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TECHNICAL MEMORANDUM

TO: Water Quality Board

FROM: Jeff Ostermiller

DATE: *10/13/2010*

SUBJECT: Evaluating the ecological threat of the of the Perry-Willard Discharge to the Willard Spur of Great Salt Lake

Summary
Estimates of potential effects of the Willard-Perry effluent on the Willard Spur ecosystem were made using a biological assessment tool under development for the managed, impounded wetlands of Great Salt Lake. These analyses necessitated numerous assumptions and conclusions and are preliminary, however, these estimates suggest that the ecosystem could be threatened if the discharge proceeded as originally planned. Alternatively, exercising the precautionary principle—minimizing effluent volume and nutrient concentrations—appears to pose little threat over the first 5-years of operation. If the precautionary alternative were implemented, DWQ could instigate studies necessary to develop appropriately protective site-specific standards to ensure the long-term protection of Willard Spur. In the interim, monitoring would be conducted to identify unanticipated negative consequences associated with the interim precautionary solution.

Introduction

DWQ recently calculated estimates of nutrient concentration increases in Willard Spur anticipated from the addition of the Perry-Willard effluent [von Stackelberg Technical Memo, 9/30/2010]. To evaluate the ecological risk of the discharge to the receiving waters requires linking projected increases in nutrient concentrations with estimates of potential alterations to the biological condition of Willard Spur. The purpose of this technical memorandum is to summarize an investigation that was recently conducted to estimate—with existing and readily available data— the extent to which the Willard-Perry discharge represents a threat to Willard Spur's biological designated uses.

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For several years DWQ has conducted research on the extent to which water quality—particularly nutrient enrichment—represents a threat to the support of aquatic life uses of Great Salt Lake (GSL) wetlands. One product of this research is a recently developed Multi-Metric Index (MMI) for Great Salt Lake Wetland ponds impounded by manmade dike (hereafter impounded wetlands), which uses multiple lines of evidence to quantify wetland condition. DWQ is currently in the process of validating this model, which will ultimately provide a method for directly evaluating narrative criteria. Also, the model was developed for impounded wetlands, which are hydrologically similar to Willard Spur at low lake levels during summer months, but not during high lake levels or during winter months when Willard Spur is directly connected to Bear River Bay of Great Salt Lake (USFWS pers. comm.). Despite these limitations, the MMI remains the best tool available to the potential impacts of Perry Willard effluent on the Willard Spur of GSL.

Details and the scientific underpinnings of the development of this MMI are provided elsewhere (http://www.deq.utah.gov/Issues/gslwetlands/assessment.htm). Here we provide a brief summary as background to the analytical methods discussed in this memorandum. The current MMI uses four lines of evidence (metrics) to quantify relative wetland conditions; one chemical and two biological (submerged aquatic vegetation, surface mats, and macroinvertebrates). Each of these primary lines of evidence consists of several constituent measures (constituent metrics) of condition. Each metric and all constituent metrics were rescaled and rescored on a scale of 1-100, with 100 representing the best condition observed among all wetlands. Although the number of wetlands uses to develop the MMI was limited (N=16), these wetlands were selected to encompass the range of conditions observed among wetlands.

These investigations focus on estimated biological responses to increased nutrient enrichment that can be anticipated from the effluent for two reasons. Preliminary observations for other GSL wetlands suggest that excessive nutrient enrichment can potentially impair wetland ecosystems. Second, nutrients are among the primary constituents of the Willard-Perry discharge that are already addressed with numeric water quality standards and associated permit limits. Also, for the purpose of these analyses, biological responses are limited to Submerged Aquatic Vegetation (SAV) and surface mat metrics (Table 1) because these lines of evidence are hypothesized to have the most direct and immediate response to nutrient increases among readily available measures of biological condition for GSL wetlands.

Table 1.
Measure of biological composition (metrics) used to evaluate the potential threat of Perry-Willard effluent on the beneficial uses of the Willard Spur of Great Salt Lake.

Primary Line of Evidence	Constituent Metrics	Rationale
Submerged Aquatic Vegetation (SAV)	*Maximum percent cover*	- Provides habitat for invertebrates and amphibians. - Food source for birds and other organisms
	Fall SAV percent cover	- SAV cover during fall represents limiting conditions - May serve as an early sign of SAV senescence problems
Surface Mats	*Algae Mat percent Cover (season maximum observation)*	- Impedes recreation uses - Impedes use of some wildlife - Excessive mats can cause prolonged anoxia - Excessive mats crush SAV
	Duckweed percent Cover (season maximum observation)	- Same as algae mats, but may response to different stressors

In addition to biological responses, estimates of risk also require predicting how biological conditions might degrade under increasing concentrations of nutrients. Often these comparisons are made on a parameter-by-parameter basis. However, these comparisons do not account for interactive or cumulative effects of pollutant increases. Also, such comparisons are typically based exclusively on measures of central tendency (i.e., average, median), which may not be the most germane summary statistic given that adverse responses to nutrients are often observed above higher thresholds. Finally, increases in the concentration cannot be interpreted similarly among contaminants because the effects vary depending on the parameter in question. As a result, a Water Quality Index (WQI) was used for evaluating biological responses. This WQI rescales numerous chemical parameters to allow them to be easily combined and compared (Table 2).

TABLE 2
Water chemistry variable screening for inclusion of variables in the water quality index (WQI)

Water Chemistry Variable	Summary Statistics Screened	Screening Decision	Notes
pH	10th percentile pH 90th percentile pH Maximum pH Minimum pH	Do not include pH in WQI	Retain parameter in the data set due to existing standards and stakeholder concerns. Variation in the summary statistics was insufficient to make this a useful component of the WQI
Total Suspended Solids (TSS)	Minimum TSS Maximum TSS	Include both minimum TSS and maximum TSS in WQI	Low TSS values may indicate favorable water quality conditions SAV growth may be inhibited at high TSS values
Chlorophyll-a (Chl-a)	Minimum Chl-a Maximum Chl-a	Include both minimum Chl-a and maximum Chl-a in WQI	High values in the water column may indicate high algal production and tendency for algal mat formation Production and respiration activities also relate to DO levels
Dissolved Oxygen (DO)	90th percentile of DO saturation (maximum) Minimum DO Geometric Mean of DO	Include only minimum DO in WQI	Interpretation of grab samples of this variable is problematic High and geometric mean values did not differ greatly among sites
Phosphorus (P)	Minimum P Maximum P Geometric Mean P	Include minimum P, maximum P and geometric mean P in WQI/MMI for dissolved P, total P, and sediment total P	RFM models suggested that minimum P was also important. It is, however, difficult to interpret in the context of measuring relative condition; data suggests that P is good for SAV to a point, after which SAV may decline
Nitrogen (N)	Minimum N Maximum N Geometric Mean N	Include minimum N, maximum N and geometric mean N in WQI/MMI for ammonia-N, nitrate/nitrite-N, dissolved organic nitrogen, and sediment total N (single measure for each pond)	RFM models suggested that minimum N was also important. It is, however, difficult to interpret in the context of measuring relative condition; data suggests that N is good for SAV to a point, after which SAV may decline

Methods

Biological responses to pollutants are dependent upon both the measures of biological condition and the pollutant. As a result, three different measures of biological condition were used to develop risk thresholds: the SAV MMI (SAV-MMI), surface mat MMI (Mat-MMI) and the average of these two measures of condition (MMI). Similarly, these measures of biological condition were compared with three measures of chemical stress: a Nitrogen index (N-WQI), Phosphorous index (P-WQI), and the combined Water Quality Index (WQI) (Table 2). Estimates of risk were determined for all combinations biological condition (MMIs) and the chemical stressor gradients (WQIs) based on data collected from 16 impounded wetlands ponds around Great Salt Lake.

Three methods were used to generate nutrient concentration thresholds. Two Best Professional Judgment (BPJ) methods tied measures of biological response to measures of chemical condition based on visual extrapolation from chemical and biological relationships. The third empirical method used recursive partitioning to quantify chemical condition value that best distinguishes between classes of wetland ponds in the best and worse biological condition.

For the BPJ methods, scatterplots were generated for all combinations of chemical and biological condition, each on a theoretical scale of 1 (worse condition) to 100 (best condition) (see Appendix). For each MMI (SAV-MMI, Mat-MMI, and MMI), ponds were classified into three classes to summarize their relative biological condition: best (MMI = 90-100), intermediate (MMI = 61-89), and worst (MMI < 61). For each graph, a line was drawn to find the WQI above which all ponds were in "best" condition. We assumed this threshold represents ***low risk*** because adverse biological conditions were never observed among ponds if the WQI was greater than this threshold. Similarly, we generated a threshold of ***high risk*** by finding the WQI value below which ponds were always in poorer biological condition. Where possible, this threshold was drawn so that all sites below the WQI were among the worst observed among impounded ponds. However, in some cases it was necessary to included 1-2 intermediate ponds as well.

The empirical estimate of risk was generated with nonparametric deviance reduction approaches (Qian et al. 2003). This method identifies the threshold that best distinguishes between the "best" and "worst" sites—as determined from MMI responses (see above). These models generate a threshold, or breakpoints, that generate the best possible predictions into the impairment classes. Error rates were calculated using reclassification techniques and probability theory, and are expressed as measures of impurity, which in this case is the probability of misclassifying a site into the incorrect class (i.e., a "best" site is actually among the "worst" sites given the modeled threshold). Unlike our BPJ evaluations of high risk, these procedures quantify error and essentially generate the most probable threshold that could be used to distinguish between the best and worst pre-defined wetland classes. As a result, for the purpose of these comparisons, we considered these empirical thresholds to represent a ***moderate risk*** to Willard Spur biota.

Each of the WQI values used for these analyses is composed of many summary characteristics (Table 2). We used linear regression analysis to translate each WQI threshold back to the corresponding nutrient concentrations. For statistically significant relationships (ANOVA, $p < 0.05$), linear equations were generated to predict the geometric means of total phosphorous, nitrate/nitrite, ammonia, and organic nitrogen from the associated WQI. The strength of these relationships was quantified with correlation coefficients (r^2).

The final step was to relate risk thresholds back to projected increases in nutrient concentrations under several different discharge scenarios (see von Stackelberg Technical Memo, 9/30/2010). These estimates were generated by taking the geometric mean of low and high risk nutrient concentrations and relating these data back to three hypothetical concentration increase scenarios: 1) the most likely scenario with status quo: medium nutrients, partial flush scenario at 0.6 MGD (estimated discharge after 5-years of plant operation); 2) a high nutrient status quo: high nutrients, partial flush, 0.6 MGD; and 3) the scenario if nutrients and plant flow rates are minimized to the extent possible: low nutrients, partial flush, 0.2 MGD (estimated minimum discharge needed for plant operation).

Results

Two broad trends, irrespective of different WQIs, were observed among risk thresholds. First, low threat thresholds were easier to cleanly identify than high risk thresholds (see Appendix). For instance, impurity values (error rates) obtained from statistical threshold techniques were consistently higher for among sites in the "best" relative condition class than for sites in the "worst" condition class (Table 3). Second, the combined chemical index generally resulted in cleaner threshold values than either the N-WQI or P-WQI.

Table 3.
Error rates, expressed as impurity values, using recursive partitioning (moderate threat) methods to develop risk thresholds. All possible combinations of WQIs were used to calculate the most likely threshold for separating sites into the Best and Worst classes. An impurity of 0 means that all of the predictions were correct, and increasing impurity values indicate increasing error rates.

WQI	MMI	Impurity	
		Best	Worst
WQI	Overall	0	0
WQI-P	Overall	0.099	0.16
WQI-N	Overall	0	0.234
WQI	SAV	0.109	0.16
WQI-P	SAV	0.109	0.16
WQI-N	SAV	0	0.234
WQI	Surface Mats	0	0.16
WQI-P	Surface Mats	0	0.16
WQI-N	Surface Mats	0	0.16

Regression analyses to predict the geometric means of total phosphorous (TP), nitrate/nitrite (NO_3), Organic Nitrogen (ON), and ammonia (NH_4) from the three WQIs were all statistically significant (ANOVA, $p<0.05$). However, the accuracy of these predictions varied extensively ($r^2 = 0.34\text{-}0.88$). Phosphorous predictions were generally more accurate than those made for nitrogen constituents. As might be anticipated, the WQI constituents (N-WQI, P-WQI) more accurately predicted their associated chemical constituents than models based on complete WQI.

Table 4.
Analytical results—p-values (N=16, ANOVA) and correlation coefficients (r^2)—of least square regressions that predict key water quality parameters (Chemical Constituents) from the Water Quality Indices (WQIs).

WQI	Chemical Constituent	p-value	r^2
WQI	TP	<0.001	0.77
WQI	NO_3	0.028	0.34
WQI	ON	0.003	0.47
WQI	NH_4	0.005	0.44
WQI-P	TP	0.001	0.88
WQI-N	NO_3	0.001	0.80
WQI-N	ON	0.003	0.47
WQI-N	NH_4	0.005	0.44

Thresholds: Combined- SAV and Surface Mats (MMI)

The combined MMI was significantly (ANOVA, $p<0.05$) related to all three WQIs. These relationships were strongest for the combined WQI ($p < 0.001$, $r^2 = 0.82$), followed by P-WQI ($p<0.001$, $r^2 = 0.67$) then N-WQI ($p = 0.003$, $r^2 = 0.49$). Low threat thresholds (WQI = 83-87) were fairly consistent among the three WQIs, whereas they were more variable for the moderate (WQI = 78-88) and high threat thresholds (WQI = 50-75). However, much of the variance was reduced once the WQI were translated back to the associated chemical constituents. Among moderate to high threat thresholds, thresholds derived from nitrogen gradients (N-WQI) were higher (more sensitive) than those derived for phosphorous (P-WQI).

Thresholds: Surface Mats

Measures of surface mat condition revealed somewhat different trends than the overall measure of condition (MMI), consistently suggesting that phosphorous plays a more important roles than nitrogen in identifying impounded wetlands with significant surface mats. The Mat-MMI was most strongly correlated with phosphorous (P-WQI, $p<0.001$, $r^2 = 0.77$), followed by the N-WQI ($p<0.001$, $r^2 = 0.59$) then the combined WQI ($p<0.001$, $r^2 = 0.59$). Also, the P-WQI resulted in higher—more sensitive—thresholds across threat levels than either the combined WQI or the N-MMI (Table 5).

Thresholds: Submerged Aquatic Vegetation (SAV-MMI)

Linear relationships between SAV and the nutrient or chemistry WQIs were weaker than the Mat-MMI or combined MMI. The relationship was strongest for the combined WQI ($p=0.002$, $r^2 = 0.52$), with a statistically significant, albeit weak, linear relationship with the P-WQI ($p=0.047$, $r^2 = 252$) and a non-significant (NS) relationships with the N-MMI. Despite the weak overall linear correlation, thresholds with reasonable low error rates could be established (Table 3), suggesting that SAV responses may be non-linear or directed by important covariates. Among all threat levels, thresholds were consistently higher for P-WQI than the N-WQI.

Table 5.
Relative risk thresholds calculated and associated predicted geometric means of chemical constituents (mg/l) generated for three measures of biological condition: Submerged Aquatic Vegetation (SAV-MMI), Surface Mats (Mat-MMI) and the average of surface mats and SAV (Overall). High risk = concentrations always associated with degraded conditions, Moderate risk = empirical techniques used to determine the most likely threshold that leads to degraded conditions, Low risk = conditions always associated with the best biological conditions.

WQI	MMI	Risk	Threshold	TP	NH4	NO3	ON
P-MMI	Overall	High	50	0.4	NA	NA	NA
N-MMI	Overall	High	55	NA	0.3	1.6	2.4
Chemistry	Overall	High	75	0.3	0.2	1.1	1.9
Chemistry	Overall	Low	83	0.2	0.2	0.8	1.5
P-MMI	Overall	Low	85	0.1	NA	NA	NA
N-MMI	Overall	Low	87	NA	0.2	0.5	1.3
P-MMI	Overall	Moderate	78	0.2	NA	NA	NA
Chemistry	Overall	Moderate	83	0.2	0.2	0.8	1.5
N-MMI	Overall	Moderate	88	NA	0.2	0.5	1.3
N-MMI	SAV	High	65	NA	0.2	1.2	2.1
P-MMI	SAV	High	70	0.2	NA	NA	NA
Chemistry	SAV	High	75	0.3	0.2	1.1	1.9
P-MMI	SAV	Low	83	0.1	NA	NA	NA
N-MMI	SAV	Low	87	NA	0.2	0.5	1.3
Chemistry	SAV	Low	91	0.1	0.2	0.6	1.1
P-MMI	SAV	Moderate	78	0.2	NA	NA	NA
Chemistry	SAV	Moderate	83	0.2	0.2	0.8	1.5
N-MMI	SAV	Moderate	88	NA	0.2	0.5	1.3
P-MMI	Surface Mats	High	45	0.4	NA	NA	NA
N-MMI	Surface Mats	High	68	NA	0.2	1.1	2.0
Chemistry	Surface Mats	High	69	0.4	0.3	1.3	2.2
P-MMI	Surface Mats	Low	62	0.3	NA	NA	NA
N-MMI	Surface Mats	Low	71	NA	0.2	1.1	1.9
Chemistry	Surface Mats	Low	89	0.1	0.2	0.7	1.2
P-MMI	Surface Mats	Moderate	67	0.3	NA	NA	NA
Chemistry	Surface Mats	Moderate	74	0.3	0.2	1.1	2.0
N-MMI	Surface Mats	Moderate	78	NA	0.2	0.8	1.6

Comparison Among Relative Risk Thresholds

Table 6 depicts the average (geometric mean) and variance of low and high risk thresholds across all MMIs. Despite the differences in response among MMIs, most thresholds showed were fairly similar once the WQIs were converted back to the constituent chemical species. Conversely, all of the chemical constituents showed clear differences between high and low risk thresholds, which bracket impounded wetlands where no negative biological effects were never observed with wetlands where appreciable degradation of mats or SAV were observed.

Table 6.
The geometric means and standard deviation (σ) of threshold nutrient concentrations within impounded wetlands of Great Salt Lake. Data are depicted for thresholds derived for two levels of relative risk. Low risk indicates average nutrient concentrations that were never associated with biological degradation in these wetlands (as measured by SAV-MMIs and Mat-MMIs). High risk indicates nutrient concentrations that were always associated with degraded biological conditions.

Relative Risk	TP	NO_3	ON	NH_4
Low Risk	0.16 (σ = 0.07)	0.70 (σ = 0.20)	0.19 (σ = 0.02)	1.39 (σ = 0.27)
High Risk	0.33 (σ = 0.07)	1.23 (σ = 0.17)	0.24 (σ = 0.02)	2.07 (σ = 0.20)

Comparison with Projected Concentration Increases

The central question with these analyses is whether existing data and information suggest that the Perry-Willard POTW effluent represents a threat to Willard Spur wetlands. Superimposing the projected nutrient increases onto calculated thresholds (Table 6) suggests potential problems with nitrate (NO_3) and phosphorous (TP) in the first few years of plant operation if the project proceeds as currently planned, whereas minimizing both flow and nutrients should not cause high risk nutrient concentrations to be exceeded for >5 year (Table 7).

Table 7
Estimated year following the discharge into Willard Spur in which nutrient concentrations are projected to exceed high risk thresholds under 3 hypothetical nutrient increase scenarios:
Status Quo = partial flush, medium nutrients, 5-year estimated discharge volume.
Status Quo, High Nutrients = partial flush, high nutrients, 5-year projected discharge volume
Proactive Scenario = partial flush, minimize nutrient inputs, minimize discharge into Willard Spur

Discharge Scenario	TP	NO_3	NH_4
Status Quo	Year 2-3	Year 2-3	>5 Years
Status Quo, High Nutrients	Year 1	Year 1	>5 Years
Proactive Scenario	>5 Years	>5 Years	>5 Years

Discussion

These calculations were made to estimate—using existing and readily available data—whether the Perry-Willard discharge represents an immediate (5-year) threat to the Willard Spur ecosystem. Little water quality, biological, or hydrological data are available for the Willard Spur ecosystem. As a result, these analyses necessitated numerous assumptions and associated caveats, including:

- The MMIs and WQIs are recently developed tools, which are still under development.
- The MMIs and WQIs were developed using data collected at managed, impounded Great Salt Lake wetlands, which are only roughly analogous to the Willard Spur at low water levels.

- The biological indices (MMIs) may not be the most appropriate measures of condition for these wetlands.
- The relationships between the WQIs and MMIs are correlations and do not imply cause-and-effect relationships.

Hence, these thresholds should not be interpreted as standards. Instead, these data simply establish a range of conditions, bracketed between those that likely do not represent a concern to Willard Spur biota (low threat) and those that have been associated with degradation elsewhere (high threat).

Caveats aside, these analyses suggest that if the plant was to proceed with operations as initially planned, the potential exists to harm the Willard Spur ecosystem relatively quickly. While we do not know precisely how nutrients will accumulate in Willard Spur, our best estimates suggest that high risk thresholds would be exceeded within 1-3 years of plant operations. In other words, there is evidence that the plant poses a risk to Willard Spur biota unless something is done to address potential threats.

Exercising the precautionary principle— if an action has a suspected risk of causing harm to the environment, in the absence of scientific consensus that the action is harmful, the burden of proof that it is *not* harmful falls on those taking the action—we also evaluated the threat if all possible efforts were made to minimize the short-term impacts of the discharge. This alternative, which involves minimizing the discharge to Willard Spur and quickly reducing nutrient concentrations to the extent possible, suggests little threat to the ecosystem through the first 5-years of plant operation.

If a precautionary approach was taken for plant operations, DWQ would have sufficient time to collect additional data and instigate investigations to minimize the uncertainty associated with these investigations. The aim of these investigations would be to develop site-specific nutrient criteria for Willard Spur. These criteria would provide certainty for Perry and Willard cities by providing numeric treatment targets. Also, numeric nutrient criteria would help establish levels of protection that are needed for the long-term protection of the Willard Spur ecosystem.

Literature Cited

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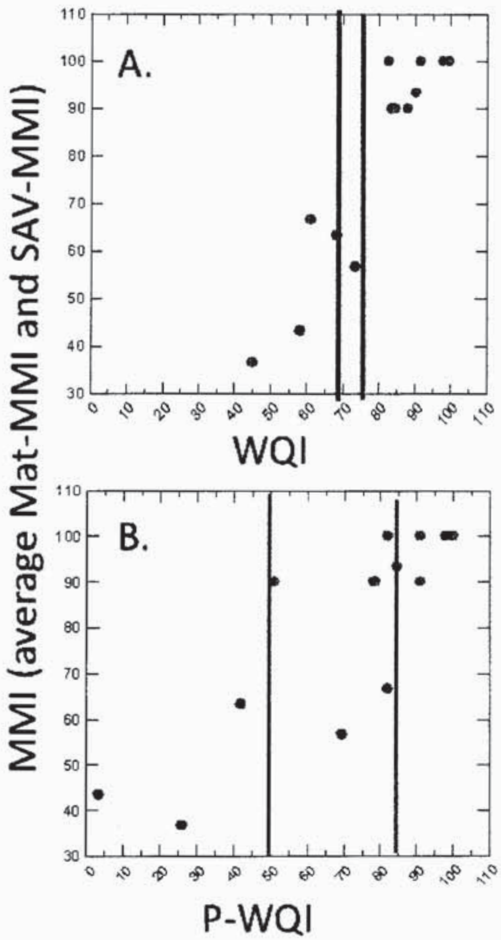
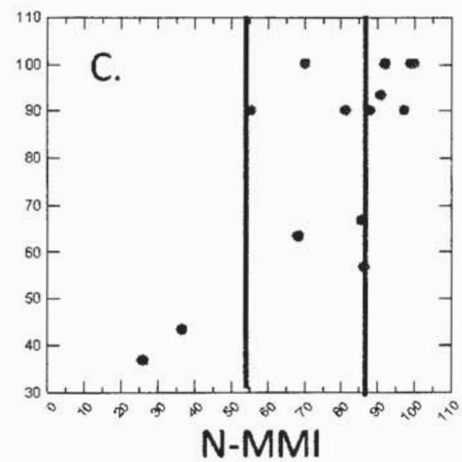
Qian, S. S., R. S. King, and C. J. Richardson. 2003. Two statistical methods for the detection of environmental thresholds. *Ecological Modeling* 166:87-97.

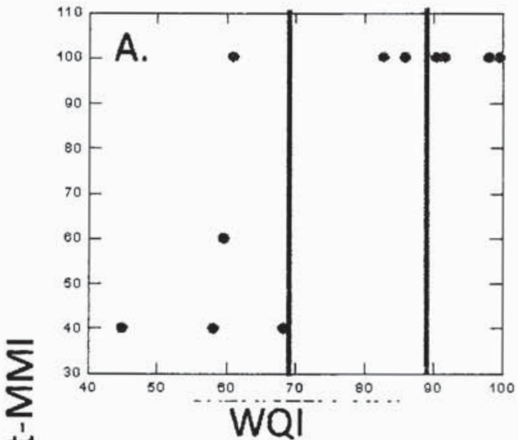
Appendix



BPJ Thresholds: MMI

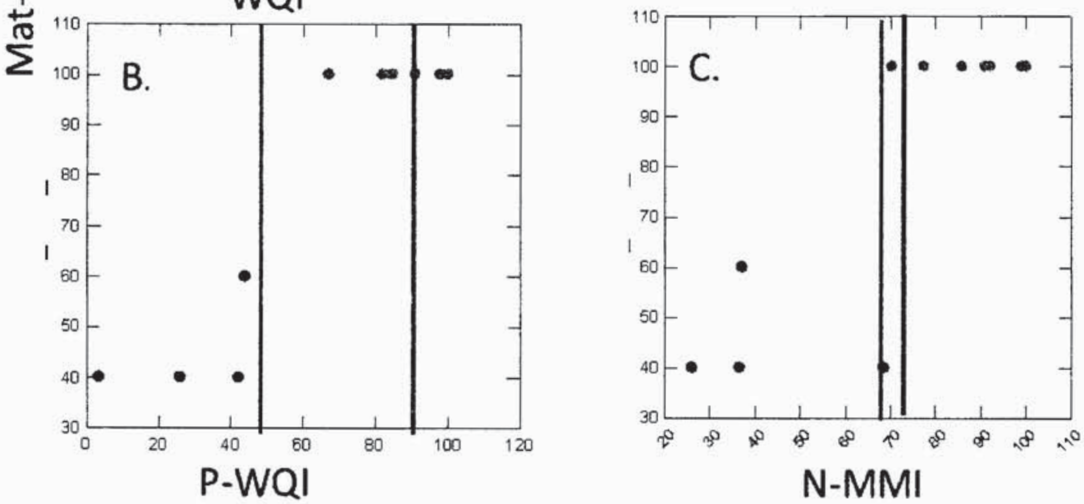
Best Professional Judgment (BPJ) thresholds for the overall (average) biological condition of impounded GSL wetlands. Both minimal threat (green lines) and high threat (red lines) boundaries are depicted for the overall WQI (panel A), and the constituent P-WQI (panel B) and N-WQI (panel C).





BPJ Thresholds: Mat-MMI

Best Professional Judgment (BPJ) thresholds for the Mat-MMIs. Both minimal threat (green lines) and high threat (red lines) boundaries are depicted for the overall WQI (panel A), and the constituent P-WQI (panel B) and N-WQI (panel C).



BPJ Thresholds: SAV-MMI

Best Professional Judgment (BPJ) thresholds for the SAV-MMIs. Both minimal threat (green lines) and high threat (red lines) boundaries are depicted for the overall WQI (panel A), and the constituent P-WQI (panel B) and N-WQI (panel C).