—that is, the MMIs that make up the draft assessment framework—through the following tasks:

1. Compile and organize existing data (datasets from 2003 to 2009, 2010 to 2011, and 2012)
2. Validate the Draft MMI against independently collected data
3. Evaluate additional metrics (covariates)
4. Characterize the range of ecological condition of IW sites using the updated IW MMIs

This technical memorandum summarizes methods used (Section 2.0), results and discussion (Section 3.0), and conclusions and recommendations (Section 4.0). Section 2.0 describes how data were collected, organized, and summarized. The process for developing and validating the MMIs is described, including how iterative changes were made to the MMIs to account for potentially useful covariates and the development of new biological response metrics. Section 3.0 presents the results of these efforts and a discussion of their significance in characterizing the GSL impounded wetlands. Section 4.0 highlights the key conclusions of this MMI validation study and provides specific recommendations for building on the IW MMI.

# 2. Methods

The objective of this study is to validate the approach and the metrics used to develop the Draft MMI for GSL IWs. The Draft MMI for GSL IWs is based on data for multiple water chemistry (and sediment nutrients), SAV, surface mat (algae and duckweed), and macroinvertebrate metrics that were collected from 2003 to 2009 (UDEQ, 2009). In 2012, data on the same metrics that formed the Draft MMI were collected from 53 GSL IW sites for testing, validating, and refining the Draft MMI (see Figure 1) (UDEQ, 2012). Since the selected IW sites in 2012 are completely independent from those used to develop the Draft MMI, they can be used to conduct a thorough independent and unbiased evaluation of the Draft MMI.

## 2.1 Compiling and Organizing Existing Data

Multi-metric biological and chemical data required for the validation and improvement of the Draft MMI were sourced from multiple years and were generally divided into the following two categories: (1) Historic data on which the Draft MMI was based (2003 to 2009) and (2) data collected in 2012 for independent validation of the Draft MMI using the approach described in Section 2.2. Considering the extensive amounts of data involved and the complexity of the dataset at hand, an important initial step in the MMI validation and improvement process involved the compilation and organization of this data to support development of the MMI and subsequent statistical analyses.

### 2.1.1 Draft MMI Database (Historic Database 2003 to 2011)

The Draft MMI was developed using water chemistry, plant, and macroinvertebrate data collected from GSL IWs from 2003 to 2009. The various metrics and time periods over which data for compiling these metrics were collected are summarized in Table 1 (Table 4-1 in the UDEQ 2009 Report). Data collection sites are summarized in Table 2 (Table 4-4 in the UDEQ 2009 Report) (see Figure 1). Selected water chemistry metrics (listed in Table 3) were used to develop the water chemistry MMI for the Draft MMI. Data from plant (SAV and surface mat) and macroinvertebrate metrics were used to calculate respective MMIs, which were then combined into an overall 'Ecosystem Health' (EH) MMI (method details are provided in Section 2.1.2.2 of this report). The water chemistry MMI and EH MMI are both components of the Draft MMI (UDEQ, 2009).

TABLE 1
Data Sources and Metrics Analyzed for Developing the Draft MMI (2003 to 2009) for Impounded Wetlands of the Great Salt Lake

| Data Group | Metric Group | Metrics Summary | Data Collection Periods |
|---|---|---|---|
| Water Chemistry | Water Quality | pH, DO, TSS, chlorophyll-a, phosphorus (dissolved P, total P and sediment total P), nitrogen (ammonia N, nitrate/nitrite N, dissolved organic N, and sediment total N), salinity | 2003 to 2009 |
| Plants | SAV<br>Algae and Duckweed (Surface Mat Cover) | Maximum SAV, fall SAV, percent change SAV<br>Maximum algal mat cover, Maximum duckweed cover | 2008 |
| Macroinvertebrates | Benthic Macroinvertebrates | Ephemeroptera (mayflies) percent of total sample number, Simpson's Diversity Index, Hyalella (Amphipods) percent of total sample number, total taxa, number of coleoptera (beetle) taxa | Mostly based on data from 2007, but also evaluated some data from 2004 to 2006 |

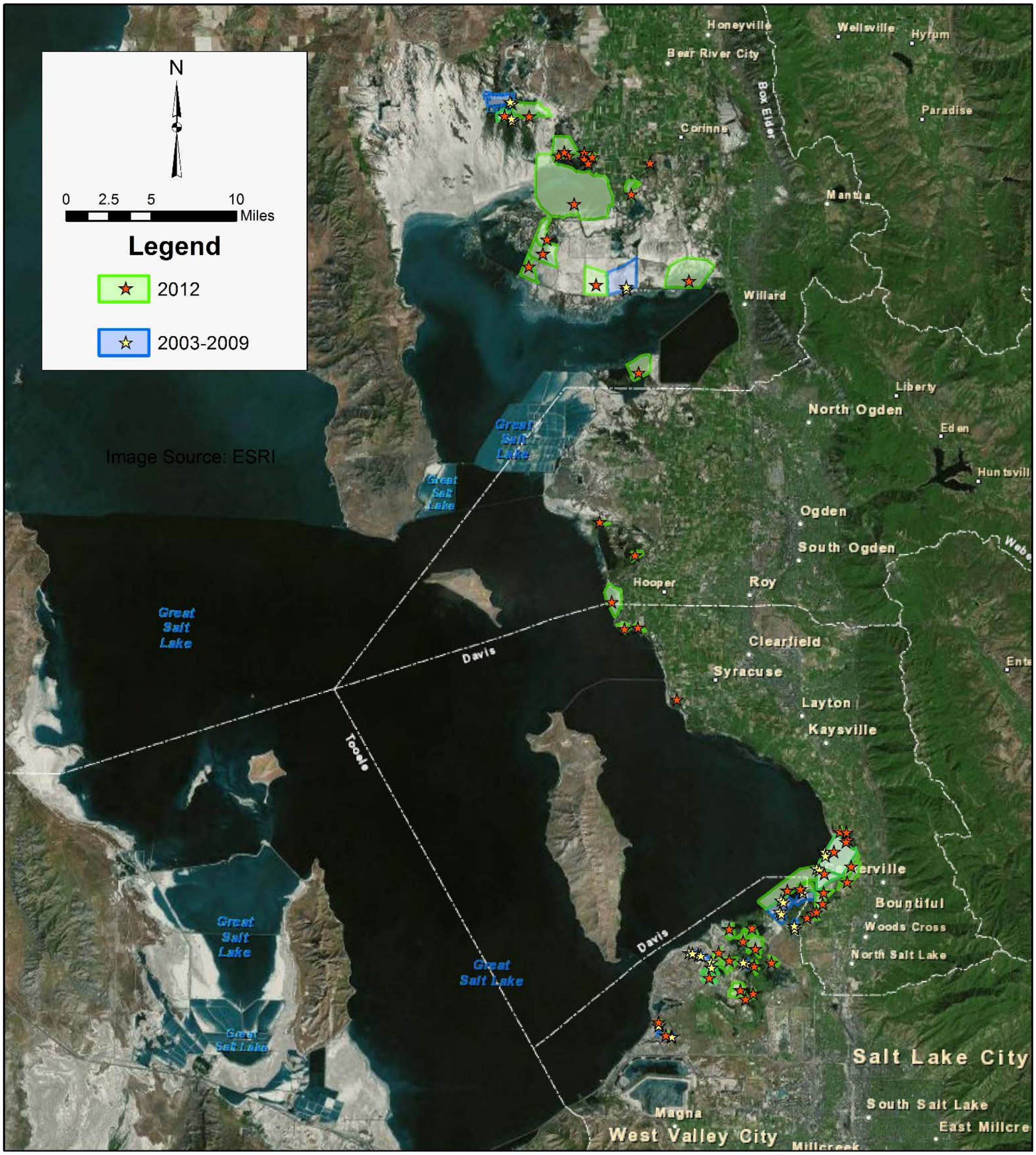
**Notes:**
DO = dissolved oxygen
N = nitrogen
P = phosphorus
SAV = submerged aquatic vegetation
TSS = total suspended solids

TABLE 2
Great Salt Lake Impoundment Wetland Sites Targeted for Sampling of Water Quality, Plant, and Macroinvertebrate Data for the Draft MMI

| Site | Water Quality | Plants | Macroinvertebrates |
|---|---|---|---|
| Farmington Wetlands Ambassador W 1 | Y | Y | Y |
| Farmington Wetlands Ambassador 100 | Y | Y | Y |
| Farmington Wetlands Ambassador W 2 | Y | Y | Y |
| Farmington Wetlands Ambassador W 5 | Y | Y | Y |
| Farmington Wetlands South B Pond | Y | Y | N |
| Farmington Wetlands West A Pond | Y | Y | N |
| Farmington Wetlands FBWMA Unit 1 Outfall | Y | Y | Y |
| Farmington Wetlands FBWMA Unit 2 Outfall | Y | Y | Y |
| IMPC Conservation Easement | Y | Y | N |
| GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall | Y | Y | Y |
| GSL Wetlands Public Shooting Ground Pintail Lake Outfall | Y | Y | Y |
| Bear River NWR Pond 4C Outfall | Y | Y | N |
| Newstate Duck Club Middle Unit | Y | Y | Y |
| GSL Wetlands Newstate Duck Club Pond 47 | Y | Y | Y |
| GSL Wetlands Newstate Duck Club Pond 20 | Y | Y | Y |
| GSL Wetlands Newstate Duck Club Unit 5-6 | Y | Y | Y |

**Notes:**
FBWMA = Farmington Bay Waterfowl Management Area
GSL = Great Salt Lake
N = Site not sampled
Y = Site sampled

FIGURE 1
Vicinity Map and Location of GSL Impounded Wetlands Sampling Sites Used from 2003-2009 and in the 2012 Sampling Season



Additional data on the same water chemistry, plant, and macroinvertebrate metrics were collected in 2010 and 2011, and this data was compiled and organized for data summarization. Although the 2010 to 2011 biological metrics data were not incorporated into the Draft MMI as part of this effort, the data were retained for further improvement of the MMI as our scientific understanding of GSL IWs increases with additional studies.

An important step in the selection of water quality metrics for the Draft MMI included the development of summary statistics that described ranges, measures of central tendency, and percentiles of data distribution. These summary statistics were then screened against known thresholds and criteria to select measures that were most likely to affect wetland biota (UDEQ, 2009). In this study, we repeated this process with the 2010 to 2011 water chemistry data added to the 2003 to 2009 water chemistry dataset to evaluate whether inclusion of the new water chemistry data would significantly affect the summary statistics, and thus selection of the metrics involved.

### 2.1.2 Independent 2012 Impounded Wetlands Database

Biological, chemical, and physical data were collected at 53 randomly selected IW sites during the summer and fall of 2012 according to UDEQ's SAP (UDEQ, 2012). Biotic, water chemistry, and sediment chemistry data collected from these 53 IW sites (used data from 50 sites in this analysis because of data gaps) were to be used to independently validate the MMI approach and to help verify whether the Draft MMI could reliably describe the range of IW conditions encountered along the margins of GSL. For purposes of comparison and validation, the same methods and metrics that described the indices in the draft IW MMI were also sampled to develop indices for water chemistry (including sediment nutrient availability), SAV, surface mat cover, and macroinvertebrates (UDEQ, 2012) for IW sites in 2012. Summary water quality statistics describing ranges, measures of central tendency, and percentiles of data distribution were developed for these IWs, and then screened against known thresholds and criteria (shown in Table 12).

Additional data that described metrics for zooplankton communities and surface sediment diatoms were also collected for the 53 IW sites in 2012, but were not used during this MMI validation process, as zooplankton and diatoms were not part of the Draft MMI. However, these may prove useful in development of supplemental indicators of impounded wetland function in the future.

Details of the field sampling procedures, laboratory procedures for sample analysis, data quality objectives, quality control requirements for field and laboratory procedures, and requirements for data analysis and record keeping are provided in the Sampling and Analysis Plan (UDEQ, 2012).

#### 2.1.2.1 Developing the Water Chemistry MMI for 2012 IW Sites

The Draft MMI validation process (described in Section 2.2) necessitates the estimation of independent MMIs for water chemistry and biotic variables for IW sites in 2012. The Water Chemistry (WC) MMI for IW sites in 2012 was developed from the same metrics that described water chemistry variables in the Draft MMI (UDEQ, 2012). Metrics for total suspended solids (TSS), chlorophyll-a (Chl-a), dissolved oxygen (DO), phosphorus (P), and nitrogen (N) that were used to develop both the draft and the 2012 water chemistry MMIs are listed in Table 3.

TABLE 3
Water Chemistry Variables and Metrics Included in the Draft and 2012 WC MMIs

| Water Chemistry Variable | Water Chemistry Metrics[1] |
|---|---|
| TSS | Minimum TSS |
| | Maximum TSS |
| Chl-a | Minimum Chl-a<br>Maximum Chl-a |
| DO | Minimum DO |
| P[2] | Dissolved P–Maximum<br>Total P–Maximum<br>Dissolved P–Geometric Mean<br>Total P–Geometric Mean<br>Sediment Total P |
| N[2] | Ammonia N–Maximum<br>Ammonia N–Geometric Mean<br>Nitrate/Nitrite N–Maximum<br>Nitrate/Nitrite N–Geometric Mean<br>Dissolved Organic N–Maximum<br>Dissolved Organic N–Geometric Mean<br>Sediment Total N |

**Notes:**
[1]Minimum, maximum, and geometric means for 2012 were based on the summer and fall samples in 2012 (two samples). See UDEQ, 2012 for definition of sampling index periods.
[2]The Draft MMI Report (UDEQ, 2009) erroneously noted the use of minimum P and N metrics in the water chemistry MMI.
Chl-a = chlorophyll-a
DO = dissolved oxygen
N = nitrogen
P = phosphorus
TSS = total suspended solids
Reexamination of the database revealed that minimum P and N metrics were not included in the Draft MMI, and these metrics were therefore not included in the 2012 MMI.

The WC MMI for 2012 IW sites was developed using the same methods used to construct the Draft MMI (UDEQ, 2009). Similar to the Draft MMI, the goal for 2012 data was to combine all summary statistics (for example, maximum, minimum, and geometric means) and parameter constituents to accommodate different units and the relative scale of changes among chemical measures. MMI values were calculated using the following steps:

A. Rescale all of the constituent measures within each chemical variable group (see Table 3) to generate a dimensionless metric:

1. Calculate the relative concentration across sites by dividing the metric value measured at the site (for example, minimum TSS and minimum DO) by the geometric mean of the metric across all sites
2. Create a metric for each constituent measure by rescaling the data so that it ranges between values from 100 (relatively good water quality) to 0 (relatively poor water quality)

   For "decreaser variables"—variables whose values are expected to decrease with stress (for example, DO)—divide the relative concentration obtained at the site by the maximum relative concentration across all sites, then multiply by 100.

   For "increaser variables"—variables whose values are expected to increase with stress (for example, TSS, CHl-a, P, and N)—follow the same process, except subtract the final value from 100 so that lower scores indicate poorer water quality.

B. Combine the constituent metrics used to summarize each parameter into a single MMI for the parameter (for example, DO MMI and Chl-a MMI):

1. Calculate the average of all constituent metrics as the $Site_{avg}$ (for example, $Avg_{chl\text{-}a}$ = (Chl-a Min Metric + Chl-a Max Metric)/2)
2. Rescale the average values so that the site with the best water quality receives a score of 100 as follows:

$$MMI_{parameter} = (Site_{avg}/\text{maximum of } Site_{avg} \text{ across sites}) \times 100$$

C. Calculate a final chemical MMI by combining the scores obtained from all parameter:

1. Calculate the average of MMIs obtained for all parameters for each site:

$$\text{Avg } MMI_{site} = (MMI_{chl\text{-}a} + MMI_{DO} + MMI_{TSS} + MMI_{N} + MMI_{P})/5$$

2. Rescale so that the site with the best relative chemistry receives a score of 100:

$$\text{WC MMI} = (\text{Avg } MMI_{site}/\text{maximum of Avg } MMI_{site} \text{ across sites}) \times 100$$

#### 2.1.2.2 Developing Biotic MMIs and the EH MMI for 2012 IW Sites

Similar to the process used in the Draft MMI (UDEQ, 2009), three biotic MMIs (SAV, Surface Mat, and Macroinvertebrate) were computed to include in the EH MMI for IW sites in 2012. The metrics contributing to each of these biotic MMIs were the same metrics as those incorporated into the Draft MMI (UDEQ, 2009). The basis for selecting the biotic MMI metrics is provided in the Draft MMI (UDEQ, 2009).

***SAV Metrics and MMI***

The following three metrics were generated to describe SAV condition from data collected from IW sites in 2012:

- Maximum SAV: the maximum of transect averages of SAV percent cover from the late-June to early-August sampling event
- Fall SAV: average percent cover from late-August to September sampling event
- Percent change in SAV: the percent change in SAV between the maximum and fall samples

The process for developing the MMI includes converting the metrics data into a common scoring base. Scoring of metrics is necessary when metrics are quantified with different units, have different absolute numerical values (numbers of taxa, percentages, densities, etc.) and show different responses to disturbance (some metrics increase, while other decrease in response to disturbance). In other cases, variables may not respond proportionally across the data range (for example, increasing cover of algal mats is not considered to be a continuously [negative] response—instead, low levels of algal mat cover are reasonable and expected, but concerns arise after some threshold cover level above which the site is usually considered degraded). To resolve such differences, scores are assigned to each metric, ideally based on expectations for the metrics at minimally disturbed or reference sites (Karr and Chu, 1999). For example, metrics at minimally disturbed or reference sites are assigned a score of 5, those that deviate somewhat from such sites are assigned a score of 3, and those that deviate strongly are scored 1 (Karr and Chu, 1999). Metrics scored in this manner can then be readily combined into a multi-metric index. Percentile rankings can help establish breakpoints in the metrics data to facilitate the scoring.

Scores were assigned to the SAV metrics based on the upper and lower quartiles of the SAV metrics data (see Table 4). In the scoring system, 1 = $25^{th}$ percentile or lower, 3 = $25^{th}$ to $75^{th}$ percentile, and 5 = higher than $75^{th}$ percentile.

TABLE 4
Scoring System for SAV Metrics—IW Sites in 2012

| Metric | Scoring[1] | | |
|---|---|---|---|
| | 1 | 3 | 5 |
| Maximum SAV | 0 to 29 percent | 30 to 91 percent | > 91 percent |
| Fall SAV | 0 to 52 percent | 53 to 88.5 percent | > 88.5 percent |
| Percent Change SAV | > 86.9 percent | 19.7 to 86.9 percent | < 19.7 percent |

**Notes:**
[1]Scores are based on the upper and lower quartiles as break points.
SAV = submerged aquatic vegetation

For each IW site, the score value for each SAV metric was scaled to the highest possible score (5) and estimated as follows:

$$\text{SAV Metric}_{\text{site}} = (\text{metric score for the site}/5) \times 100$$

The average SAV MMI for each site was estimated as the average of three SAV metrics, and then scaled to the maximum average SAV MMI across all sites to estimate the SAV MMI for each site.

### *Surface Mat MMI*

The Surface Mat MMI consisted of a single metric, maximum percent mat cover, based on the late-June to early-August and late-August to September sampling events.

Scores were assigned to the surface mat metric based on the quartiles of the metric data (see Table 5).

TABLE 5
Scoring System for Surface Mat Metric—IW Sites in 2012

| Metric | Scoring[1] | | |
|---|---|---|---|
| | 1 | 3 | 5 |
| Maximum Percent Mat Cover | >50 percent | 14 to 50 percent | 0 to 13 percent |

**Note:**
[1]Scores are based on the upper and lower quartiles as break points.

For each IW site, the metric score value was scaled to the highest possible score (5) to estimate the Surface Mat MMI:

$$\text{Surface Mat MMI}_{\text{site}} = (\text{metric score for the site}/5) \times 100$$

### *Macroinvertebrate Metrics and MMI*

Five macroinvertebrate metrics were evaluated for IW sites in 2012, based on the same macroinvertebrate metrics that were used in the Draft MMI:

- Percent *Ephemeroptera* (mayflies): percent of total count
- Percent *Hyallela*: percent of total count
- Total number of macroinvertebrate taxa
- Simpson's Diversity Index
- Number of *Coleoptera* (beetle) taxa

All macroinvertebrate metrics used the maximum values observed between the summer (late-June to early-August) and early autumn (late-August to September) sampling events in 2012.

Scores were assigned to the macroinvertebrate metrics based on the percentiles of the metrics data (see Table 6).

TABLE 6
Scoring System for Macroinvertebrate Metrics—IW Sites in 2012

| Metric | Scoring[1] | | |
|---|---|---|---|
| | **1** | **3** | **5** |
| Percent Ephemeroptera | 0.8 percent or less | >0.8 to 24.8 percent | >24.8 percent |
| Percent Hyallela | 0 percent | >0 to 9.2 percent | >9.2 percent |
| Total Taxa | 7 or less | 8 to 13 | 14 or more |
| Simpson's Diversity Index | 0.63 or less | 0.64 to 0.81 | >0.81 |
| Number Coleoptera Taxa | 0 | 1 | 2 or more |

**Note:**
[1]Scores are based on the upper and lower quartiles as break points.

For each site, the scores for all five metrics were summed to provide the MMI score for that site. Values of macroinvertebrate scores ranged from a minimum of 5 (each of the five metrics received a score of 1) to a maximum of 25 (each of the five metrics received a score of 5) for each site. The macroinvertebrate MMI for each site was then estimated as follows:

$$\text{Macroinvertebrate MMI} = (\text{Summed Score}/25) \times 100$$

***Ecosystem Health MMI***

The EH MMI was estimated as the average of the plant and macroinvertebrate MMIs:

$$\text{EH MMI} = (\text{SAV}_{\text{MMI}} + \text{Surface Mat}_{\text{MMI}} + \text{Macroinvertebrate}_{\text{MMI}})/3$$

## 2.2 Draft MMI Validation and Improvement: An Iterative Approach

An iterative approach was adopted for validating and improving the Draft MMI (see Figure 2). This approach includes the testing, initial validation, calibration, and revalidation of the Draft MMI using data collected at the 53 independent IW sites in 2012, and involves the following steps (see Figure 2):

1. **Compute the MMIs for 2012 IW Sites—Observed EH:** Data on water chemistry (includes sediment nutrient availability), SAV, surface mat, and macroinvertebrate metrics collected from the 53 IW sites in 2012 were organized and compiled to compute MMIs for these individual lines of evidence (see Section 2.1.2 for method details). These MMIs were computed using the same metrics and processes that were used to develop the Draft MMI from the 2003 to 2009 dataset (UDEQ, 2009). The 2012 MMIs for the biota (SAV, Surface Mat, and Macroinvertebrates) were then combined to compute the 2012 EH MMIs. The 2012 EH MMIs were subsequently used in the MMI validation process as independently observed EH values representing the 53 IW sites in 2012 (see Figure 2).
2. **Use the Draft MMI to Predict EH for 2012 IW Sites:** The Draft MMI based on 2003 to 2009 GSL IW data consists of metrics that describe the relationship of ecosystem health (SAV, Surface Mat, and Macroinvertebrates) to water chemistry (UDEQ, 2009). Since the same metrics are used to develop WC and Biotic MMIs for both the 2003 through 2009 and the 2012 datasets, the relationship observed between the Chemistry MMI and EH MMI for the draft dataset is used to estimate Predicted EH-MMI values based on the 2012 Chemistry MMI. As such, the 2012 WC MMI values are plugged into the Draft MMI to predict EH MMI for each of the 53 IW sites for 2012 (see Figure 2). This step is depicted conceptually in Figure 3.

3. **Conduct Initial Validation of the Draft MMI:** Predicted EH values for 2012 IW sites are then statistically compared to observed EH values at those sites to evaluate the accuracy of the Draft MMI model (see Figure 2). These statistical tests (described in Section 2.2.1) provide insights into the relative sources and distributions of systematic and random errors in the regression model of observed versus predicted EH values, and thus allow a rigorous and quantitative validation of the Draft MMI (Rice and Cochran, 1984).

4. **Explore Sources of Errors, Calibrate, and Revalidate the Draft MMI:** The results of the validation conducted in Step 3 will have two possible outcomes (see Figure 2):

    a. Successful validation, indicating that the Draft MMI predicts EH values with reasonable accuracy and relatively minor contributions by systematic errors. In this case, no further steps are required and the Draft MMI is deemed acceptable for evaluating EH.

    b. Unsuccessful validation, with relatively large contributions by systematic errors. The accuracy of the MMI may be improved by exploring the use of additional metrics or covariate effects. These additional metrics or covariates are selected for evaluation based on ecological knowledge gained from multi-year studies on the GSL IWs (CH2M HILL, 2005 and 2006; Gray, 2005 and 2009; Miller and Hoven, 2007; UDEQ, 2009). The adjusted (calibrated) MMIs are then revalidated using Steps 2 and 3, until successful validation of the Draft MMI (see Step 4a) is attained.

FIGURE 2
Iterative Approach for Validation and Improvement of the Draft MMI using 2012 IW Data
*(Note: BMI = benthic macroinvertebrates)*

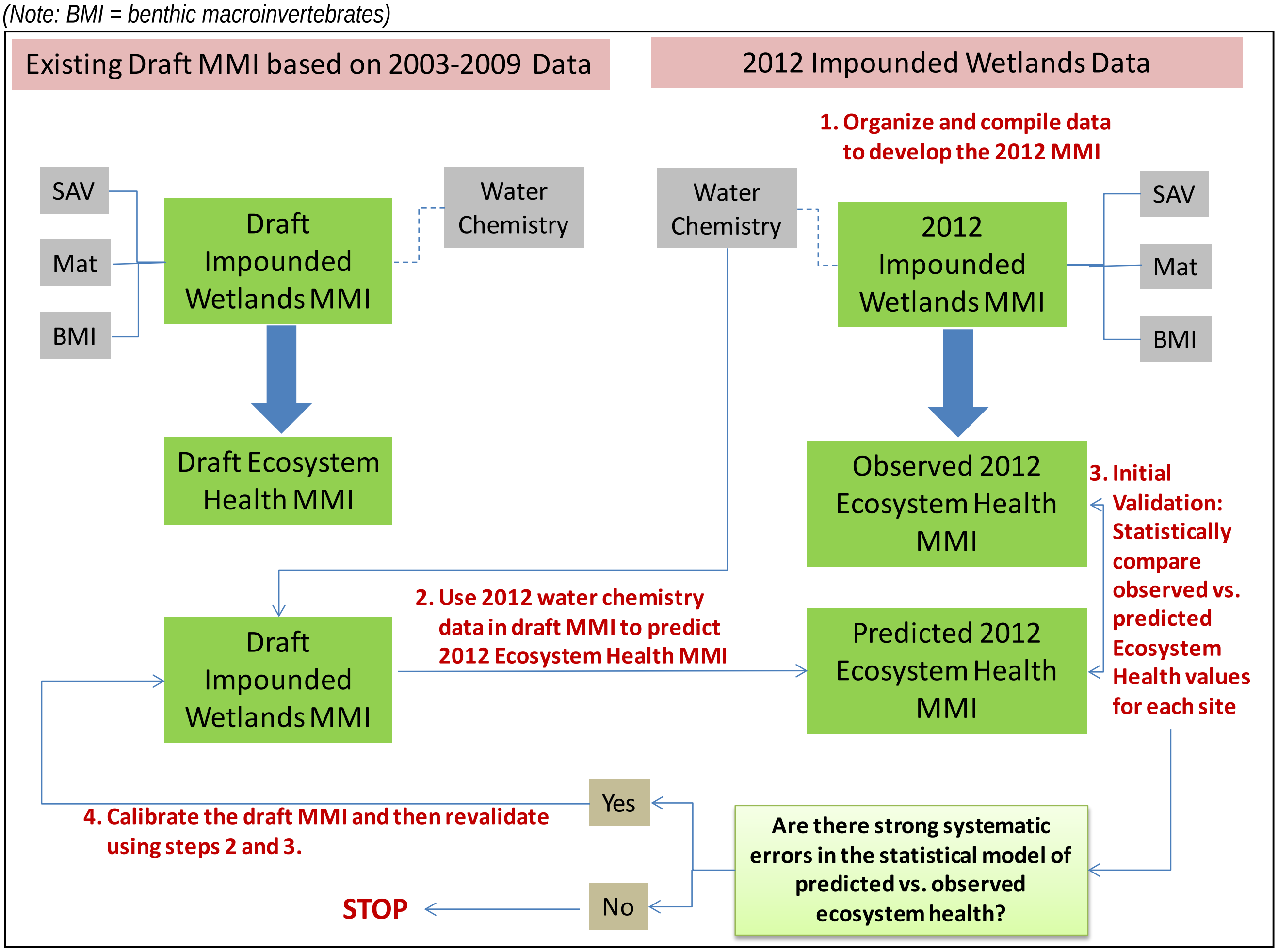
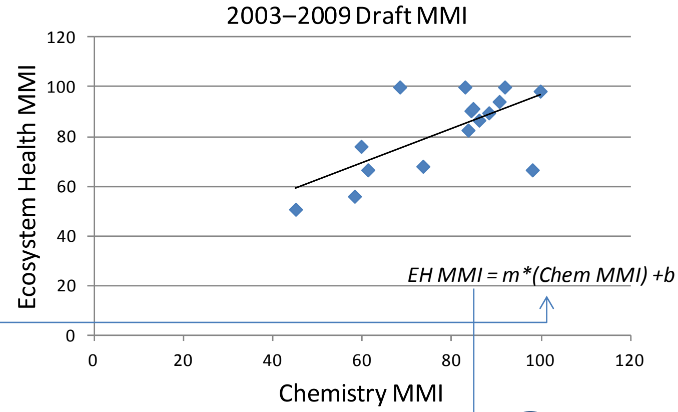


FIGURE 3
Conceptual Schematic Depicting the Process of Using the Draft MMI to Predict EH MMIs for IW Sites in 2012
*(Note: Only a few of the 53 IW sites are shown here, and all values are considered hypothetical, and shown here only for process depiction purposes.)*

**1. Input 2012 observed chemistry MMI data for each site into Draft MMI of Ecosystem Health vs. Chemistry MMI relationship**

2012 Data

| StationID | SiteName | CHEM MMI |
|---|---|---|
| 5971040 | ISSR SW POND | 84 |
| 5971050 | HDC1 | 85 |
| 5971060 | UNIT 7 | 85 |
| 5971070 | LFDC1 | 84 |
| 5971080 | HDC2 | 60 |
| 5971090 | TURPIN UNIT FBWMA | 88 |
| 5971100 | LFDC2 | 93 |
| 5971110 | LFDC3 | 83 |
| 5971120 | NSDC1 | 82 |
| . | . | . |
| . | . | . |
| . | . | . |
| . | . | . |




**2. Predict 2012 Ecosystem Health for each site and compare to observed EH values**

| StationID | SiteName | 2012 CHEM MMI | Observed 2012 Ecosystem Health MMI | Predicted 2012 Ecosystem Health MMI (from Draft MMI) |
|---|---|---|---|---|
| 5971040 | ISSR SW POND | 84 | 23 | 86 |
| 5971050 | HDC1 | 85 | 72 | 87 |
| 5971060 | UNIT 7 | 85 | 68 | 87 |
| 5971070 | LFDC1 | 84 | 95 | 86 |
| 5971080 | HDC2 | 60 | 60 | 70 |
| 5971090 | TURPIN UNIT FBWMA | 88 | 80 | 89 |
| 5971100 | LFDC2 | 93 | 81 | 92 |
| 5971110 | LFDC3 | 83 | 81 | 86 |
| 5971120 | NSDC1 | 82 | 73 | 85 |

## 2.2.1 Draft MMI Validation Statistics

A statistically rigorous validation process was selected based on three independent statistical tests to evaluate how accurately the Draft MMI predicts EH MMIs for each of the 2012 IW sites. This process is partly based on a regression of observed EH values on predicted EH values for 2012 IWs, and involves the following three statistical tests conducted on various parameters associated with the regression:

1. **Partitioning of the Mean Squared Error (MSE):** This test is based on the decomposition of the MSE derived from observed and predicted EH values into the mean, slope, and random error components to assess the relative sources and proportion of errors attributed to those sources. As such, the MSE serves as a diagnostic test of the degree and sources of errors in the Draft MMI model predictions (Rice and Cochran, 1984):

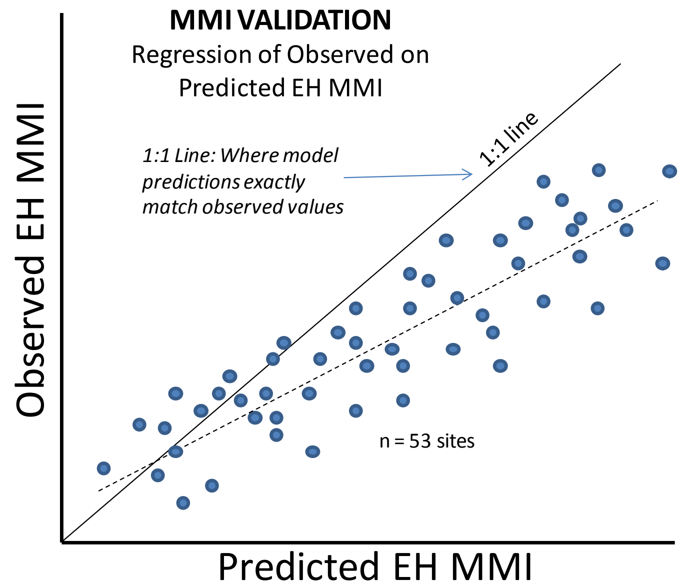
$$MSE = \frac{1}{n}\sum_{i=1}^{n}(P_i - A_i)^2$$

$$= (\bar{P} - \bar{A})^2 + (S_P - rS_A)^2 + (1 + r^2){S_A}^2,$$

Where: $P_i$ and $A_i$ represent the series of predicted and observed (actual) EH MMI values for 2012, respectively, and $\bar{P}, \bar{A}, S_P$, and $S_A$ are the means and standard deviations of the series $P_i$ and $A_i$, and $r$ is their correlation coefficient.

A least squares regression of observed $(A_i)$ on predicted $(P_i)$ EH MMI values allows easy interpretation of the decomposition of MSE test (see Figure 4).

FIGURE 4
Conceptualized Least Squares Regression of Observed EH MMI on Predicted EH MMI




In the regression depicted in Figure 4, all points would fall on the 1:1 line in the ideal case, and the regression would have a slope of one and an intercept of 0. The MSE represents the variance of these points around the 1:1 line. Dividing the decomposition shown in the equation above by the MSE yields the proportions of MSE attributed to the three sources of error:

$$1 = \frac{(\bar{P} - \bar{A})^2}{MSE} + \frac{(S_P - rS_A)^2}{MSE} + \frac{(1 + r^2){S_A}^2}{MSE}$$

= MC + SC + RC

Where, MC is the mean component, or the bias due to differences in the means of predicted and observed values; SC is the slope component, or the error resulting from the slope deviating from unity; and RC is the random component, or the proportion of MSE due to random error (Rice and Cochran, 1984). When perfect predictions (all points fall on the 1:1 line and MSE = 0) cannot be obtained, the desirable distribution of MSE over the three sources of is MC ~ 0, SC ~ 0, and RC ~ 1, indicating that errors are not systematic. For example, a result of MC = 0.75, SC = 0.10, and RC = 0.15 indicates large contributions of systematic errors in the MSE due to the MC. In another case, MC = 0.1, SC = 0.1, and RC = 0.80 indicate a desirable distribution of MSE, since 80 percent of the errors in the MSE are due to the random variations, whereas contributions by systematic errors are relatively minor (20 percent for MC and SC combined). For this study, RC $\geq$ 0.80 was selected as acceptable for successful validation.

2. **Bonferroni Joint Confidence Intervals (BJCI) Test:** While the MSE test determines the sources of deviations between predicted and observed values, the BJCI test assesses the *significance* of systematic errors represented by the MC and SC by testing the joint null hypothesis that the regression of observed$(A_i)$ on

predicted $(P_i)$ EH MMI values has a slope of 1 and an intercept of zero (Rice and Cochran, 1984; Neter et al., 1989). The BJCI test estimates the joint confidence intervals for the intercept and slope as follows:

$$b_0 \pm \ t\left(1-\frac{\alpha}{2};n-2\right)s\{b_0\}$$

$$b_1 \pm \ t\left(1-\frac{\alpha}{2};n-2\right)s\{b_1\}$$

where $b_0$ is the intercept, $b_1$ is the slope, and $s\{b_0\}$ and $s\{b_1\}$ are standard errors of the intercept and slope, respectively, $t$ is the Student's t-value for a statistical significance level of $\alpha$ and number of observed to predicted pairs of values (*n*). If the null hypothesis cannot be rejected, then the regression of observed on predicted EH MMI values is judged to be not significantly different from the 1:1 line.

For example, assume that a particular regression of observed versus predicted EH MMI values across $n$ = 53 sites is defined by the following parameters:

$b_0$= 0.6, $s\{b_0\}$ = 0.08, $b_1$ = 0.7, $s\{b_1\}$ = 0.15.

At the 95 percent confidence level ($\alpha$ = 0.05), it follows that:

$t\left(1-\frac{0.05}{2};53-2\right)$, that is, $t(0.975;51)$ = 2.01 (from t-value table in Neter et al., 1989)

The BJCI of the intercept is 0.6 ± (2.01 × 0.08) = 0.6 ±0.161. This BJCI indicates that the values of this intercept range from (0.6 – 0.161) = 0.439 to (0.6 + 0.161) = 0.761. Since this intercept interval (0.439 to 0.761) does not include a value of 0, the null hypothesis can be rejected as the intercept component of the regression of observed versus predicted values is significantly different from the intercept of the 1:1 line (which has an intercept of 0).

Similarly, the BJCI of the slope is 0.7 ± (2.01 × 0.08) = 0.7 ± 0.161. This BJCI indicates that the values of this slope range from (0.7 – 0.161) = 0.539 to (0.7 + 0.161) = 0.861. Since this slope interval (0.539 to 0.861) does not include a value of 1, the null hypothesis can again be rejected as the SC of the regression of observed versus predicted values is significantly different from the slope of the 1:1 line (which has a slope of 1).

It follows from the above example that since the regression of observed versus predicted EH MMI values did not contain an intercept of 0 and a slope of 1 based on the BJCI results, the regression significantly differs from the 1:1 line and thus fails this validation test.

3. **The Reliability Index (RI):** The RI was developed by Leggett and Williams (1981) and integrates the statistical properties of the distributions of observed and predicted values to quantify the average factor by which predictions differ from observations. As such, the RI $(k)$ is a number ≥1, and its interpretation is that model predictions agree with observed values within a factor of $k$.

$$k=\frac{1+\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{1-\left(\frac{y_i}{\hat{y}_i}\right)}{1+\left(\frac{y_i}{\hat{y}_i}\right)}\right]^2}}{1-\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{1-\left(\frac{y_i}{\hat{y}_i}\right)}{1+\left(\frac{y_i}{\hat{y}_i}\right)}\right]^2}}$$

Where, $y_i$= observed values, $\hat{y}_i$ = predicted values, and n = the number of observed versus predicted pairs of values.

Statistically, “accurate within a factor of$k$” means that approximately 68 percent of all possible observations are expected to be between $1/k$ and $k$ times the predicted value (Rice and Cochran, 1984). An RI of $k$ = 1 indicates a perfect fit between all observed and predicted values. An RI of 2 or less generally indicates a reasonable fit between observed and predicted values, and is selected as being acceptable for successful validation in this study. For example, a result of RI = 2 indicates that approximately 68 percent of all possible observations will be between 0.5 and 2 times the predicted values. As RI approaches 1, the accuracy of the predictions gets higher. An RI of 5 indicates that predicted values differ from observed values by half an order of magnitude (Leggett and Williams, 1981).

### 2.2.2 Iterative Validation and Calibration Process

The statistical validation tests discussed in Section 2.2.1 are used iteratively in the Draft MMI validation and calibration process to systematically improve the Draft MMI (see Figure 1). This iterative process is further detailed in Figure 4, where four different outcomes (of several possible outcomes) of the statistical validation tests are conceptually shown in Figure 5, Step 1:

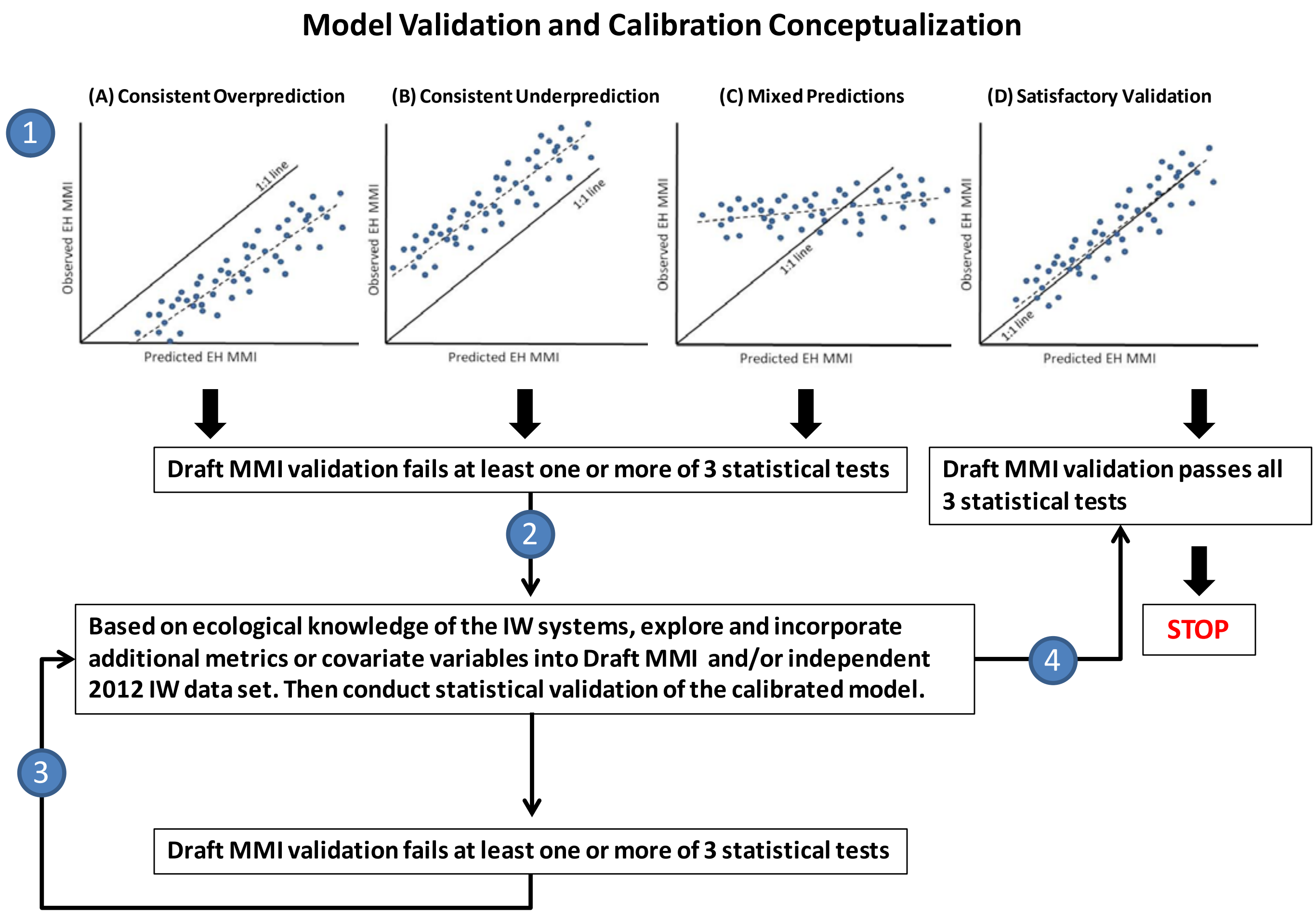
A. **Consistent Over-prediction:** The Draft MMI consistently over-predicts EH MMI values for each site, possibly indicating additional metrics or covariates that need to be incorporated into the Draft MMI, and/or 2012 IW datasets. In this case, the validation will fail at least one statistical test (likely the MSE decomposition test), if not more.

B. **Consistent Under-prediction:** The Draft MMI consistently under-predicts EH MMI values for each site, possibly indicating additional metrics or covariates that need to be incorporated into the Draft MMI and/or 2012 IW datasets. In this case, the validation will fail at least one statistical test (likely the MSE decomposition test), if not more.

C. **Mixed Predictions:** The Draft MMI is inconsistent and inaccurate at prediction EH MMI values, leading to gross under- and over-predictions. A large range of EH MMI values are predicted, when in fact the actual (observed) range of EH MMI values is much smaller. In this case, the validation will fail the MSE decomposition test, the BJCI test, and the RI test.

D. **Satisfactory Validation:** Predictions of EH MMIs match the observed EH MMI values reasonably well and the validation passed all three statistical tests. A large proportion of the variation in the scatterplot of observed EH MMI over predicted EH MMI is due to random errors and not systematic errors. In this case, the Draft MMI is considered to be successfully validated and no further calibration may be required.

FIGURE 5
Conceptualization of the Draft MMI Validation and Calibration Process, Using Four Statistical Validation Outcomes




In the case of Draft MMI validation outcomes A through C, Step 2 would involve further exploration of metrics, including covariate variables that could have a strong effect on metric responses. This data exploration step is specifically guided by the Draft MMI validation outcomes and, in combination with the knowledge on the ecology of GSL IWs, leads to a more focused exploration of metrics/covariate variables that could potentially be incorporated into the Draft MMI and/or 2012 validation data set.

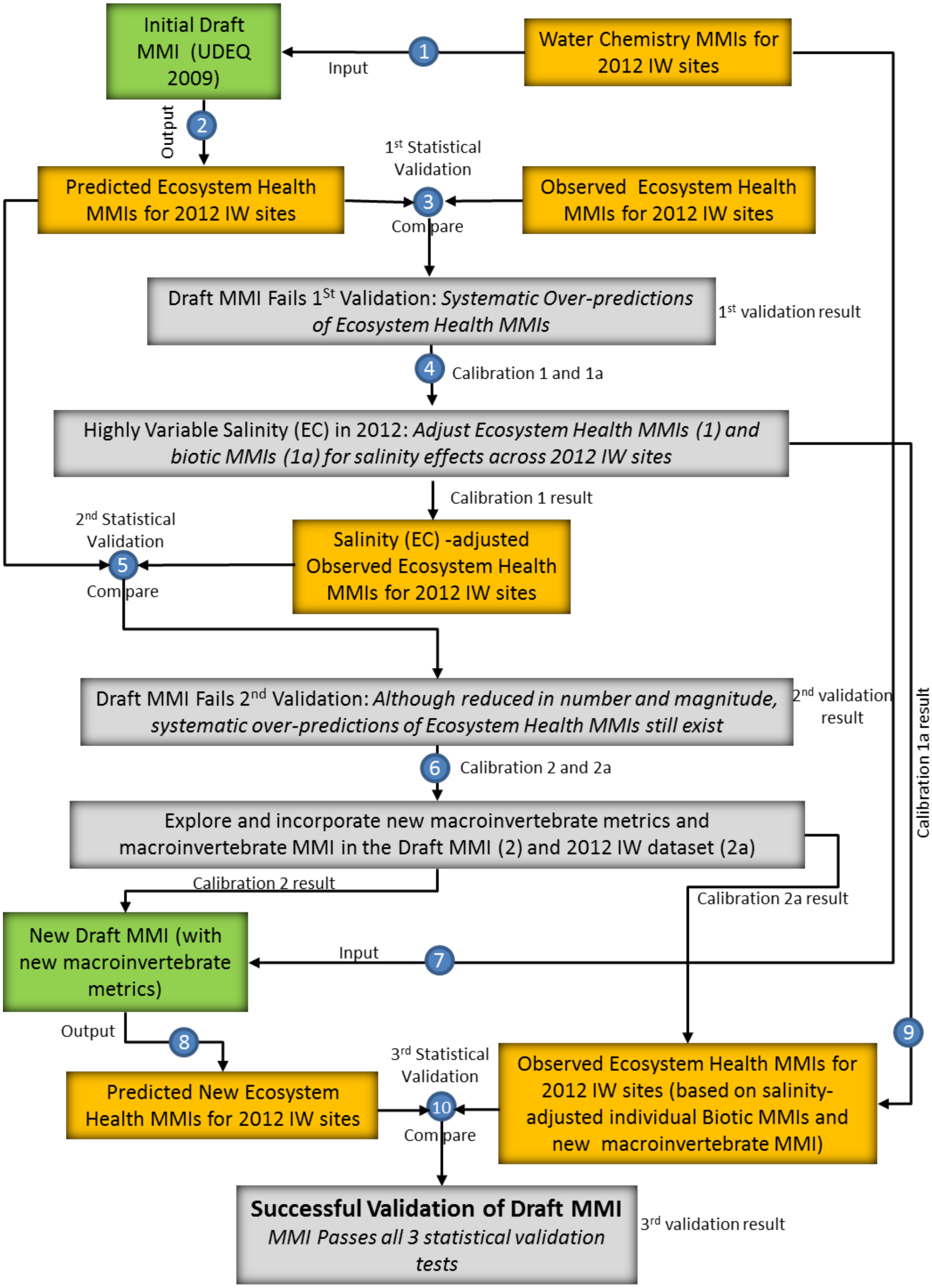
Step 3 would involve conducting the statistical validation using the modified Draft MMI and/or 2012 validation data set and Steps 2 and 3 would be repeated until the Draft MMI passes all three statistical validation tests (see Step 4).

### 2.2.3 Evaluating Additional Metrics and Covariate Variables within the Iterative Validation Framework

The evaluation of additional metrics and covariate variables affecting metric responses is an important component of the iterative Draft MMI validation and calibration process (see Steps 2 and 3 in Figure 5). These calibration steps are initiated when the Draft MMI fails one or more of the three statistical validation tests described in Section 2.2, and seek to improve the Draft MMI by focused exploration and inclusion of additional metrics and covariates variables, followed by revalidation of the improved Draft MMI to assess improvement.

Figure 6 outlines the iterative validation and Draft MMI calibration steps used in this study and highlights how the Draft MMI was statistically tested and improved by the exploration and addition of new macroinvertebrate metrics and a covariate variable salinity (method details are provided in Sections 2.2.3.1 and 2.2.3.2, respectively).

FIGURE 6
Iterative Validation and Calibration Process used in This Study to Improve the Draft MMI




In the overall validation process (see Figure 5), Step 1 consisted of using water chemistry MMIs for 2012 IW sites as input in the Draft MMI model to predict EH MMIs for each respective IW site (see Step 2). EH MMI predictions were statistically compared to EH MMI observed at those sites (see Step 3), resulting in a failed validation due to significant over-predictions of EH MMIs by the Draft MMI model.

One reason for this over-prediction of EH could be that the range of the small number of sites targeted for the Draft MMI dataset (n = 16) was too narrow relative to the range of conditions observed in 2012. Among these conditions, variable salinity (electrical conductance [EC]) across the IW sites in 2012 was identified as a potential covariate responsible at least in part for these over-predictions (see Step 4), and a decision was made to adjust EH MMI observations to account for these salinity effects (see Section 2.2.3.1 for details on how salinity effects adjustments were made). Salinity-adjusted EH MMI observations were then statistically compared to EH MMIs predicted with the Draft MMI (see Step 5, second validation), which still resulted in a failed validation due to over-predictions of the EH MMIs (see Step 6), even though the number and magnitude of over-predictions now was significantly reduced from the first validation.

This prompted the evaluation, and eventually the decision to incorporate new macroinvertebrate metrics into the Draft MMI and the 2012 IW dataset (see Section 2.2.3.2 for details on the methods). Step 7 involved using the WC MMIs for 2012 IW sites as input in the new Draft MMI model to predict new EH MMIs for each respective IW site (see Step 8). Salinity-adjustments were also made to the biotic MMIs (SAV and new macroinvertebrate MMI), which were then averaged along with the surface mat MMI (not adjusted for salinity, as it showed no response to salinity) to produce new EH MMI observations for IW sites (see Step 9). These new EH MMI observations were statistically compared to EH MMIs predicted by the new Draft MMI model (see Step 10), resulting in a successful validation. This validation process highlights how key covariates (EC) and new metrics (macroinvertebrates) were identified systematically and included iteratively into the validation of the Draft MMI.

#### 2.2.3.1 Electrical Conductivity (Salinity) as a Covariate

The GSL IWs vary considerably in EC, and EC remains a potential covariate that could alter the interpretation of chemical or biological differences observed among different IW sites. In the development of the Draft MMI, no significant covariate effects of EC on chemical and biological metrics were noted likely because of the relatively small number (n = 16) of IW sites sampled for the Draft MMI (UDEQ, 2009). EC was therefore not factored into the Draft MMI (UDEQ, 2009). However, the 2012 data set included 53 IWs with considerable inter-site variability in EC (EC range = 451 to 17,017 microsiemens per centimeter [µS/cm]), and the iterative Draft MMI validation/calibration process indicated that EC adjustments to biotic MMIs (for example, SAV and Macroinvertebrates) may be necessary for 2012 data. Observed biotic MMIs ($bMMI_{Ob}$) for each IW site were adjusted (standardized) for EC effects using the following procedure:

- Estimate average EC ($EC_a$) for each site from summer and fall EC measurements
- Estimate the geometric mean of average ECs across all 53 sites ($EC_{gm}$)
- Estimate relative average EC ($EC_r$) for each site ($EC_r = EC_a/EC_{gm}$)
- Develop regression models to define the relationships between the observed biotic MMIs (bMMI) and $EC_r$ across the 53 IW sites (for each biotic MMI, if this relationship is nonlinear, estimate separate linear regression models for ascending [positively correlated values] and descending [inversely correlated values] portions)
- Use the regression models to estimate expected values for the biotic MMI ($bMMI_{ev}$) for each site, based on the input of estimated $EC_r$ for that site
- Use the regression models to estimate the standardized biotic MMI for each site ($bMMI_s$), based on $EC_r = 1$ ($EC_r$ standardized to the geometric mean of ECs across all sites)
- Estimate the EC adjustment multiplier ($EC_m$) = $bMMI_s/bMMI_{ev}$
- Estimate EC adjusted biotic MMIs for each site ($bMMI_{EC}$) = $bMMI_{Ob} \times EC_m$

#### 2.2.3.2 New Macroinvertebrate Metrics and Macroinvertebrate MMI

The Macroinvertebrate MMI component of the Draft MMI included the following five key metrics: percent *Ephemeroptera*, percent *Hyallela*, total macroinvertebrate taxa, Simpson's Diversity Index, and number of

*Coleoptera* taxa (UDEQ, 2009). As discussed in Section 2.1.2.2 of this report, these same metrics were used to develop the Macroinvertebrate MMI component the EH MMI for IW sites in 2012 for the initial validation. The key criterion for the selection of these five macroinvertebrate metrics was based on the sensitivity of macroinvertebrates to different pollutants and the disturbance caused by stressor gradients (for example, nutrient gradients) in wetland ecosystems (UDEQ, 2009).

However, GSL studies have shown that macroinvertebrate taxa in impounded wetlands are generally tolerant of stressors typical in these systems, such as low DO, high pH, and high nutrients (Gray, 2013). Rather, any changes in macroinvertebrate composition in IWs other than seasonal life-cycle events and presence of extreme conditions reflect differences in salinity and the amount, condition and persistence of aquatic vegetation (Gray, 2013). For this reason, new macroinvertebrate metrics (suggested by Gray, 2013) that are linked to the quantity, quality, and persistence of rooted aquatic vegetation were evaluated and incorporated into a new Macroinvertebrate MMI (NMBI) for both the Draft MMI and the 2012 IW sites. The NMBI is predicated on the hypothesis that it better reflects habitat conditions in IWs, is aligned with the goal of preservation of wetlands diversity, and is more closely linked to the management goal of maintaining SAV to serve as food for migrating waterfowl and the public's (also known as duck hunters) perception of "good" IW habitats.

***New Macroinvertebrate Metrics***

The new macroinvertebrate metrics evaluated for GSL IWs are as follows:

- Phytophilous macroinvertebrates index (PMI): proportion of the total sample count consisting of macroinvertebrates that are closely associated with SAV for habitat, reproduction, and food resources (see Table 7)
- *Chrysomelids-Odonata-Trichoptera-Ephemeroptera* (COTE): proportion of the total sample count consisting of COTE species (see Table 7)
- Top three taxa (T3): proportion of the total sample count consisting of the three most abundant taxa associated with SAV
- Simpson's Diversity Index: overall measure of macroinvertebrate diversity

TABLE 7
Macroinvertebrate Taxa Contributing to the PMI and COTE Metrics and Ecological Association with SAV
*(data from by Gray, 2013)*

| PMI | COTE | Taxon | Association with SAV | Clinger | Oviposition in SAV | Food Resource |
|---|---|---|---|---|---|---|
| X | X | Callibaetis | Strong | Yes | Facultative | Collector (epiphytes/detritus) |
| X | X | Caenis | Strong | Yes | Facultative | Collector (epiphytes/detritus) |
| X | X | Damselflies (Ischnura) | Strong | Yes | Yes | Predator |
| X | X | Libellulid Dragonflies (Erythemis) | Strong | Yes | Yes | Predator |
| X | X | Chrysomelidae larvae | Strong | Yes | Yes | Shredder (SAV) |
| X | X | Haliplus | Strong | Yes | Yes | Shredder (SAV) |
| X | X | Ylodes | Strong | Yes | Yes | Shredder (SAV) |
| X | | Gyraulus | Moderate-Strong | No | Facultative | Grazer (periphyton) |
| X | | Hesperocorixa | Moderate | No | Yes | Predator; Piercer-herbivore? |

**Notes:**
COTE = *Chrysomelids-Odonata-Trichoptera-Ephemeroptera*
PMI = phytophilous macroinvertebrates index
SAV = submerged aquatic vegetation

### *Developing the NMBI for the Draft MMI and 2012 IW Sites*

Maximum metric values among the sampling events were used for all of the new macroinvertebrate metrics. Three of these metrics—PMI, COTE, and Simpson's Diversity Index—were incorporated into the NMBI. As noted in Table 7, the PMI and COTE metrics have considerable overlap in the characteristics of the macroinvertebrate community they represent, and as such, COTE is a sub-set of PMI as all of the taxa representing COTE are also considered in PMI. Scores were assigned to the maximum values for each of the new macroinvertebrate metrics based on the quartiles of the metrics data across sites for the Draft MMI (see Table 8) and the 2012 IWs (see Table 9).

TABLE 8
Scoring System for New Macroinvertebrate Metrics for the Draft MMI

| Metric[1, 2] | Scoring[3] | | |
|---|---|---|---|
| | 1 | 3 | 5 |
| PMI | <0.59 | 0.59 to 0.77 | >0.77 |
| COTE | <0.027 | 0.027 to 0.814 | >0.814 |
| Simpson's Diversity Index | <0.027 | 0.027 to 0.425 | >0.425 |

**Notes:**
[1]The T3 metric was unresponsive to water chemistry and was not used in the macroinvertebrate MMI (see results in Section 3)
[2]Future sensitivity analyses will be required to determine if only one of either PMI or COTE should be used, rather than both, as there is overlap in the characteristics they represent (Gray, 2013)
[3]Scores are based on the upper and lower quartiles as break points.
COTE = *Chrysomelids-Odonata-Trichoptera-Ephemeroptera*
PMI = phytophilous macroinvertebrates index
T3 = top three taxa

TABLE 9
Scoring System for New Macroinvertebrate Metrics for the IW in 2012

| Metric[1, 2] | Scoring[3] | | |
|---|---|---|---|
| | 1 | 3 | 5 |
| PMI | <0.227 | 0.227 to 0.718 | >0.718 |
| COTE | <0.168 | 0.168 to 0.544 | >0.544 |
| Simpson's Diversity Index | <0.625 | 0.625 to 0.811 | >0.811 |

**Notes:**
[1]The T3 metric was unresponsive to water chemistry and was not used in the macroinvertebrate MMI (see results in Section 3)
[2]Future sensitivity analyses will be required to determine if only one of either PMI or COTE should be used, rather than both, as there is overlap in the characteristics they represent (Gray, 2013)
[3]Scores are based on the upper and lower quartiles as break points.
COTE = *Chrysomelids-Odonata-Trichoptera-Ephemeroptera*
PMI = phytophilous macroinvertebrates index
T3 = top three taxa

For each site, the scores for all metrics were summed to provide the MMI score for that site. Values of macroinvertebrate scores ranged from a minimum of 5 (each of the five metrics received a score of 1) to a maximum of 15 (each of the three metrics received a score of 5) for each site. The Macroinvertebrate MMI for each site was then estimated as follows:

$$\text{Macroinvertebrate MMI} = (\text{summed score}/15) \times 100$$

# 3. Results and Discussion

## 3.1 Compiling and Organizing Existing Data

### 3.1.1 Draft MMI Database (Historic Database 2003 to 2011)

Data from past studies on wetlands of GSL indicated water quality stressor gradients related to nutrients, total dissolved solids, TSS, pH, and DO (CH2M HILL, 2005 and 2006; Miller and Hoven, 2007). These previous studies and a screening of water quality variables (sampled from 2003 to 2009) against known thresholds aided in the selection of water quality metrics to include in the Draft MMI (see Table 3-1, from UDEQ, 2009). This process was repeated in this study to generate summary water quality statistics with 2010 to 2011 water quality data (see Table 11).

Summary statistics and screening thresholds for the 2010 to 2011 dataset were generally consistent (see Table 11) with those previously reported for the 2003 to 2009 sampling period (see Table 10, from UDEQ, 2009).

### 3.1.2 Independent 2012 IW Database

Summary statistics and screening thresholds for the 2012 water quality dataset were generally consistent (see Table 12) with those for the 2003 to 2009 and 2010 to 2011 sampling periods (see Tables 10 and 11). If the data were not consistent, then a different approach may have been required in the consideration of which water quality metrics should be used. As the 2012 and 2003 to 2009 datasets were generally consistent, the same water chemistry metrics for IWs in 2012 could be used for validation of the Draft MMI.

TABLE 10
Water Quality Characteristics and Potential Stressors for All Ponds (2003 to 2009)

| Parameter | Units | Count | Min | GeoMean | Percentiles | | | Max. | Screening value | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 50th (Median) | 75th | 90th | | | |
| Chlorophyll-a | µg/L | 98 | 0.9 | 8.8 | 8 | 21 | 45 | 104 | 15 | Eutrophic |
| D-Phosphorus | mg/L | 85 | 0.02 | 0.2 | 0.2 | 0.7 | 1.0 | 1.4 | 0.1 | Eutrophic (Utah code is 0.05) |
| T-Phosphorus | mg/L | 494 | 0.02 | 0.2 | 0.2 | 0.6 | 1.0 | 6.4 | 0.1 | Eutrophic (Utah code is 0.05) |
| Nitrogen, ammonia as N | mg/L | 447 | 0.05 | 0.2 | 0.2 | 0.4 | 0.7 | 26.6 | 1.56 | Toxicity (at pH 8.9, Classes 3B, C, and D) |
| Nitrogen, Nitrite+ Nitrate as N | mg/L | 146 | 0.1 | 1.1 | 1.6 | 2.4 | 4.1 | 7.8 | 4 | Eutrophic |
| Nitrogen, organic | mg/L | 80 | 0.5 | 1.6 | 1.4 | 2.5 | 4.7 | 25.4 | 1.9 | Eutrophic |
| T-Nitrogen | mg/L | 80 | 0.5 | 2.0 | 1.6 | 3.3 | 7.8 | 52.0 | 1.9 | Eutrophic |
| Dissolved oxygen | mg/L | 483 | 0.04 | 8.4 | 9 | 12 | 14 | 23 | < 3 | Toxicity |
| pH | — | 881 | 6.21 | 8.9 | 8.9 | 9.3 | 9.7 | 13.0 | <6.5 or >9 | Toxicity |
| Salinity[1] | g/L (ppt) | 473 | 0.2 | 1.8 | 1.4 | 3.0 | 6.4 | 59.9 | 3.9 | Toxicity; tolerance limit for freshwater marsh |
| Temperature | ˚C | | | | | | | 35.0 | >27 | Toxicity |
| Total Dissolved Solids | mg/L | 534 | 254 | 1,719 | 1,360 | 2,790 | 6,104 | 204,000 | (6,100) | Toxicity (90th percentile) |
| Total Suspended Solids | mg/L | 442 | 4 | 23.2 | 22 | 48 | 91 | 4,458 | (91) | Toxicity (90th percentile) |
| Electrical Conductance[1] | µS/cm | 828 | 276.2 | 2,082.7 | 1,797 | 3,165 | 6,019 | 15,440 | 6,000 | Toxicity; tolerance limit for freshwater marsh |
| Sulfate | mg/L | 380 | 21 | 224 | 218 | 315 | 652 | 7,930 | (650) | Toxicity (90th percentile) |

**Notes:**
[1]Freshwater marsh salinity and electrical conductance tolerance limits from Smith et al., 2009
˚C = degree(s) Celsius
µg/L = milligram(s) per liter
µS/cm = microsiemen(s) per centimeter
g/L = gram(s) per liter
Max. = maximum
mg/L = milligram(s) per liter
Min. = minimum
ppt = part(s) per trillion
Grey shaded values exceed screening criteria.

TABLE 11
Water Quality Characteristics and Potential Stressors for All Ponds (2010 to 2011)

| Parameter | Units | Count | Min | GeoMean | Percentiles 50th (Median) | Percentiles 75th | Percentiles 90th | Max. | Screening Value | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll-a | µg/L | 311 | 0.4 | 9.9 | 11.3 | 27.3 | 70.4 | 298.0 | 15 | Eutrophic |
| D-Phosphorus | mg/L | 247 | 0.002 | 0.21 | 0.24 | 0.52 | 0.83 | 3.50 | 0.1 | Eutrophic (Utah code is 0.05) |
| T-Phosphorus | mg/L | 64 | 0.006 | 0.28 | 0.29 | 0.66 | 0.91 | 1.43 | 0.1 | Eutrophic (Utah code is 0.05) |
| Nitrogen, ammonia as N | mg/L | 282 | 0.03 | 0.10 | 0.09 | 0.24 | 0.57 | 2.83 | 1.56 | Toxicity (at pH 8.9, Class 3B, C, and D) |
| Nitrogen, Nitrite+ Nitrate as N | mg/L | 310 | 0.00 | 0.15 | 0.14 | 1.01 | 2.76 | 6.82 | 4 | Eutrophic |
| Nitrogen, organic[2] | mg/L | ** | ** | ** | ** | ** | ** | ** | 1.9 | Eutrophic |
| T-Nitrogen | mg/L | 310 | 0.3 | 1.4 | 1.2 | 2.3 | 4.5 | 7.7 | 1.9 | Eutrophic |
| Dissolved Oxygen | mg/L | 284 | 0.0 | 8.4 | 8.9 | 11.7 | 15.8 | 26.4 | < 3 | Toxicity |
| pH | - | 290 | 7.0 | 8.8 | 8.8 | 9.3 | 9.6 | 10.4 | <6.5 or >9 | Toxicity |
| Salinity[1] | g/L (ppt) | 290 | 0.0 | 1.2 | 1.0 | 1.4 | 3.7 | 16.7 | 3.9 | Toxicity; tolerance limit for freshwater marsh |
| Temperature | °C | 290 | 0.0 | 11.5 | 16.2 | 21.3 | 24.3 | 32.3 | > 27 | Toxicity |
| Total Dissolved Solids | mg/L | 308 | 286.0 | 1,227.5 | 1,042.0 | 1,449.5 | 3,407.0 | 15,480.0 | 3407 | Toxicity (90th percentile) |
| Total Suspended Solids | mg/L | 308 | 2.0 | 27.5 | 27.1 | 74.0 | 86.3 | 984.0 | 86.3 | Toxicity (90th percentile) |
| Electrical Conductance1 | µS/cm | 297 | 243 | 1,890.4 | 1,708 | 2,340 | 3,936 | 10,560 | 6000 | Toxicity; tolerance limit for freshwater marsh |
| Sulfate as $SO_4$ | mg/L | 308 | 10.0 | 172.8 | 195.0 | 228.3 | 326.3 | 1690.0 | 326.3 | Toxicity (90th percentile) |

**Notes:**
[1]Freshwater marsh salinity and electrical conductance tolerance limits from Smith et al., 2009.
[2]No data available.
˚C = degree(s) Celsius
µg/L = microgram(s) per liter
µS/cm = microsiemen(s) per centimeter
g/L = gram(s) per liter
Max. = maximum
mg/L = milligram(s) per liter
Min. = minimum
ppt = parts per trillion
Grey shaded values exceed screening criteria.

TABLE 12
Water Quality Characteristics and Potential Stressors for All Ponds (2012)

| Parameter | Units | Count | Min | GeoMean | Percentiles 50th (Median) | 75th | 90th | Max | Screening value | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll-a | µg/L | 104 | 0.4 | 2.8 | 2.7 | 9.5 | 27.7 | 173.1 | 15 | Eutrophic |
| D-Phosphorus | mg/L | 104 | 0.01 | 0.10 | 0.09 | 0.18 | 0.55 | 1.12 | 0.1 | Eutrophic (Utah code is 0.05) |
| T-Phosphorus | mg/L | 104 | 0.01 | 0.13 | 0.13 | 0.27 | 0.60 | 1.19 | 0.1 | Eutrophic (Utah code is 0.05) |
| Nitrogen, ammonia as N | mg/L | 104 | 0.02 | 0.04 | 0.03 | 0.08 | 0.21 | 1.08 | 1.56 | Toxicity (at pH 8.9, Class 3B, C, and D) |
| Nitrogen, Nitrite+ Nitrate as N | mg/L | 104 | 0.004 | 0.05 | 0.04 | 0.06 | 0.55 | 3.27 | 4 | Eutrophic |
| Nitrogen, organic | mg/L | 104 | 0.114 | 0.82 | 0.82 | 1.12 | 1.83 | 4.65 | 1.9 | Eutrophic |
| T-Nitrogen | mg/L | 104 | 0.3 | 1.0 | 1.0 | 1.4 | 2.0 | 4.0 | 1.9 | Eutrophic |
| Dissolved Oxygen | mg/L | 102 | 0.8 | 9.0 | 9.6 | 12.3 | 14.5 | 22.7 | < 3 | Toxicity |
| pH | - | 102 | 7.3 | 8.9 | 8.9 | 9.4 | 9.9 | 10.5 | <6.5 or >9 | Toxicity |
| Salinity[1] | g/L (ppt) | | | | | | | | 3.9 | Toxicity; tolerance limit for freshwater marsh |
| Temperature | deg. C | 102 | 15.0 | 23.0 | 23.0 | 25.8 | 27.9 | 34.4 | > 27 | Toxicity |
| Total Dissolved Solids | mg/L | 104 | 270 | 1,481 | 1,177 | 2,703 | 4,946 | 8,888 | 4946 | Toxicity (90th percentile) |
| Total Suspended Solids | mg/L | 104 | 2.0 | 15.5 | 15.5 | 32.0 | 113.0 | 1640.0 | 113 | Toxicity (90th percentile) |
| Electrical Conductance[1] | µS/cm | 102 | 451.0 | 2,707.9 | 2,033.0 | 5,212.3 | 8,772.5 | 17,017.0 | 6000 | Toxicity; tolerance limit for freshwater marsh |
| Sulfate as $SO_4$ | mg/L | 64 | 1.2 | 133.0 | 184.5 | 228.3 | 336.1 | 2,890.0 | 336 | Toxicity (90th percentile) |

**Notes:**
[1]Freshwater marsh salinity and electrical conductance tolerance limits from Smith et al., 2009
˚C = degrees Celsius
µg/L = micrograms per liter
µS/cm = microsiemens per centimeter
g/L = gram(s) per liter
Max. = maximum
mg/L = milligram(s) per liter
Min. = minimum
ppt = parts per trillion
Grey shaded values exceed screening criteria.

### 3.1.3 WC MMI for 2012 IW Sites

The WC MMI for 2012 IW sites ranged from 56 to 100, reflecting the variability in constituent water parameters and water quality among sites (see Table A1 in Appendix A)

### 3.1.4 Observed Biotic MMIs and the Observed EH MMI for 2012 IW Sites

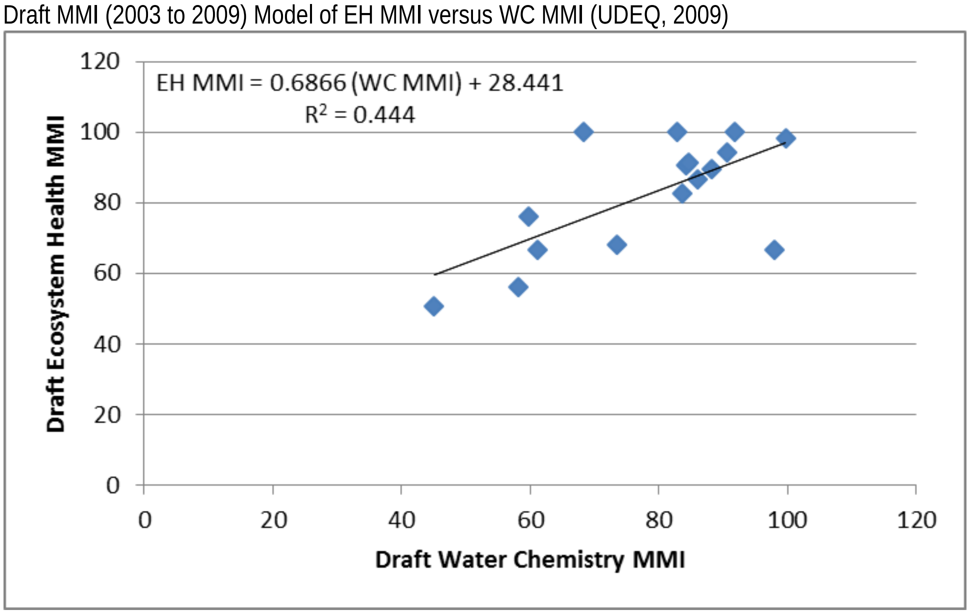
The observed biotic MMIs (SAV, Surface Mat, and Macroinvertebrates) and the observed EH MMI for IW sites in 2012 are shown in Table 2A in Appendix A. The EH MMIs represent observations on the ecological health of the IW sites against which the Draft MMI is to be initially validated (see following section on Draft MMI validation).

## 3.2 Draft MMI Validation and Improvement: An Iterative Approach

### 3.2.1 Draft MMI: Initial Validation with 2012 IW Data (Steps 1 through 3 in Figure 6)

The Draft MMI model (UDEQ, 2009) describes the relationship between the EH MMIs and water chemistry MMIs for the 16 GSL IWs sites sampled from 2003 to 2009 (see Figure A6 and Table A3 in Appendix A). Independently observed water chemistry MMIs for the 2012 IW sites were used in this Draft MMI model to predict EH MMIs for each IW site in 2012 (see Table A4 in Appendix A). These predicted EH MMIs were then statistically compared to EH MMIs observed at those sites in 2012 (see Table A4 in Appendix A). The methods are described in Section 2.2 and illustrated in Steps 1 through 3 (first statistical validation) of Figure 7.

FIGURE 7
Draft MMI (2003 to 2009) Model of EH MMI versus WC MMI (UDEQ, 2009)




The scatterplot of observed versus predicted EH MMIs indicates that the Draft MMI consistently over-predicts EH MMIs for 2012 IW sites, and all but two sites fall under the 1:1 line indicating strong systematic errors (see Figure 8). The best fit regression line of observed versus predicted EH MMIs indicates that on average, the Draft MMI over-predicts EH MMIs by approximately 30 to 40 percent.

The Draft MMI clearly fails at least one of the three statistical validation procedures, specifically the decomposition of MSE test (see Table 13). Over 70 percent of the errors were attributable to MC of the MSE in the regression of observed versus predicted EH MMIs, indicating substantial differences between the means of observations and predictions, and, therefore, strong systematic errors. However, the SC contributed insignificantly to the MSE (0.2 percent of the MSE) and the slope of the regression of observed versus predicted EH MMIs approximately paralleled the 1:1 line (see Figure 8). This verifies that the Draft MMI provides a reasonable approximation of the variation in EH MMIs observed across sites in GSL. This is further supported by the BJCI test, which indicated that the BJCI of the regression of observed versus predicted EH MMIs includes an intercept of 0 and a slope of 1, and thus does not deviate substantially from the 1:1 line. The reliability index for this Draft MMI validation was 1.5, indicating that approximately 68 percent of all observed EH MMI values are expected to be between 0.67 and 1.5 times the predicted values.

FIGURE 8
Initial Validation Comparing EH MMIs Predicted by the Draft MMI to EH MMIs Observed in IWs of GSL in 2012

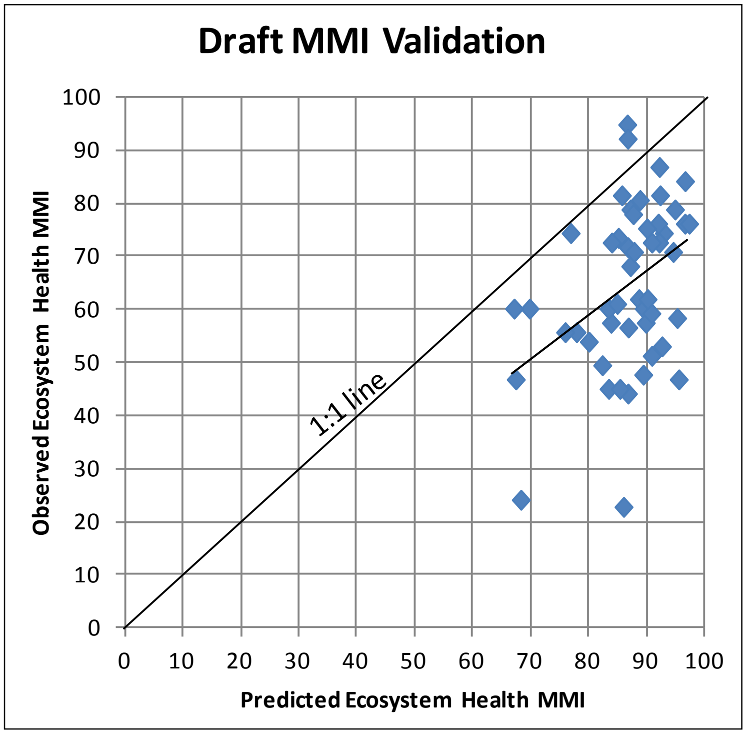



TABLE 13
Statistical Tests for Initial Validation of the Draft MMI

| Statistical Validation Test | Test Results | Notes |
|---|---|---|
| **Decomposition of Mean Square Error:** | | |
| Mean Component (% MC): | 70.7 | Large systematic errors due to MC – FAIL TEST |
| Slope Component (% SC): | 0.2 | Insignificant error due to SC – PASS TEST |
| Random Component (% RC): | 29.0 | Small proportion of random errors - FAIL TEST |
| **Bonferroni Joint Confidence Intervals (BJCI):** | | |
| BJCI for Intercept: | -57.5 – 39.6 | Includes intercept of 0 – PASS TEST |
| BJCI for Slope: | 0.29 – 1.41 | Includes slope of 1 – PASS TEST |
| **Reliability Index:** | | |
| k: | 1.5 | Approximately 68 percent of all observed Ecosystem Health MMI values are expected to be between 0.67 and 1.5 times the predicted values – PASS TEST |

### 3.2.2 Calibrating 2012 EH MMIs for Salinity Effects and Draft MMI Revalidation (see Steps 4 through 5 and Figure 6)

Consistent over-predictions of 2012 EH MMIs by the Draft MMI highlighted the need to explore potential factors contributing to these systematic errors. Further exploration of the 2012 data pointed to highly variable salinity (EC) among IW sites in 2012 as a potential contributor to variations in EH MMIs observed among the sites. Furthermore, EH MMIs showed a nonlinear response to average EC, increasing up to an average EC of approximately 4,000 µS/cm and then declining at higher ECs (see Figure 9). Based on this response, all EH MMI observations were adjusted for EC effects based on regression models of EH versus relative average EC (see Figure 10), followed by standardization of EH values to a relative average EC of 1 and application of the estimated multiplier. The EC-adjusted EH MMI observations for 2012 IW sites were then compared to EH MMIs that are predicted with the Draft MMI, using 2012 WC MMIs as the input (see Table A5 in Appendix A). The methods are described in Section 2.2 and illustrated in Steps 4 and 5 (calibration and first statistical validation) of Figure 6.

FIGURE 9
EH MMIs Plotted versus Average EC for 2012 IW Sites

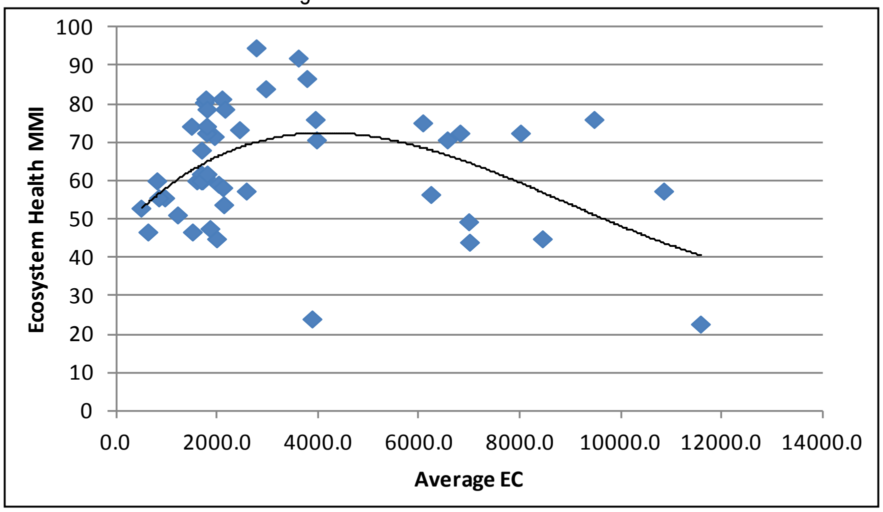
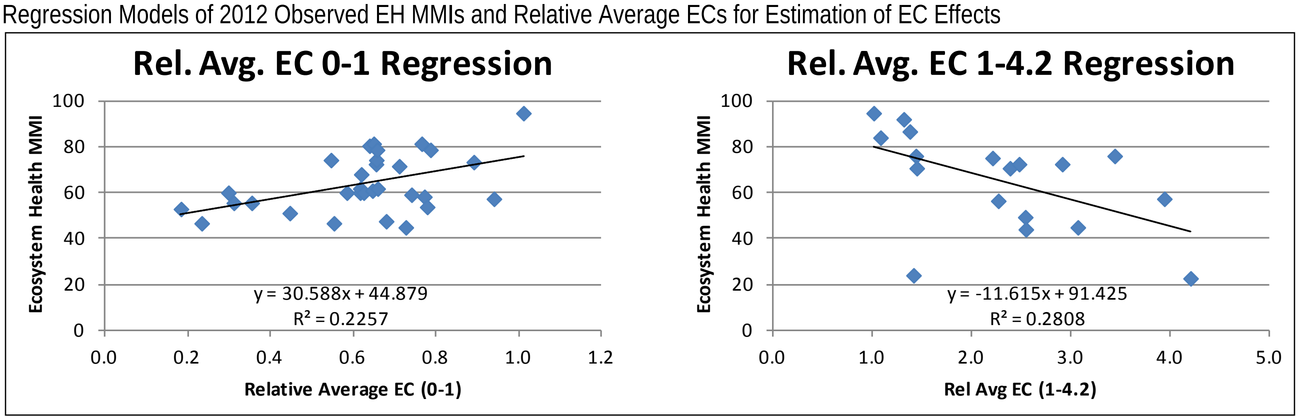



FIGURE 10
Regression Models of 2012 Observed EH MMIs and Relative Average ECs for Estimation of EC Effects




The scatterplot of EC-adjusted observed EH MMIs versus predicted EH MMIs indicates a significant improvement in the Draft MMI's accuracy in predicting ecosystem health for 2012 IW sites. Compared to the previous validation without EC adjustments, significantly more EH observations match predicted values, indicating a reduction in systematic errors (see Figure 11), due to reduction in variation from removal of EC effects. The best fit regression line of EC-adjusted observed versus predicted EH MMIs indicates that on average, the Draft MMI now over-predicts EH MMIs by approximately 12 to 15 percent, a significant improvement over the previous validation that over-predicted EH by 30 to 40 percent.

With EC adjustments to the 2012 IW EH MMIs, the Draft MMI performs significantly better at all three statistical validation procedures (see Table 14). A little over 32 percent of the MSE error was attributable to the MC in the regression of EC-adjusted observed versus predicted EH MMIs, and while this still represents a significant proportion of the MSE, it indicates a 54 percent decrease in MC error from the previous validation. The SC still contributed insignificantly to the MSE (0.2 percent of the MSE) and the slope of the regression of EC-adjusted observed EH MMI versus predicted EH MMIs approximately paralleled the 1:1 line (see Figure 4). Over 67 percent of the MSE was now attributable to the RC, and overall, the MSE test indicated a more desirable distribution of MSE over the three sources of error (MC, SC, and RC) than in the previous validation (see Table 14). The BJCI of the regression of EC-adjusted observed EH MMI versus predicted EH MMIs includes an intercept of 0 and a slope of 1, and thus does not deviate substantially from the 1:1 line. The reliability index for this Draft MMI validation was 1.29, indicating that approximately 68 percent of all observed EH MMI values are expected to be between 0.78 and 1.29 times the predicted values. This reflects an improvement in the RI from the previous validation, further supporting an improvement in the accuracy of the Draft MMI.

The significant improvement in the EC-adjusted EH MMI validation indicated that further exploration of how EC may affect each individual biological MMI (SAV, Surface Mat, and Macroinvertebrates) was warranted.

FIGURE 11
Second Validation Test Comparing EH MMIs Predicted by the Draft MMI to EC-adjusted EH MMIs Observed in IWs of GSL in 2012

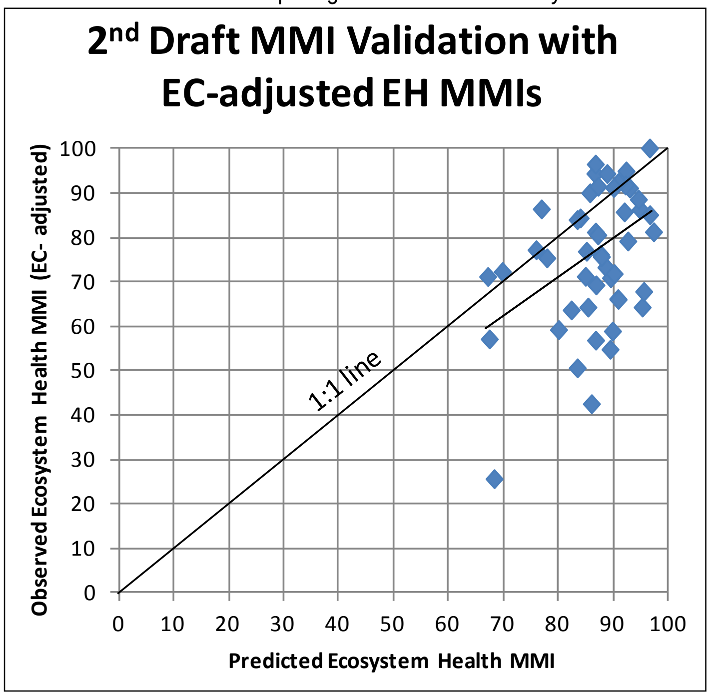


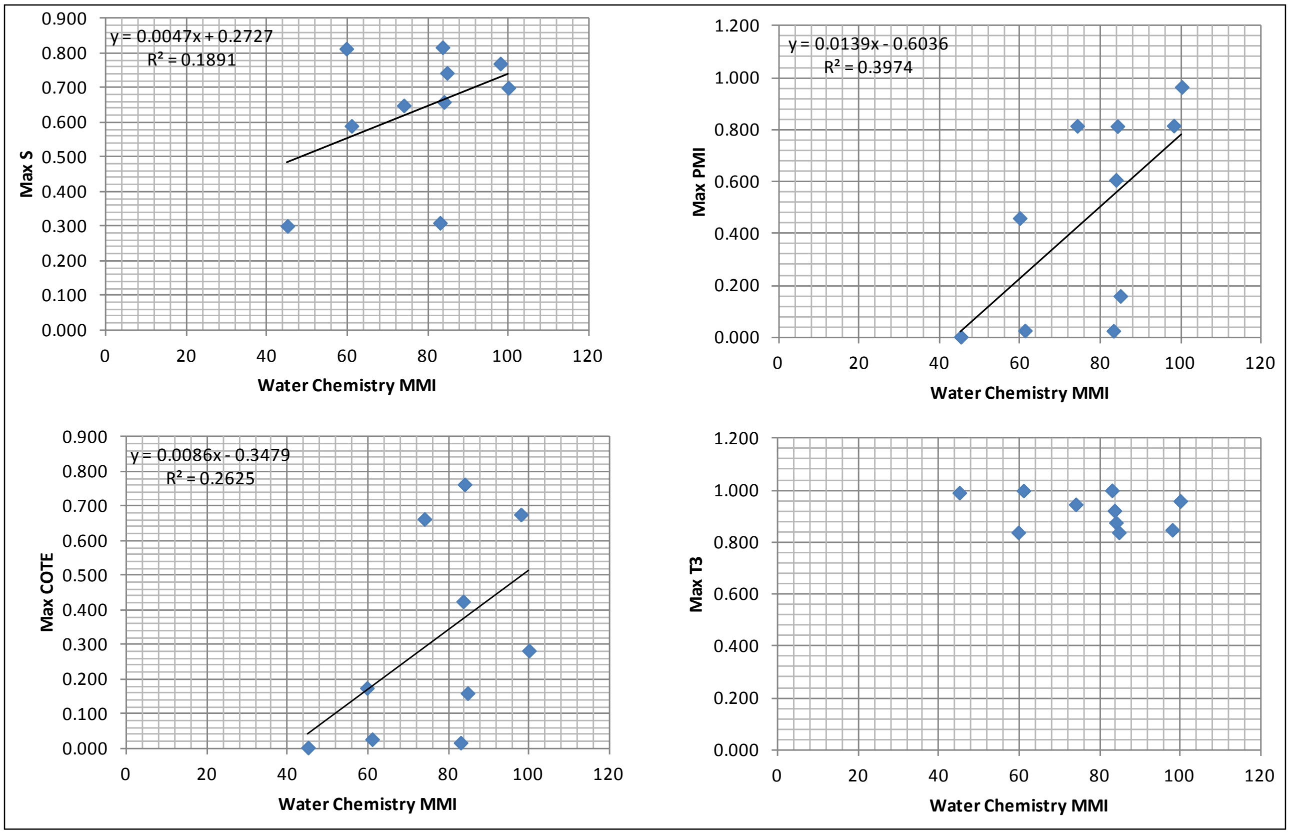

TABLE 14
Statistical Tests for Second Validation of the Draft MMI with EC-adjusted 2012 EH MMI

| Statistical Validation Test | Test Results | Notes |
|---|---|---|
| **Decomposition of Mean Square Error:** | | |
| Mean Component (% MC): | 32.4 | Lower MC error than validation 1 – FAILS TEST |
| Slope Component (% SC): | 0.2 | Insignificant error due to SC – PASS TEST |
| Random Component (% RC): | 67.4 | Largest contributor to MSE error – FAILS TEST |
| **Bonferroni Joint Confidence Intervals (BJCI):** | | |
| BJCI for Intercept: | -49.9 to 48.8 | Includes intercept of 0 – PASS TEST |
| BJCI for Slope: | 0.32 to 1.46 | Includes slope of 1 – PASS TEST |
| Reliability Index<br>k: | 1.29 | Approximately 68 percent of all observed EH MMI values are expected to be between 0.78 and 1.29 times the predicted values – PASS TEST |

### 3.2.3 Updated MMI: Revising the Draft MMI (2003 to 2009) with New Macroinvertebrate Metrics (see Step 6 in Figure 6)

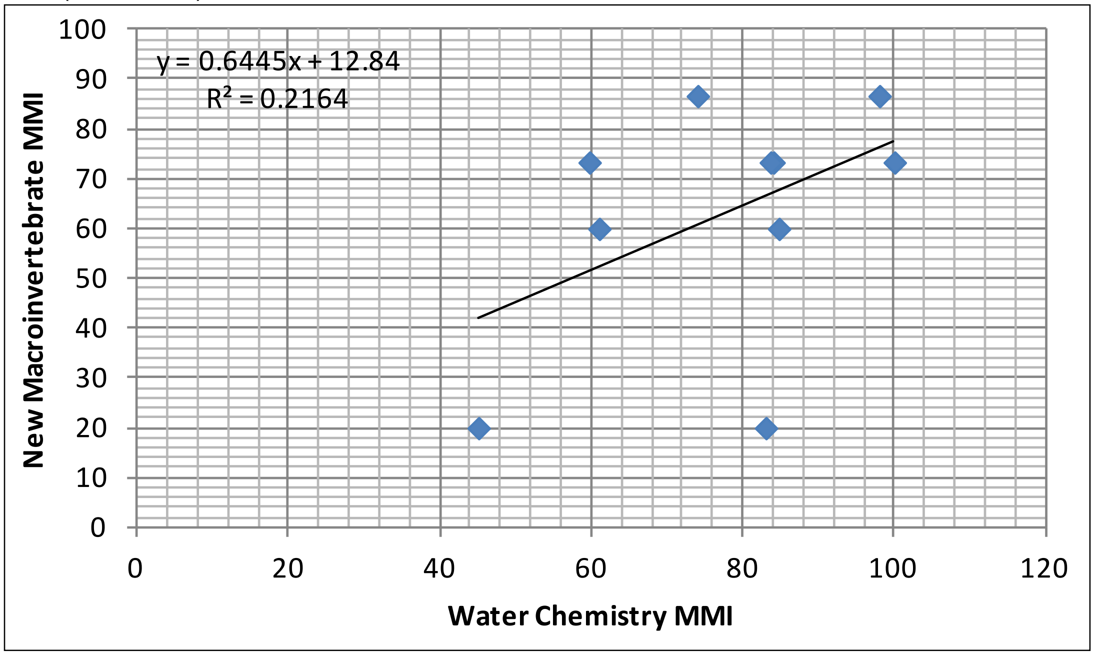
The responses of new macroinvertebrate metrics (suggested in Gray, 2013) including Simpson's Diversity Index (S), and proportions of PMI, T3, and COTE, to the draft water chemistry MMI were explored (see Figure 12A).

FIGURE 12A
New Macroinvertebrate Metrics versus Draft WC MMI




Except for T3, all other metrics were positively correlated with the WC MMI, and were included in the NMBI (Figure 12B). As previously noted, the PMI and COTE metrics have considerable overlap in the characteristics of the macroinvertebrate community they represent. As such, COTE is a sub-set of PMI as all of the taxa representing COTE are also considered in PMI (see Table 7). It is recommended that additional sensitivity analysis be conducted in the future to determine if only one of either PMI or COTE should be used, rather than both metrics in the development of the Macroinvertebrate MMI (Gray, 2013).

FIGURE 12B
NMBI (2003 to 2009) versus Draft WC MMI




The NMBI was then added to the 2003 to 2009 SAV MMI and Surface Mat MMI to calculate the updated EH MMI. The NMBI improved the linear regression fit between the EH MMI and the WC MMI (see Figure 13), and particularly when a power fit was used to describe the relationship between these two variables (see Figure 14). This power fit model was then selected as the updated MMI (see Figure 14).

FIGURE 13
Comparison of the Old and Updated MMIs Fitted with Linear Regressions

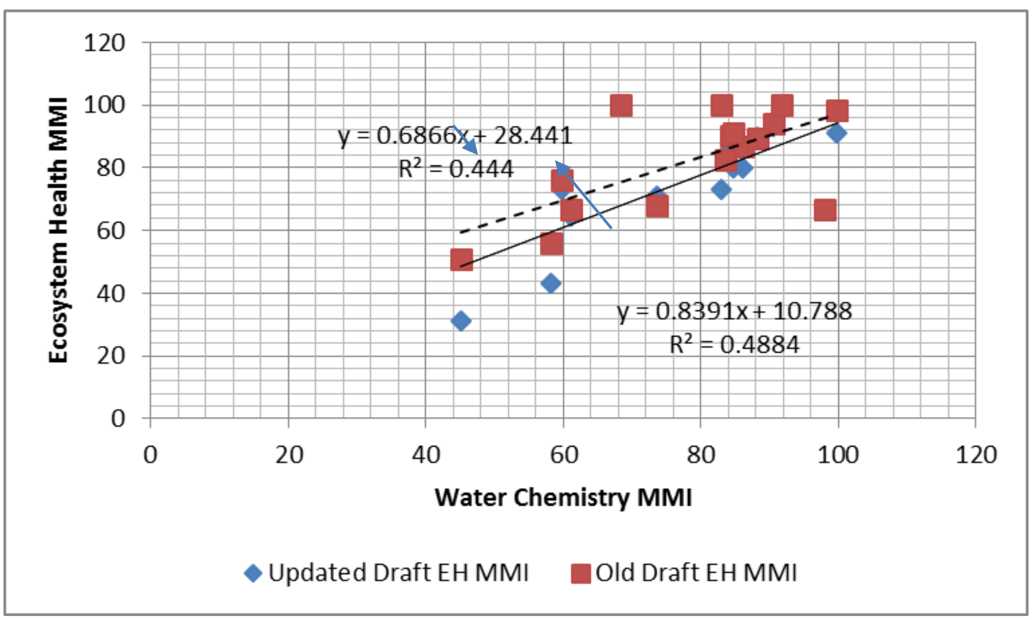
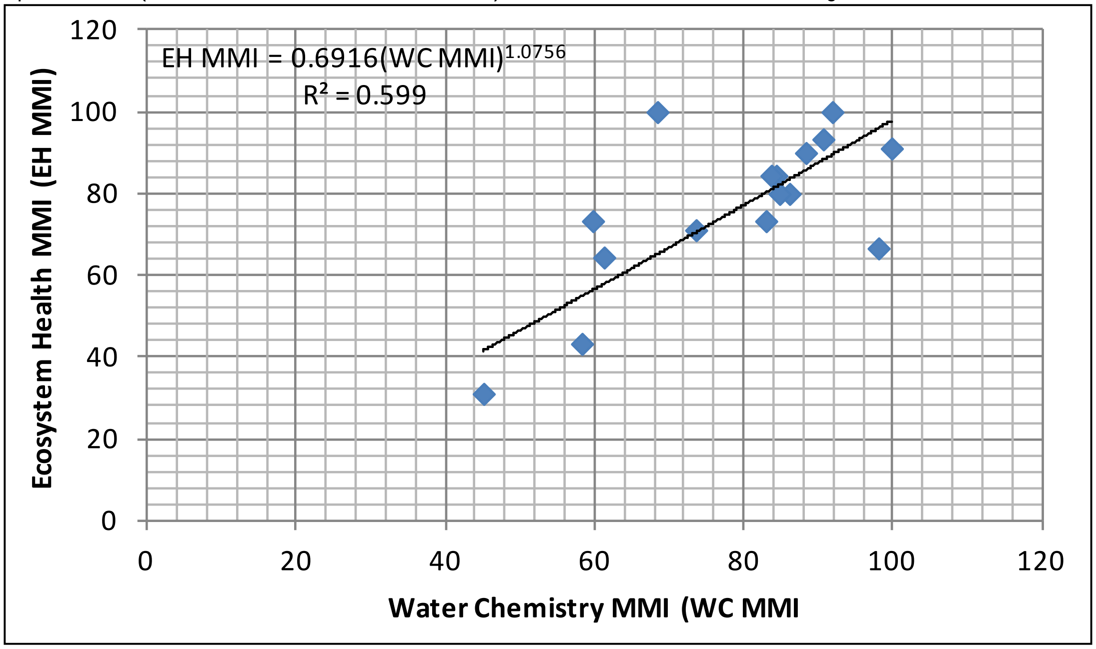


FIGURE 14
Updated MMI (with New Macroinvertebrate Metrics) Described with a Power-fitted Regression Line




### 3.2.4 Incorporating New Macroinvertebrate Metrics into the 2012 EH MMI (see Steps 6 and 9 in Figure 6)

The macroinvertebrate metrics including Simpson's Diversity Index, proportions of PMI, and the COTE were combined to develop the NMBI for IW sites in 2012 (see Step 6 of Figure 6 and Table A6 in Appendix A). The T3 metric was excluded because it was unresponsive to the WC MMI. The NMBI was adjusted for EC effects (see Step 9 in Figure 6) as described previously, and then combined with the EC-adjusted SAV MMI and Surface Mat MMI to develop the new EC-adjusted EH MMI draft for IW sites in 2012 (see Table A6 in Appendix A). The Surface Mat MMI was not adjusted for EC effects as it was found to be unresponsive to EC.

### 3.2.5 Validating the Updated MMI

The WC MMIs for 2012 IW sites were used in the updated MMI model (see Figure 14) to predict EH MMIs, which were then compared to EC-adjusted EH MMI observations for those sites (see Table A7 in Appendix A). For comparison, EH MMI observations that were not adjusted for EC are also listed in Table A8, Appendix A.

The scatterplot of EC-adjusted observed versus predicted EH MMIs indicates a significant improvement in the updated MMI's accuracy in predicting ecosystem health for 2012 IW sites. Compared to the previous validation of the old Draft MMI with EC adjustments, significantly more EH observations matched the predicted values, indicating a reduction in systematic errors (see Figure 15). The best fit regression line of EC-adjusted observed versus predicted EH MMIs indicates that on average, the updated MMI on average now over-predicts EH MMIs only by less than 8 percent, indicating a significant improvement over the previous validations of 30 to 40 percent (first validation) and 12 to 15 percent (second validation).

With EC adjustments and new macroinvertebrate metrics added to the 2012 IW EH MMI observations, the updated MMI (with new macroinvertebrate metrics) performs significantly better at all three statistical validation procedures (see Table 15) than the old Draft MMI. Compared to the previous validations, only 16.6 percent of the MSE error was attributable to the MC in the regression of EC-adjusted observed versus predicted EH MMIs (see Table 14), indicating a 77 and 49 percent decrease in MC error from the first and second validations, respectively. The SC contributed little error to the MSE (1.6 percent of the MSE) and the slope of the regression of EC-adjusted observed EH MMI versus predicted EH MMIs approximately paralleled the 1:1 line (see Figure 15). The majority of the error in the MSE (81.8 percent) was attributed to the RC.

Overall, the MSE test indicated a more desirable distribution of MSE over the three sources of error (MC, SC, and RC) than in the previous two validations (see Table 15). The BJCI of the regression of EC-adjusted observed EH MMI versus predicted EH MMIs included an intercept of 0 and a slope of 1, and did not deviate substantially from the 1:1 line. The reliability index for the updated MMI validation was 1.26, indicating that approximately 68 percent of all observed EH MMI values are expected to be between 0.79 and 1.26 times the predicted values. Overall, the accuracy of updated MMI was significantly improved over the old Draft MMI by the addition of new macroinvertebrate metrics.

FIGURE 15
Final Validation Test Comparing New EH MMI Predicted by the Updated MMI to EC-adjusted EH MMIs Observed in IWs of GSL in 2012

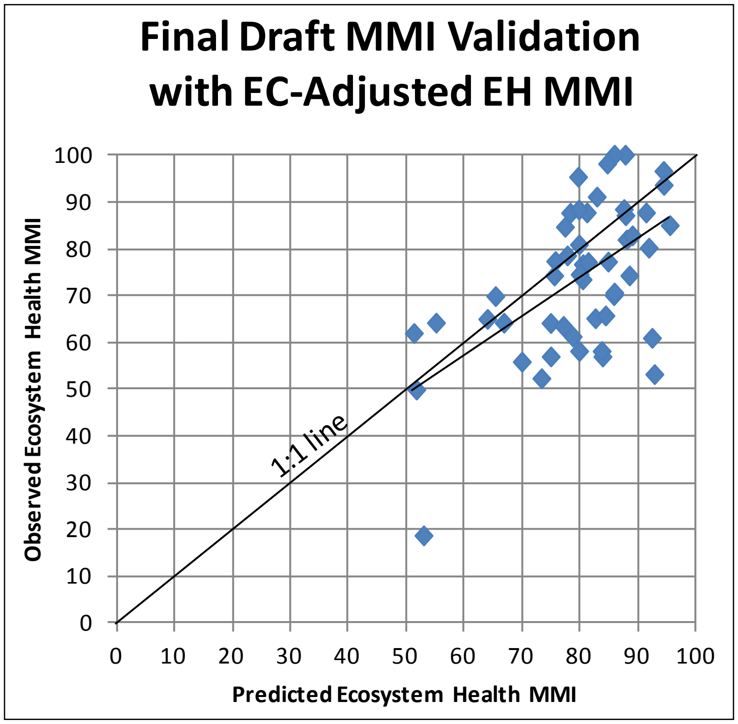



TABLE 15
Statistical Tests for Final Validation of the Updated Draft MMI with EC-adjusted 2012 EH MMI

| Statistical Validation Test | Test Results | Notes |
|---|---|---|
| **Decomposition of Mean Square Error** | | |
| Mean Component (% MC): | 16.6 | Low MC error – PASS TEST |
| Slope Component (% SC): | 1.6 | Very low SC error – PASS TEST |
| Random Component (% RC): | 81.8 | High random error – PASS TEST |
| **Bonferroni Joint Confidence Intervals (BJCI)** | | |
| BJCI for Intercept: | -21.0 – 35.9 | Includes intercept of 0 – PASS TEST |
| BJCI for Slope: | 0.47 – 1.19 | Includes slope of 1 – PASS TEST |
| **Reliability Index** k: | 1.26 | Approximately 68 percent of all observed EH MMI values are expected to be between 0.79 and 1.26 times the predicted values – PASS TEST |

Conversely, the updated MMI (with new macroinvertebrate metrics) does not perform as well when compared to the 2012 observed EH MMIs without EC adjustments (Figure 16, Table 16, and Appendix A – Table A8).

FIGURE 16
Validation Test Comparing New EH MMI Predicted by the Updated MMI to EH MMIs without EC Adjustments Observed in IWs of GSL in 2012

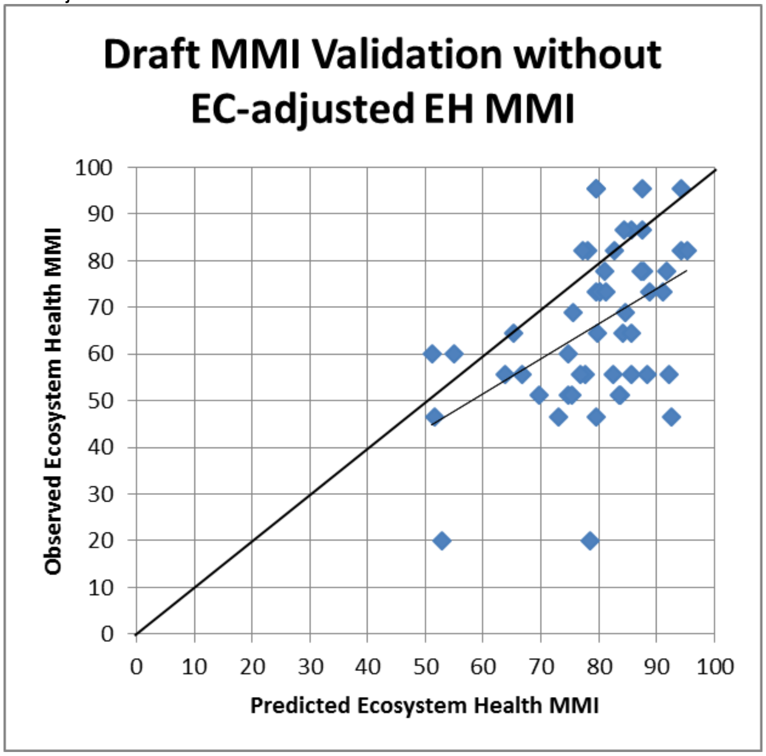


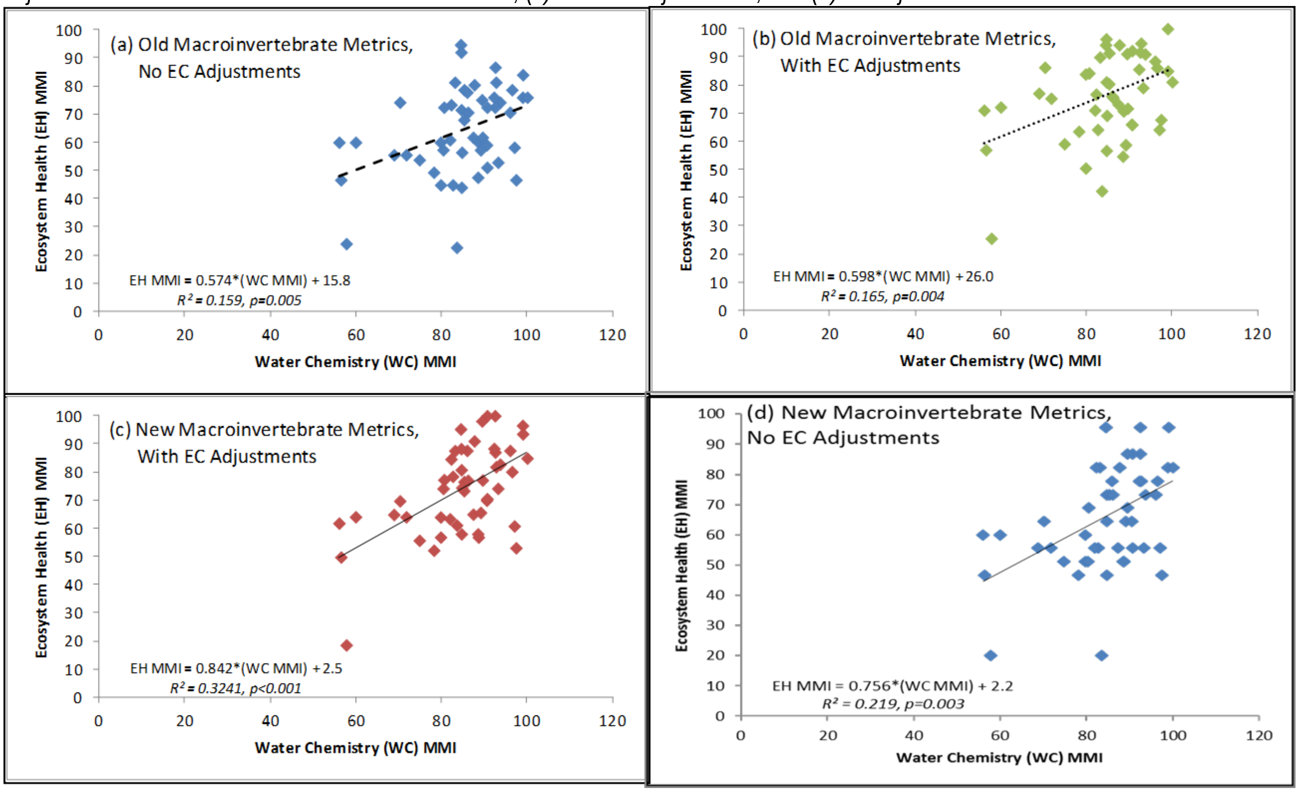

TABLE 16
Statistical Tests for Validation of the Updated Draft MMI with 2012 EH MMI without EC Adjustments

| Statistical Validation Test | Test Results | Notes |
|---|---|---|
| **Decomposition of Mean Square Error** | | |
| Mean Component (% MC): | 42.4 | Relatively large MC error – FAIL TEST |
| Slope Component (% SC): | 1.2 | Very low SC error – PASS TEST |
| Random Component (% RC): | 56.4 | Relatively low RC error – FAIL TEST |
| **Bonferroni Joint Confidence Intervals (BJCI)** | | |
| BJCI for Intercept: | -26.6 – 40.2 | Includes intercept of 0 – PASS TEST |
| BJCI for Slope: | 0.33 – 1.17 | Includes slope of 1 – PASS TEST |
| **Reliability Index** k: | 1.4 | Approximately 68 percent of all observed EH MMI values are expected to be between 0.71 and 1.4 times the predicted values – PASS TEST |

## 3.2.6 EH and WC MMIs for 2012 IW Sites

Scatterplots and linear regressions of EH MMIs versus WC MMIs observed at IW sites in 2012 are also significantly improved when EC effects are accounted for in EH observations and when new macroinvertebrate metrics replace the old metrics in the EH MMI (Figure 17, a through d). The WC MMI accounted for only 15.9 percent ($r^2$ = 0.159) of the variation in EH MMIs with no EC adjustments and old macroinvertebrate metrics (see Figure 17a). The regression coefficient improves marginally ($r^2$ = 0.165) but with a higher intercept value when EC effects are accounted for, indicating that EC adjustments generally increased the EH MMI values (see Figure 17b). Accounting for both EC effects and new macroinvertebrate metrics in the EH MMIs leads to an overall reduction in variation around the line of best fit and an approximate doubling of the regression coefficient to $r^2$ = 0.324 (see Figure 17c). The fit of the regression between EH MMI and WC MMI weakens a bit without any EC adjustments and with only the new macroinvertebrate metrics (Figure 17d), but is still better than when the old macroinvertebrate metrics were used (Figures 17a and 17b).

FIGURE 17
Linear Regressions of EH MMIs on WC MMIs for IW sites in 2012
*Regressions are for observed EH MMIs estimated with old macroinvertebrate metrics and (a) no adjustments for EC, (b) with EC adjustments and with new macroinvertebrate metrics, (c) with EC adjustments, and (d) no adjustments for EC.*




## 3.2.7 Relative Comparisons of EH for 2012 IW Sites

The observed EC-adjusted EH MMI values (see Table A7 in Appendix A) were sorted to facilitate a relative comparison of ecosystem health among the 2012 IW sites (Table 17). These comparisons are not intended to indicate the absolute condition of the IWs, but are only provided as a relative measure of how the IWs compare when based on EH MMIs estimated from SAV, new benthic macroinvertebrate, and surface mat metrics discussed in this study. Exploration of additional metrics that further helps characterize water/sediment chemistry and the biota of these IWs may be warranted to improve the MMI and better enable its use in estimating the condition of IWs of GSL.

TABLE 17
Sorted EC-Adjusted EH MMI Observations for IWs in 2012

| Storet Identification | Site Name | EC-adjusted EH MMI Observed in 20122 |
|---|---|---|
| 5971330 | UNIT3 | 100 |
| 5971440 | UNIT 35 | 100 |
| 5971530 | WIDGEON | 98 |
| 5971340 | N GEDDYS | 97 |
| 5971070 | LFDC1 | 95 |
| 5971730 | UNIT 3 | 94 |
| 5971090 | TURPIN UNIT FBWMA | 91 |
| 5971450 | SHALLOW | 88 |
| 5971850 | W100 | 88 |
| 5971270 | BIG BEAR | 88 |
| 5971490 | BRCCN | 88 |
| 5971110 | LFDC3 | 88 |
| 5971380 | GARD POND | 87 |
| 5971360 | STELLA MARSH | 85 |
| 5971120 | NSDC1 | 85 |
| 5971300 | TRADE LAKE | 83 |
| 5971100 | LFDC2 | 82 |
| 5971050 | HDC1 | 81 |
| 5971230 | HDC3 | 80 |
| 5971470 | CORPORATION POND | 78 |
| 5971160 | NSDC2 | 77 |
| 5971780 | FB SE UNIT 1 | 77 |
| 5971670 | MAIN UNIT EAST | 77 |
| 5971220 | NPDC3 | 77 |
| 5971390 | HULL LAKE | 74 |
| 5971560 | FB NE POND | 74 |
| 5971480 | UNIT 3N | 74 |
| 5971060 | UNIT 7 | 73 |
| 5971640 | HS-S | 71 |
| 5971410 | BRCC NE | 70 |
| 5971570 | SOUTH AREA | 70 |

TABLE 17
Sorted EC-Adjusted EH MMI Observations for IWs in 2012

| Storet Identification | Site Name | EC-adjusted EH MMI Observed in 2012[2] |
|---|---|---|
| 5971190 | LFDC4 | 66 |
| 5971140 | RDC | 65 |
| 5971720 | STEEDS POND | 65 |
| 5971080 | HDC2 | 64 |
| 5971690 | HSE | 64 |
| 5971680 | WEBER DELTA | 64 |
| 5971740 | FBS UNIT 1 | 63 |
| 5971750 | NSDC WALK IN | 62 |
| 5971040 | ISSR SW POND | 61 |
| 5971510 | BRCC SE | 61 |
| 5971370 | UNIT 4 | 58 |
| 5971660 | UNIT 2 FBWMA | 58 |
| 5971210 | NPDC2 | 57 |
| 5971170 | NPDC1 | 57 |
| 5971770 | FB UNIT 1 | 56 |
| 5971590 | BIG POND FBWMA | 53 |
| 5971130 | ISSR WEST B POND | 52 |
| 5971710 | FBS | 50 |
| 5971540 | UNIT IN | 19 |
| 5971400 | UNIT 5[1] | - |
| 5971650 | RMP POND[1] | - |
| 5971700 | UNIT 1 NW[1] | - |

**Notes:**
[1]Missing chemistry data in Unit 5, RMP, and Unit 1 NW impounded wetlands sites excluded those sites from the Draft MMI validation.
[2]EC-adjusted observed EH MMI is the EH MMI calculated using EC-adjusted biotic MMI (SAV and new Macroinvertebrate) and non-adjusted surface mat data collected in 2012.

Out of the 53 IW sites for which complete data were available (Table 17), 7 sites (14 percent) had EH MMIs ranging from 90 to 100, 12 (24 percent) sites had EH MMIs in the 80 to 89 range, and an equal number of sites (12) in the 70 to 79 range. EH MMIs at 10 sites (20 percent) ranged from 60 to 69, and at 8 sites (16 percent) from 50 to 59. One site (2 percent) had an EH MMI considerably below 50. Table A9 in Appendix A provides summary statistics comparing the distribution of values for the draft and updated MMIs.

# 4. Conclusions and Recommendations

The independent evaluation of the Draft MMI conducted in this study strongly supports the validity and portability of the MMI approach in assessing the ecological health of IWs of GSL. The Draft MMI used data from multiple lines of evidence including WC, SAV, surface mat, and benthic macroinvertebrates, to describe condition of the IWs of GSL. Developed with data collected from 16 IW sites during 2003 to 2009, the Draft MMI was tested for its ability to predict the ecological health of 53 independent GSL IWs in 2012. Key results of the validation of the Draft MMI are summarized as follows:

- Thresholds of the summary statistics on water quality variables that were used to screen potential water quality metrics to include in the MMI did not change significantly when water quality data from 2010 and 2011 were added to the 2003 to 2009 water quality dataset. This indicates that the same water quality metrics could be used in future studies that seek to refine and improve the MMI with data collected in 2010 and 2011 (see Section 3.1.1).
- Summary statistics on water quality for IW sites in 2012 were consistent with those observed for the 2003 to 2011 period, indicating that it was acceptable to use the water quality metrics used in the Draft MMI to develop an independent water quality (Chemistry) MMI for IWs sites in 2012 (see Section 3.1.2).
- Metrics scoring criteria used for developing the biota MMIs (SAV, Surface Mat, and Macroinvertebrates) for the Draft MMI are not portable to the independent IWs dataset (2012 dataset). As such, separate metrics scoring criteria needed to be developed based on the individual biological metrics data collected in 2012 (see Sections 2.1.2.2 and 2.2.3.2).
- The Draft MMI validation approach uses independently observed WC MMIs for the 2012 IW sites to predict and compare EH MMIs to those observed independently at the IW sites. This approach provides a reasonable framework for validation of the Draft MMI based on a statistically rigorous comparison of independently observed and predicted EH MMIs (see Section 3.2).
- The validation approach used in this study is also useful for iteratively identifying potential sources of systematic errors in the EH predictions made by the Draft MMI, and then refining the Draft MMI to address those sources of error. This approach allowed for the identification and incorporation of salinity as a significant covariate variable affecting biotic MMIs (SAV and Macroinvertebrates) at IW sites in 2012. It also provided the basis for the incorporation of NMBI metrics (developed by Dr. Larry Gray, Utah Valley University) to improve the predictive capability of the Draft MMI (see Section 3.2).
- At initial validation, the Draft MMI consistently over-predicted EH MMIs for IW sites in 2012. Over 70 percent of the systematic errors were attributable to the fact that observed EH MMIs were consistently lower (by as much as 30 to 40 percent) across IW sites in 2012 than those predicted by the Draft MMI (see Section 3.2.1).
- Consistent over-prediction bias in the initial validation of the Draft MMI pointed to salinity (EC) as a potential factor contributing to these systematic errors. In fact, variable salinity among IW sites in 2012 contributed significantly to variations in EH MMIs observed among the sites. EH MMIs in 2012 were nonlinearly correlated to average EC across sites, and adjusting all EH MMI observations for EC effects significantly reduced the bias due to systematic errors (see Section 3.2.2).
- The second validation of the Draft MMI consisted of comparing EH MMIs predicted with the Draft MMI, to salinity-adjusted EH MMIs observed at IW sites in 2012. The Draft MMI's accuracy at predicting EH MMIs was now significantly improved and significantly more salinity-adjusted EH MMI observations matched predicted values. Systematic errors were reduced from over 70 percent in the initial validation to just over 32 percent when salinity adjustments were made to the observed EH MMIs. The Draft MMI now over-predicted salinity-adjusted EH MMIs by approximately 12 to 15 percent, which was a significant improvement over the previous validation (30 to 40 percent) (see Section 3.2.2).

- The Draft MMI was updated to incorporate the NMBI developed by Dr. Larry Gray that included metrics such as Simpson's Diversity Index (S), proportions of PMI, and the COTE. These three metrics more closely reflected the variations observed in macroinvertebrate communities at IW sites due to differences in salinity and the amount, condition, and persistence of SAV. The NMBI, based on these three metrics, was also developed for IW sites in 2012. The original Macroinvertebrate MMI in the Draft MMI consisted of the following five metrics: percent *Ephemeroptera*, percent *Hyallela*, total macroinvertebrate taxa, Simpson's Diversity Index, and number of *Coleoptera* taxa. The new NMBI significantly improved the predictive accuracy of the updated Draft MMI (Section 3.2.3).
- The PMI and COTE metrics that are components of the NMBI have considerable overlap in the characteristics of the macroinvertebrate community they represent. Additional sensitivity analysis should be conducted in the future to determine if only one of either PMI or COTE should be used, rather than both metrics in the development of the Macroinvertebrate MMI.
- The third (final) validation consisted of comparing EH MMIs predicted with the updated Draft MMI, to EC-adjusted EH MMIs observed at IW sites in 2012. Significantly more EC-adjusted EH observations now matched EH values predicted by the updated Draft MMI, indicating a further reduction in systematic errors from the previous two validations (see Figure 15). The updated draft MMI on average over-predicted EH MMIs by less than 8 percent indicating a significant improvement over the previous validations of 30 to 40 percent (first validation) and 12 to 15 percent (second validation). Systematic errors were now reduced to only 16.6 percent of the MSE error, reflecting a 49 percent decrease in error from the Draft MMI without new macroinvertebrate metrics (second validation). Based on all three statistical tests, the overall accuracy of updated Draft MMI was significantly improved by the addition of new macroinvertebrate metrics (see Section 3.2.4).
- The capacity of the WC MMI to explain observed variations in EH MMI was tested for IW sites in 2012. Even when both EC effects and the new macroinvertebrate metrics were included in the EH MMI for 2012, the WC MMI explained only approximately 32 percent of the variation in EH MMI. This indicates that additional metrics, including the evaluation of separate disturbance gradients, should be explored to provide a stronger stressor response model describing the health of GSL IWs.

## 4.1 Next Steps

It is recommended that UDWQ move forward with the updated MMI as described in this study that incorporates the new macroinvertebrate metrics, with the caveat that further consideration be given to exploration and potential inclusion of additional metrics to improve the MMI. Suggested next steps in improving the IW MMI include consideration of metrics that describe additional lines of evidence including, but not limited to, water/sediment chemistry (ammonia) toxicity potential, pH and sediment organic matter, sediment toxicity (heavy metals, sulfate), and zooplankton. Based on analysis completed to date for 2012 IW data, it appears that focusing first on exploration of biotic responses to pH would be warranted. In addition, the effects of inter-annual and intra-annual variations in hydrology including the evaluation of effects of wet year versus dry year, residence time, water depth, and operational/maintenance characteristics of each IW site will further benefit MMI refinement by highlighting potential covariates/metrics that could be considered.

## 4.2 Acknowledgements

We thank Larry Gray, Utah Valley University, for providing data on the new macroinvertebrate metrics and for input on the macroinvertebrate component of the MMI, and Jeff Ostermiller and Toby Hooker, UDWQ, for discussion and input that markedly shaped the analyses completed.

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## Appendix A
# Supporting Tables

TABLE A1
Observed WC MMI for 2012 Impounded Wetland Sites and Constituent Water Parameter MMIs

| Storet Identification | Site Name | TSS MMI | Chlorophyll-a MMI | DO MMI | Phosphorus MMI | Nitrogen MMI | Average Chemistry MMI | 2012 WC MMI |
|---|---|---|---|---|---|---|---|---|
| 5971040 | ISSR SW POND | 80 | 95 | 56 | 95 | 63 | 78 | 84 |
| 5971050 | HDC1 | 99 | 100 | 84 | 30 | 80 | 79 | 85 |
| 5971060 | UNIT 7 | 99 | 94 | 57 | 53 | 93 | 79 | 85 |
| 5971070 | LFDC1 | 95 | 100 | 33 | 76 | 88 | 79 | 84 |
| 5971080 | HDC2 | 98 | 93 | 28 | 10 | 49 | 56 | 60 |
| 5971090 | TURPIN UNIT FBWMA | 88 | 94 | 58 | 75 | 92 | 81 | 88 |
| 5971100 | LFDC2 | 100 | 100 | 69 | 72 | 90 | 86 | 93 |
| 5971110 | LFDC3 | 84 | 100 | 40 | 73 | 90 | 77 | 83 |
| 5971120 | NSDC1 | 89 | 81 | 51 | 82 | 78 | 76 | 82 |
| 5971130 | ISSR WEST B POND | 89 | 91 | 39 | 80 | 65 | 73 | 78 |
| 5971140 | RDC | 100 | 99 | 86 | 29 | 92 | 81 | 87 |
| 5971160 | NSDC2 | 97 | 85 | 42 | 60 | 90 | 75 | 81 |
| 5971170 | NPDC1 | 100 | 99 | 52 | 71 | 90 | 82 | 89 |
| 5971190 | LFDC4 | 99 | 100 | 42 | 89 | 84 | 83 | 89 |
| 5971210 | NPDC2 | 98 | 100 | 44 | 55 | - | 74 | 80 |
| 5971220 | NPDC3 | 100 | 99 | 69 | 38 | 90 | 79 | 85 |
| 5971230 | HDC3 | 100 | 100 | 95 | 65 | 89 | 90 | 96 |
| 5971270 | BIG BEAR | 88 | 95 | 45 | 94 | 78 | 80 | 86 |
| 5971300 | TRADE LAKE | 92 | 92 | 79 | 89 | 83 | 87 | 94 |
| 5971330 | UNIT3 | 96 | 94 | 62 | 97 | 82 | 86 | 92 |
| 5971340 | N GEDDYS | 98 | 99 | 75 | 99 | 89 | 92 | 99 |
| 5971360 | STELLA MARSH | 99 | 99 | 88 | 95 | 85 | 93 | 100 |
| 5971370 | UNIT 4 | 92 | 84 | 44 | 89 | 84 | 79 | 85 |
| 5971380 | GARD POND | 98 | 100 | 59 | 87 | 86 | 86 | 93 |
| 5971390 | HULL LAKE | 86 | 98 | 30 | 93 | 87 | 79 | 85 |
| 5971400 | UNIT 5 | — | — | — | — | — | — | — |
| 5971410 | BRCC NE | 95 | 95 | 71 | 90 | 70 | 84 | 91 |
| 5971440 | UNIT 35 | 95 | 97 | 50 | 94 | 86 | 84 | 91 |
| 5971450 | SHALLOW | 95 | 97 | 53 | 96 | 87 | 86 | 92 |
| 5971470 | CORPORATION POND | 85 | 96 | 47 | 89 | 67 | 77 | 83 |
| 5971480 | UNIT 3N | 88 | 56 | 62 | 87 | 81 | 75 | 80 |
| 5971490 | BRCCN | 98 | 97 | 64 | 96 | 91 | 89 | 96 |

TABLE A1
Observed WC MMI for 2012 Impounded Wetland Sites and Constituent Water Parameter MMIs

| Storet Identification | Site Name | TSS MMI | Chlorophyll-a MMI | DO MMI | Phosphorus MMI | Nitrogen MMI | Average Chemistry MMI | 2012 WC MMI |
|---|---|---|---|---|---|---|---|---|
| 5971510 | BRCC SE | 97 | 97 | 76 | 93 | 87 | 90 | 97 |
| 5971530 | WIDGEON | 98 | 97 | 36 | 98 | 87 | 83 | 89 |
| 5971540 | UNIT IN | 60 | 16 | 42 | 70 | 81 | 54 | 58 |
| 5971560 | FB NE POND | 98 | 98 | 43 | 98 | 96 | 87 | 93 |
| 5971570 | SOUTH AREA | 86 | 98 | 32 | 21 | 89 | 65 | 70 |
| 5971590 | BIG POND FBWMA | 92 | 94 | 85 | 92 | 90 | 91 | 97 |
| 5971640 | HS-S | 99 | 100 | 47 | 85 | 90 | 84 | 91 |
| 5971650 | RMP POND | — | — | — | — | — | — | — |
| 5971660 | UNIT 2 FBWMA | 99 | 99 | 46 | 77 | 91 | 82 | 88 |
| 5971670 | MAIN UNIT EAST | 91 | 93 | 37 | 93 | 87 | 80 | 86 |
| 5971680 | WEBER DELTA | 91 | 53 | 50 | 84 | 92 | 74 | 80 |
| 5971690 | HSE | 73 | 97 | 22 | 72 | 69 | 67 | 72 |
| 5971700 | UNIT 1 NW | — | — | — | — | — | — | — |
| 5971710 | FBS | 85 | 89 | 19 | 33 | 36 | 52 | 56 |
| 5971720 | STEEDS POND | 43 | 64 | 41 | 83 | 88 | 64 | 69 |
| 5971730 | UNIT 3 | 99 | 96 | 100 | 84 | 80 | 92 | 99 |
| 5971740 | FBS UNIT 1 | 95 | 93 | 37 | 70 | 86 | 76 | 82 |
| 5971750 | NSOC WALK IN | 44 | 2 | — | 72 | 90 | 52 | 56 |
| 5971770 | FB UNIT 1 | 100 | 99 | 6 | 56 | 87 | 70 | 75 |
| 5971780 | FB SE UNIT 1 | 95 | 96 | 55 | 79 | 90 | 83 | 90 |
| 5971850 | W100 | 100 | 100 | 33 | 76 | 84 | 79 | 85 |

**Notes:**
DO = dissolved oxygen
MMI = multi-metric index
TSS = total suspended solids
WC = water chemistry
WC MMI could not be estimated in Unit 5, RMP, and Unit 1 NW impounded wetlands sites because of missing data.

TABLE A2
Observed Biotic and EH MMIs for Impounded Wetland Sites – 2012

| Storet Identification | Site Name | SAV MMI | Surface Mat MMI | Macroinvertebrate MMI | EH MMI |
|---|---|---|---|---|---|
| 5971040 | ISSR SW POND | 20 | 20 | 28 | 23 |
| 5971050 | HDC1 | 87 | 60 | 68 | 72 |
| 5971060 | UNIT 7 | 100 | 20 | 84 | 68 |
| 5971070 | LFDC1 | 100 | 100 | 84 | 95 |
| 5971080 | HDC2 | 100 | 20 | 60 | 60 |
| 5971090 | TURPIN UNIT FBWMA | 73 | 100 | 68 | 80 |
| 5971100 | LFDC2 | 100 | 60 | 84 | 81 |
| 5971110 | LFDC3 | 60 | 100 | 84 | 81 |
| 5971120 | NSDC1 | 60 | 100 | 60 | 73 |
| 5971130 | ISSR WEST B POND | 20 | 100 | 28 | 49 |
| 5971140 | RDC | 73 | 20 | 92 | 62 |
| 5971160 | NSDC2 | 73 | 60 | 84 | 72 |
| 5971170 | NPDC1 | 20 | 60 | 100 | 60 |
| 5971190 | LFDC4 | 60 | 60 | 52 | 57 |
| 5971210 | NPDC2 | 47 | 20 | 68 | 45 |
| 5971220 | NPDC3 | 100 | 60 | 76 | 79 |
| 5971230 | HDC3 | 100 | 60 | 76 | 79 |
| 5971270 | BIG BEAR | 73 | 100 | 60 | 78 |
| 5971300 | TRADE LAKE | 47 | 100 | 76 | 74 |
| 5971330 | UNIT3 | 73 | 100 | 44 | 72 |
| 5971340 | N GEDDYS | 100 | 100 | 28 | 76 |
| 5971360 | STELLA MARSH | 100 | 60 | 68 | 76 |
| 5971370 | UNIT 4 | 20 | 60 | 52 | 44 |
| 5971380 | GARD POND | 100 | 100 | 60 | 87 |
| 5971390 | HULL LAKE | 33 | 100 | 36 | 56 |
| 5971400 | UNIT 5 | — | 100 | 68 | 84 |
| 5971410 | BRCC NE | 73 | 60 | 44 | 59 |
| 5971440 | UNIT 35 | 73 | 100 | 44 | 72 |
| 5971450 | SHALLOW | 100 | 100 | 28 | 76 |
| 5971470 | CORPORATION POND | 47 | 60 | 28 | 45 |
| 5971480 | UNIT 3N | 20 | 100 | 52 | 57 |
| 5971490 | BRCCN | 60 | 100 | 52 | 71 |

TABLE A2
Observed Biotic and EH MMIs for Impounded Wetland Sites – 2012

| Storet Identification | Site Name | SAV MMI | Surface Mat MMI | Macroinvertebrate MMI | EH MMI |
|---|---|---|---|---|---|
| 5971510 | BRCC SE | 87 | 20 | 68 | 58 |
| 5971530 | WIDGEON | 73 | 100 | 52 | 75 |
| 5971540 | UNIT IN | — | 20 | 28 | 24 |
| 5971560 | FB NE POND | 47 | 60 | 52 | 53 |
| 5971570 | SOUTH AREA | 47 | 100 | 76 | 74 |
| 5971590 | BIG POND FBWMA | 20 | 100 | 20 | 47 |
| 5971640 | HS-S | 73 | 20 | 60 | 51 |
| 5971650 | RMP POND | — | 20 | 52 | 36 |
| 5971660 | UNIT 2 FBWMA | 47 | 20 | 76 | 48 |
| 5971670 | MAIN UNIT EAST | 60 | 100 | 52 | 71 |
| 5971680 | WEBER DELTA | — | 100 | 20 | 60 |
| 5971690 | HSE | 47 | 100 | 20 | 56 |
| 5971700 | UNIT 1 NW | — | 100 | 28 | 64 |
| 5971710 | FBS | 20 | 100 | 20 | 47 |
| 5971720 | STEEDS POND | 47 | 100 | 20 | 56 |
| 5971730 | UNIT 3 | 100 | 100 | 52 | 84 |
| 5971740 | FBS UNIT 1 | 87 | 20 | 76 | 61 |
| 5971750 | NSDC WALK IN | — | 100 | 20 | 60 |
| 5971770 | FB UNIT 1 | 73 | 20 | 68 | 54 |
| 5971780 | FB SE UNIT 1 | 73 | 60 | 52 | 62 |
| 5971850 | W100 | 100 | 100 | 76 | 92 |

**Notes:**
EH = ecosystem health
MMI = multi-metric index
SAV = submerged aquatic vegetation

TABLE A3
Draft MMI Data for Great Salt Lake Impounded Wetlands Sites, 2003 to 2009 (UDEQ, 2009)

| Storet Identification | Site Name | EH MMI | WC MMI |
|---|---|---|---|
| 4985320 | Farmington Wetlands Ambassador W 1 | 56 | 58 |
| 4985330 | Farmington Wetlands Ambassador 100 | 87 | 86 |
| 4985340 | Farmington Wetlands Ambassador W 2 | 94 | 91 |
| 4985350 | Farmington Wetlands Ambassador W 5 | 90 | 88 |
| 4985430 | Farmington Wetlands South B Pond | 100 | 83 |
| 4985440 | Farmington Wetlands West A Pond | 67 | 61 |
| 4985465 | IMPC Conservation Easement | 100 | 68 |
| 4985500 | Farmington Wetlands FBWMA Unit 2 Outfall | 68 | 74 |
| 4985520 | Farmington Wetlands FBWMA Unit 1 Outfall | 67 | 98 |
| 4985620 | GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall | 90 | 84 |
| 4985630 | GSL Wetlands Public Shooting Ground Pintail Lake Outfall | 98 | 100 |
| 4985655 | Bear River NWR Pond 4C Outfall | 100 | 92 |
| 4985860 | Newstate Duck Club Middle Unit | 83 | 84 |
| 4985870 | GSL Wetlands Newstate Duck Club Pond 47 | 51 | 45 |
| 4985880 | GSL Wetlands Newstate Duck Club Pond 20 | 91 | 85 |
| 4985890 | GSL Wetlands Newstate Duck Club Unit 5-6 | 76 | 60 |

**Notes:**
EH = ecosystem health
MMI = multi-metric index
WC = water chemistry

TABLE A4
2012 Water Chemistry and Ecosystem Health MMI Observations in Impounded Wetlands of the Great Salt Lake and EH MMI Predicted for 2012 Sites from the Draft MMI
*Data for the first statistical validation of the Draft MMI*

| Storet Identification | Site Name | Draft MMI Model Input<br>Observed 2012 WC MMI[1] | Independent Observations<br>Observed 2012 EH MMI[2] | Draft MMI Model Output<br>Predicted 2012 EH MMI[3] |
|---|---|---|---|---|
| 5971040 | ISSR SW POND | 84 | 23 | 86 |
| 5971050 | HDC1 | 85 | 72 | 87 |
| 5971060 | UNIT 7 | 85 | 68 | 87 |
| 5971070 | LFDC1 | 84 | 95 | 86 |
| 5971080 | HDC2 | 60 | 60 | 70 |
| 5971090 | TURPIN UNIT FBWMA | 88 | 80 | 89 |
| 5971100 | LFDC2 | 93 | 81 | 92 |
| 5971110 | LFDC3 | 83 | 81 | 86 |
| 5971120 | NSDC1 | 82 | 73 | 85 |
| 5971130 | ISSR WEST B POND | 78 | 49 | 82 |
| 5971140 | RDC | 87 | 62 | 88 |
| 5971160 | NSDC2 | 81 | 72 | 84 |
| 5971170 | NPDC1 | 89 | 60 | 89 |
| 5971190 | LFDC4 | 89 | 57 | 90 |
| 5971210 | NPDC2 | 80 | 45 | 83 |
| 5971220 | NPDC3 | 85 | 79 | 87 |
| 5971230 | HDC3 | 96 | 79 | 95 |
| 5971270 | BIG BEAR | 86 | 78 | 87 |
| 5971300 | TRADE LAKE | 94 | 74 | 93 |
| 5971330 | UNIT3 | 92 | 72 | 92 |
| 5971340 | N GEDDYS | 99 | 76 | 96 |
| 5971360 | STELLA MARSH | 100 | 76 | 97 |
| 5971370 | UNIT 4 | 85 | 44 | 87 |
| 5971380 | GARD POND | 93 | 87 | 92 |
| 5971390 | HULL LAKE | 85 | 56 | 87 |
| 5971400 | UNIT 5 | — | 84 | — |
| 5971410 | BRCC NE | 91 | 59 | 91 |
| 5971440 | UNIT 35 | 91 | 72 | 91 |
| 5971450 | SHALLOW | 92 | 76 | 92 |
| 5971470 | CORPORATION POND | 83 | 45 | 85 |

TABLE A4
2012 Water Chemistry and Ecosystem Health MMI Observations in Impounded Wetlands of the Great Salt Lake and EH MMI Predicted for 2012 Sites from the Draft MMI
*Data for the first statistical validation of the Draft MMI*

| | | **Draft MMI Model Input** | **Independent Observations** | **Draft MMI Model Output** |
|---|---|---|---|---|
| **Storet Identification** | **Site Name** | **Observed 2012 WC MMI[1]** | **Observed 2012 EH MMI[2]** | **Predicted 2012 EH MMI[3]** |
| 5971480 | UNIT 3N | 80 | 57 | 84 |
| 5971490 | BRCCN | 96 | 71 | 94 |
| 5971510 | BRCC SE | 97 | 58 | 95 |
| 5971530 | WIDGEON | 89 | 75 | 90 |
| 5971540 | UNIT IN | 58 | 24 | 68 |
| 5971560 | FB NE POND | 93 | 53 | 92 |
| 5971570 | SOUTH AREA | 70 | 74 | 77 |
| 5971590 | BIG POND FBWMA | 97 | 47 | 95 |
| 5971640 | HS-S | 91 | 51 | 91 |
| 5971650 | RMP POND | — | 36 | — |
| 5971660 | UNIT 2 FBWMA | 88 | 48 | 89 |
| 5971670 | MAIN UNIT EAST | 86 | 71 | 88 |
| 5971680 | WEBER DELTA | 80 | 60 | 83 |
| 5971690 | HSE | 72 | 56 | 78 |
| 5971700 | UNIT 1 NW | — | 64 | — |
| 5971710 | FBS | 56 | 47 | 67 |
| 5971720 | STEEDS POND | 69 | 56 | 76 |
| 5971730 | UNIT 3 | 99 | 84 | 96 |
| 5971740 | FBS UNIT 1 | 82 | 61 | 85 |
| 5971750 | NSDC WALK IN | 56 | 60 | 67 |
| 5971770 | FB UNIT 1 | 75 | 54 | 80 |
| 5971780 | FB SE UNIT 1 | 90 | 62 | 90 |
| 5971850 | W100 | 85 | 92 | 87 |

**Notes:**
[1]Observed WC MMI is the MMI calculated from WC data collected in 2012.
[2]Observed EH MMI is the EH MMI calculated using biotic MMI (SAV, Surface Mat, and Macroinvertebrates) data collected in 2012.
[3]EH MMIs were predicted from the Draft MMI model (see Figure 7) using the observed WC MMIs for each site.
EH = ecosystem health
MMI = multi-metric index
SAV = submerged aquatic vegetation
WC = water chemistry
Missing chemistry data in Unit 5, RMP, and Unit 1 NW impounded wetlands sites excluded those sites from the Draft MMI validation.

TABLE A5
EC-adjusted EH MMI Compared to EH MMI Predicted with the Draft MMI
*Original 2012 observations of EH MMIs and WC MMIs used as input in the Draft MMI are also shown*

| Storet Identification | Site Name | Observed 2012 EH MMI (not EC adjusted)[4] | Draft MMI Model Input<br>Observed 2012 WC MMI[1] | Independent Observations<br>EC-adjusted EH MMI Observed in 2012[3] | Draft MMI Model Output<br>Predicted 2012 EH MMI (from Draft MMI)[2] |
|---|---|---|---|---|---|
| 5971040 | ISSR SW POND | 23 | 84 | 42 | 86 |
| 5971050 | HDC1 | 72 | 85 | 81 | 87 |
| 5971060 | UNIT 7 | 68 | 85 | 80 | 87 |
| 5971070 | LFDC1 | 95 | 84 | 94 | 86 |
| 5971080 | HDC2 | 60 | 60 | 72 | 70 |
| 5971090 | TURPIN UNIT FBWMA | 80 | 88 | 94 | 89 |
| 5971100 | LFDC2 | 81 | 93 | 95 | 92 |
| 5971110 | LFDC3 | 81 | 83 | 90 | 86 |
| 5971120 | NSDC1 | 73 | 82 | 77 | 85 |
| 5971130 | ISSR WEST B POND | 49 | 78 | 64 | 82 |
| 5971140 | RDC | 62 | 87 | 73 | 88 |
| 5971160 | NSDC2 | 72 | 81 | 84 | 84 |
| 5971170 | NPDC1 | 60 | 89 | 71 | 89 |
| 5971190 | LFDC4 | 57 | 89 | 59 | 90 |
| 5971210 | NPDC2 | 45 | 80 | 50 | 83 |
| 5971220 | NPDC3 | 79 | 85 | 91 | 87 |
| 5971230 | HDC3 | 79 | 96 | 86 | 95 |
| 5971270 | BIG BEAR | 78 | 86 | 76 | 87 |
| 5971300 | TRADE LAKE | 74 | 94 | 91 | 93 |
| 5971330 | UNIT3 | 72 | 92 | 100 | 92 |
| 5971340 | N GEDDYS | 76 | 99 | 100 | 96 |
| 5971360 | STELLA MARSH | 76 | 100 | 81 | 97 |
| 5971370 | UNIT 4 | 44 | 85 | 57 | 87 |
| 5971380 | GARD POND | 87 | 93 | 92 | 92 |
| 5971390 | HULL LAKE | 56 | 85 | 69 | 87 |
| 5971400 | UNIT 5 | 84 | — | — | — |
| 5971410 | BRCC NE | 59 | 91 | 66 | 91 |
| 5971440 | UNIT 35 | 72 | 91 | 92 | 91 |
| 5971450 | SHALLOW | 76 | 92 | 86 | 92 |
| 5971470 | CORPORATION POND | 45 | 83 | 64 | 85 |
| 5971480 | UNIT 3N | 57 | 80 | 100 | 84 |
| 5971490 | BRCCN | 71 | 96 | 88 | 94 |
| 5971510 | BRCC SE | 58 | 97 | 64 | 95 |

TABLE A5
EC-adjusted EH MMI Compared to EH MMI Predicted with the Draft MMI
*Original 2012 observations of EH MMIs and WC MMIs used as input in the Draft MMI are also shown*

| Storet Identification | Site Name | Observed 2012 EH MMI (not EC adjusted)[4] | Draft MMI Model Input<br>Observed 2012 WC MMI[1] | Independent Observations<br>EC-adjusted EH MMI Observed in 2012[3] | Draft MMI Model Output<br>Predicted 2012 EH MMI (from Draft MMI)[2] |
|---|---|---|---|---|---|
| 5971530 | WIDGEON | 75 | 89 | 91 | 90 |
| 5971540 | UNIT IN | 24 | 58 | 26 | 68 |
| 5971560 | FB NE POND | 53 | 93 | 79 | 92 |
| 5971570 | SOUTH AREA | 74 | 70 | 86 | 77 |
| 5971590 | BIG POND FBWMA | 47 | 97 | 68 | 95 |
| 5971640 | HS-S | 51 | 91 | 66 | 91 |
| 5971650 | RMP POND | 36 | — | — | — |
| 5971660 | UNIT 2 FBWMA | 48 | 88 | 55 | 89 |
| 5971670 | MAIN UNIT EAST | 71 | 86 | 76 | 88 |
| 5971680 | WEBER DELTA | 60 | 80 | 84 | 83 |
| 5971690 | HSE | 56 | 72 | 75 | 78 |
| 5971700 | UNIT 1 NW | 64 | — | — | — |
| 5971710 | FBS | 47 | 56 | 57 | 67 |
| 5971720 | STEEDS POND | 56 | 69 | 77 | 76 |
| 5971730 | UNIT 3 | 84 | 99 | 85 | 96 |
| 5971740 | FBS UNIT 1 | 61 | 82 | 71 | 85 |
| 5971750 | NSDC WALK IN | 60 | 56 | 71 | 67 |
| 5971770 | FB UNIT 1 | 54 | 75 | 59 | 80 |
| 5971780 | FB SE UNIT 1 | 62 | 90 | 72 | 90 |
| 5971850 | W100 | 92 | 85 | 96 | 87 |

**Notes:**
[1]Observed WC MMI is the MMI calculated from WC data collected in 2012.
[2]EH MMIs were predicted from the Draft MMI model (Figure 7) using the observed WC MMIs for each site.
[3]EC-adjusted observed EH MMI is the EH MMI calculated using biotic MMI (SAV, Surface Mat, and Macroinvertebrates) data collected in 2012, which was then adjusted to remove the variation in the data due to EC effects.
[4]Observed EH MMI is the EH MMI calculated using biotic MMI (SAV, surface mat, and macroinvertebrates) data collected in 2012, which was not adjusted for EC effects and is shown here for comparison purposes.
EC = electrical conductance
EH = ecosystem health
MMI = multi-metric index
SAV = submerged aquatic vegetation
WC = water chemistry
Missing chemistry data in Unit 5, RMP, and Unit 1 NW impounded wetlands sites excluded those sites from the Draft MMI validation.

TABLE A6
New EC-adjusted EH MMI for 2012 Impounded Wetland Sites Derived from Biotic Variables

| Storet Identification | Site Name | 2012 EC-adjusted SAV MMI | Surface Mat MMI | 2012 EC-adjusted NMBI | Observed 2012 EC-adjusted New EH MMI[1] |
|---|---|---|---|---|---|
| 5971040 | ISSR SW POND | 65 | 20 | 98 | 61 |
| 5971050 | HDC1 | 99 | 60 | 83 | 81 |
| 5971060 | UNIT 7 | 100 | 20 | 100 | 73 |
| 5971070 | LFDC1 | 100 | 100 | 86 | 95 |
| 5971080 | HDC2 | 100 | 20 | 72 | 64 |
| 5971090 | TURPIN UNIT FBWMA | 87 | 100 | 86 | 91 |
| 5971100 | LFDC2 | 100 | 60 | 86 | 82 |
| 5971110 | LFDC3 | 67 | 100 | 96 | 88 |
| 5971120 | NSDC1 | 63 | 100 | 91 | 85 |
| 5971130 | ISSR WEST B POND | 28 | 100 | 29 | 52 |
| 5971140 | RDC | 88 | 20 | 87 | 65 |
| 5971160 | NSDC2 | 86 | 60 | 85 | 77 |
| 5971170 | NPDC1 | 24 | 60 | 87 | 57 |
| 5971190 | LFDC4 | 62 | 60 | 75 | 66 |
| 5971210 | NPDC2 | 53 | 20 | 98 | 57 |
| 5971220 | NPDC3 | 100 | 60 | 70 | 77 |
| 5971230 | HDC3 | 100 | 60 | 80 | 80 |
| 5971270 | BIG BEAR | 63 | 100 | 100 | 88 |
| 5971300 | TRADE LAKE | 58 | 100 | 90 | 83 |
| 5971330 | UNIT3 | 100 | 100 | 100 | 100 |
| 5971340 | N GEDDYS | 100 | 100 | 90 | 97 |
| 5971360 | STELLA MARSH | 100 | 60 | 95 | 85 |
| 5971370 | UNIT 4 | 28 | 60 | 86 | 58 |
| 5971380 | GARD POND | 86 | 100 | 75 | 87 |
| 5971390 | HULL LAKE | 43 | 100 | 80 | 74 |
| 5971400 | UNIT 5 | — | 100 | — | — |
| 5971410 | BRCC NE | 83 | 60 | 67 | 70 |
| 5971440 | UNIT 35 | 100 | 100 | 100 | 100 |
| 5971450 | SHALLOW | 99 | 100 | 66 | 88 |
| 5971470 | CORPORATION POND | 75 | 60 | 100 | 78 |
| 5971480 | UNIT 3N | 44 | 100 | 79 | 74 |

TABLE A6
New EC-adjusted EH MMI for 2012 Impounded Wetland Sites Derived from Biotic Variables

| Storet Identification | Site Name | 2012 EC-adjusted SAV MMI | Surface Mat MMI | 2012 EC-adjusted NMBI | Observed 2012 EC-adjusted New EH MMI[1] |
|---|---|---|---|---|---|
| 5971490 | BRCCN | 81 | 100 | 82 | 88 |
| 5971510 | BRCC SE | 96 | 20 | 66 | 61 |
| 5971530 | WIDGEON | 94 | 100 | 100 | 98 |
| 5971540 | UNIT IN | — | 20 | 17 | 19 |
| 5971560 | FB NE POND | 73 | 60 | 90 | 74 |
| 5971570 | SOUTH AREA | 55 | 100 | 54 | 70 |
| 5971590 | BIG POND FBWMA | 30 | 100 | 29 | 53 |
| 5971640 | HS-S | 97 | 20 | 95 | 71 |
| 5971650 | RMP POND | — | 20 | — | — |
| 5971660 | UNIT 2 FBWMA | 54 | 20 | 100 | 58 |
| 5971670 | MAIN UNIT EAST | 65 | 100 | 66 | 77 |
| 5971680 | WEBER DELTA | | 100 | 28 | 64 |
| 5971690 | HSE | 65 | 100 | 27 | 64 |
| 5971700 | UNIT 1 NW | — | 100 | — | — |
| 5971710 | FBS | 25 | 100 | 24 | 50 |
| 5971720 | STEEDS POND | 67 | 100 | 28 | 65 |
| 5971730 | UNIT 3 | 97 | 100 | 84 | 94 |
| 5971740 | FBS UNIT 1 | 100 | 20 | 70 | 63 |
| 5971750 | NSDC WALK IN | — | 100 | 24 | 62 |
| 5971770 | FB UNIT 1 | 81 | 20 | 66 | 56 |
| 5971780 | FB SE UNIT 1 | 86 | 60 | 85 | 77 |
| 5971850 | W100 | 88 | 100 | 77 | 88 |

**Notes:**

[1]EC-adjusted observed EH MMI was estimated as the average of Surface Mat MMI, EC-adjusted SAV MMI, and the new EC-adjusted Macroinvertebrate MMI, based on actual independent data that was collected at impounded wetlands sites in 2012.

EC = electrical conductance
EH = ecosystem health
MMI = multi-metric index
NMBI = new Macroinvertebrate MMI
SAV = submerged aquatic vegetation

TABLE A7
New EC-adjusted EH MMI Observations Compared to EH MMI Predicted Using the Updated MMI

| Storet Identification | Site Name | Observed 2012 New EH MMI[1] | Updated MMI Model Input<br>Observed 2012 WC MMI[2] | Independent Observations<br>EC-adjusted EH MMI Observed in 2012[4] | Updated MMI Model Output<br>Predicted 2012 EH MMI[3] |
|---|---|---|---|---|---|
| 5971040 | ISSR SW POND | 20 | 84 | 61 | 79 |
| 5971050 | HDC1 | 73 | 85 | 81 | 80 |
| 5971060 | UNIT 7 | 73 | 85 | 73 | 80 |
| 5971070 | LFDC1 | 96 | 84 | 95 | 79 |
| 5971080 | HDC2 | 60 | 60 | 64 | 55 |
| 5971090 | TURPIN UNIT FBWMA | 82 | 88 | 91 | 83 |
| 5971100 | LFDC2 | 78 | 93 | 82 | 88 |
| 5971110 | LFDC3 | 82 | 83 | 88 | 78 |
| 5971120 | NSDC1 | 82 | 82 | 85 | 77 |
| 5971130 | ISSR WEST B POND | 47 | 78 | 52 | 73 |
| 5971140 | RDC | 56 | 87 | 65 | 82 |
| 5971160 | NSDC2 | 69 | 81 | 77 | 76 |
| 5971170 | NPDC1 | 51 | 89 | 57 | 84 |
| 5971190 | LFDC4 | 64 | 89 | 66 | 84 |
| 5971210 | NPDC2 | 51 | 80 | 57 | 75 |
| 5971220 | NPDC3 | 73 | 85 | 77 | 80 |
| 5971230 | HDC3 | 78 | 96 | 80 | 92 |
| 5971270 | BIG BEAR | 78 | 86 | 88 | 81 |
| 5971300 | TRADE LAKE | 73 | 94 | 83 | 89 |
| 5971330 | UNIT3 | 87 | 92 | 100 | 88 |
| 5971340 | N GEDDYS | 82 | 99 | 97 | 94 |
| 5971360 | STELLA MARSH | 82 | 100 | 85 | 95 |
| 5971370 | UNIT 4 | 47 | 85 | 58 | 80 |
| 5971380 | GARD POND | 96 | 93 | 87 | 88 |
| 5971390 | HULL LAKE | 64 | 85 | 74 | 80 |
| 5971400 | UNIT 5 | 87 | — | — | — |
| 5971410 | BRCC NE | 64 | 91 | 70 | 86 |
| 5971440 | UNIT 35 | 87 | 91 | 100 | 86 |
| 5971450 | SHALLOW | 78 | 92 | 88 | 87 |
| 5971470 | CORPORATION POND | 56 | 83 | 78 | 78 |
| 5971480 | UNIT 3N | 51 | 80 | 74 | 75 |
| 5971490 | BRCCN | 73 | 96 | 88 | 91 |
| 5971510 | BRCC SE | 56 | 97 | 61 | 92 |
| 5971530 | WIDGEON | 87 | 89 | 98 | 84 |

TABLE A7
New EC-adjusted EH MMI Observations Compared to EH MMI Predicted Using the Updated MMI

| Storet Identification | Site Name | Observed 2012 New EH MMI[1] | Updated MMI Model Input<br>Observed 2012 WC MMI[2] | Independent Observations<br>EC-adjusted EH MMI Observed in 2012[4] | Updated MMI Model Output<br>Predicted 2012 EH MMI[3] |
|---|---|---|---|---|---|
| 5971540 | UNIT IN | 20 | 58 | 19 | 53 |
| 5971560 | FB NE POND | 56 | 93 | 74 | 88 |
| 5971570 | SOUTH AREA | 64 | 70 | 70 | 65 |
| 5971590 | BIG POND FBWMA | 47 | 97 | 53 | 93 |
| 5971640 | HS-S | 56 | 91 | 71 | 86 |
| 5971650 | RMP POND | 20 | — | — | — |
| 5971660 | UNIT 2 FBWMA | 51 | 88 | 58 | 84 |
| 5971670 | MAIN UNIT EAST | 73 | 86 | 77 | 81 |
| 5971680 | WEBER DELTA | 60 | 80 | 64 | 75 |
| 5971690 | HSE | 56 | 72 | 64 | 67 |
| 5971700 | UNIT 1 NW | 60 | — | — | — |
| 5971710 | FBS | 47 | 56 | 50 | 52 |
| 5971720 | STEEDS POND | 56 | 69 | 65 | 64 |
| 5971730 | UNIT 3 | 96 | 99 | 94 | 94 |
| 5971740 | FBS UNIT 1 | 56 | 82 | 63 | 77 |
| 5971750 | NSDC WALK IN | 60 | 56 | 62 | 51 |
| 5971770 | FB UNIT 1 | 51 | 75 | 56 | 70 |
| 5971780 | FB SE UNIT 1 | 69 | 90 | 77 | 85 |
| 5971850 | W100 | 96 | 85 | 88 | 80 |

**Notes:**

[1]Based on actual data collected from impounded wetlands sites in 2012, and includes new macroinvertebrate metrics─MMI is not adjusted for salinity (EC) effects and is provided here for comparison.

[2]Observed WC MMI is the MMI calculated from WC data collected from impounded wetlands sites in 2012.

[3]EH MMIs were predicted from the updated MMI model (see Figure 14) using the observed WC MMIs for each site.

[4]EC-adjusted observed EH MMI is the EH MMI calculated using EC-adjusted biotic MMI (SAV and new Macroinvertebrate) and non-adjusted surface mat data collected in 2012.

EC = electrical conductance
EH = ecosystem health
MMI = multi-metric index
SAV = submerged aquatic vegetation
WC = water chemistry
Missing chemistry data in Unit 5, RMP and Unit 1 NW impounded wetlands sites excluded those sites from the Draft MMI validation.

TABLE A8
New EH MMI Observations without EC Adjustments, Compared to EH MMI Predicted Using the Updated MMI

| Storet Identification | Site Name | Observed 2012 New EH MMI[1] | Updated MMI Model Input<br>Observed 2012 WC MMI[2] | Updated MMI Model Output<br>Predicted 2012 EH MMI[3] |
|---|---|---|---|---|
| 5971040 | ISSR SW POND | 20 | 84 | 79 |
| 5971050 | HDC1 | 73 | 85 | 80 |
| 5971060 | UNIT 7 | 73 | 85 | 80 |
| 5971070 | LFDC1 | 96 | 84 | 79 |
| 5971080 | HDC2 | 60 | 60 | 55 |
| 5971090 | TURPIN UNIT FBWMA | 82 | 88 | 83 |
| 5971100 | LFDC2 | 78 | 93 | 88 |
| 5971110 | LFDC3 | 82 | 83 | 78 |
| 5971120 | NSDC1 | 82 | 82 | 77 |
| 5971130 | ISSR WEST B POND | 47 | 78 | 73 |
| 5971140 | RDC | 56 | 87 | 82 |
| 5971160 | NSDC2 | 69 | 81 | 76 |
| 5971170 | NPDC1 | 51 | 89 | 84 |
| 5971190 | LFDC4 | 64 | 89 | 84 |
| 5971210 | NPDC2 | 51 | 80 | 75 |
| 5971220 | NPDC3 | 73 | 85 | 80 |
| 5971230 | HDC3 | 78 | 96 | 92 |
| 5971270 | BIG BEAR | 78 | 86 | 81 |
| 5971300 | TRADE LAKE | 73 | 94 | 89 |
| 5971330 | UNIT3 | 87 | 92 | 88 |
| 5971340 | N GEDDYS | 82 | 99 | 94 |
| 5971360 | STELLA MARSH | 82 | 100 | 95 |
| 5971370 | UNIT 4 | 47 | 85 | 80 |
| 5971380 | GARD POND | 96 | 93 | 88 |
| 5971390 | HULL LAKE | 64 | 85 | 80 |
| 5971400 | UNIT 5 | 87 | — | — |
| 5971410 | BRCC NE | 64 | 91 | 86 |
| 5971440 | UNIT 35 | 87 | 91 | 86 |
| 5971450 | SHALLOW | 78 | 92 | 87 |
| 5971470 | CORPORATION POND | 56 | 83 | 78 |

TABLE A8
New EH MMI Observations without EC Adjustments, Compared to EH MMI Predicted Using the Updated MMI

| Storet Identification | Site Name | Observed 2012 New EH MMI[1] | Updated MMI Model Input<br>Observed 2012 WC MMI[2] | Updated MMI Model Output<br>Predicted 2012 EH MMI[3] |
|---|---|---|---|---|
| 5971480 | UNIT 3N | 51 | 80 | 75 |
| 5971490 | BRCCN | 73 | 96 | 91 |
| 5971510 | BRCC SE | 56 | 97 | 92 |
| 5971530 | WIDGEON | 87 | 89 | 84 |
| 5971540 | UNIT IN | 20 | 58 | 53 |
| 5971560 | FB NE POND | 56 | 93 | 88 |
| 5971570 | SOUTH AREA | 64 | 70 | 65 |
| 5971590 | BIG POND FBWMA | 47 | 97 | 93 |
| 5971640 | HS-S | 56 | 91 | 86 |
| 5971650 | RMP POND | 20 | — | — |
| 5971660 | UNIT 2 FBWMA | 51 | 88 | 84 |
| 5971670 | MAIN UNIT EAST | 73 | 86 | 81 |
| 5971680 | WEBER DELTA | 60 | 80 | 75 |
| 5971690 | HSE | 56 | 72 | 67 |
| 5971700 | UNIT 1 NW | 60 | — | — |
| 5971710 | FBS | 47 | 56 | 52 |
| 5971720 | STEEDS POND | 56 | 69 | 64 |
| 5971730 | UNIT 3 | 96 | 99 | 94 |
| 5971740 | FBS UNIT 1 | 56 | 82 | 77 |
| 5971750 | NSDC WALK IN | 60 | 56 | 51 |
| 5971770 | FB UNIT 1 | 51 | 75 | 70 |
| 5971780 | FB SE UNIT 1 | 69 | 90 | 85 |
| 5971850 | W100 | 96 | 85 | 80 |

**Notes:**
[1]Based on actual data collected from impounded wetlands sites in 2012, and includes new macroinvertebrate metrics—MMI is not adjusted for salinity (EC) effects.
[2]Observed WC MMI is the MMI calculated from WC data collected from IW sites in 2012.
[3]EH MMIs were predicted from the updated MMI model (see Figure 14) using the observed WC MMIs for each site.
EC = electrical conductance
EH = ecosystem health
MMI = multi-metric index
WC = water chemistry
Missing chemistry data in Unit 5, RMP and Unit 1 NW impounded wetlands sites excluded those sites from the Draft MMI validation.

TABLE A9
MMI Data Summary for the Draft (2003 to 2009) and 2012 Datasets

| MMI Data Summary | Min | Percentiles | | | Max. |
|---|---|---|---|---|---|
| | | 25th | 50th (Median) | 75th | |
| **Draft MMI Data (2003 to 2009)** | | | | | |
| Chemistry MMI | 45 | 67 | 84 | 89 | 100 |
| SAV MMI | 33 | 57 | 93 | 100 | 100 |
| Surface Mat MMI | 40 | 75 | 80 | 100 | 100 |
| Macroinvertebrate MMI | 68 | 81 | 88 | 94 | 100 |
| Ecosystem Health MMI | 51 | 68 | 88 | 95 | 100 |
| New Macroinvertebrate MMI[1] | 20 | 60 | 73 | 73 | 87 |
| Updated Ecosystem Health MMI[2] | 31 | 70 | 80 | 90 | 100 |
| **2012 Survey Data** | | | | | |
| Chemistry MMI | 56 | 81 | 86 | 92 | 100 |
| SAV MMI | 20 | 47 | 73 | 93 | 100 |
| Surface Mat MMI | 20 | 60 | 100 | 100 | 100 |
| Macroinvertebrate MMI | 20 | 36 | 52 | 76 | 100 |
| Ecosystem Health MMI | 23 | 56 | 62 | 76 | 95 |
| New Macroinvertebrate MMI[1] | 20 | 47 | 60 | 73 | 100 |
| Updated Ecosystem Health MMI[2] | 20 | 56 | 64 | 78 | 96 |

**Notes:**
[1] Based on macroinvertebrate metrics, including PMI, COTE, and Simpson’s Diversity Index
[2] Includes New Macroinvertebrate MMI
Max. = maximum
MMI = multi-metric index
SAV = submerged aquatic vegetation