An Ecological Design for the 40th Avenue West Remediation-to-Restoration Project

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Background

The lower 21 miles of the St. Louis River, the largest U.S. tributary to Lake Superior, form the 4856 ha St. Louis River estuary. Despite the effects of more than 100 years of industrialized and urban development as a major Great Lakes port, the estuary remains the most significant source of biological productivity for western Lake Superior, and provides important wetland, sand beach, forested, and aquatic habitat types for a wide variety of fish and wildlife communities.

The lower St. Louis River and surrounding watershed were designated an 'area of concern' (AOC) under the Great Lakes Water Quality Agreement in 1989 because of the presence of chemical contaminants, poor water quality, reduced fish and wildlife populations, and habitat loss. Nine beneficial use impairments (BUIs) have been identified in the AOC, including: loss of fish and wildlife habitat, degraded fish and wildlife populations, degradation of benthos, and fish tumors and deformities. The St. Louis River Citizens Action Committee, now the St. Louis River Alliance (SLRA), was formed in 1996 to facilitate meeting the needs of the AOC. Following the recommendations of the St. Louis River AOC Stage II Remedial Action Plan, the SLRA completed the ***Lower St. Louis River Habitat Plan*** (Habitat Plan) in 2002 as 'an estuary-wide guide for resource management and conservation that would lead to adequate representation, function, and protection of ecological systems in the St. Louis River, so as to sustain biological productivity, native biodiversity, and ecological integrity.' The SLRA also facilitated development of 'delisting targets' for each BUI in the St. Louis River AOC in December 2008.

The Habitat Plan identified several sites within the AOC with significant habitat limitations. One of these sites, the **'40th Avenue West Habitat Complex'** (approximately 130 ha; Figure 1), was identified by a focus group within the SLRA habitat workgroup as a priority for a 'remediation-to-restoration' project. The purpose of the 'remediation to restoration' process is to implement remediation activities to address limiting factors such as sediment contamination, followed by restoration projects that best complement the desired ecological vision. The focus group developed a general description of desired future ecological conditions at the 40th Avenue West Habitat Complex, hereafter referred to as the 'project area,' including known present conditions and potential limiting factors of the area. In addition, the focus group recommended a process to develop specific plans and actions to achieve the desired outcomes at the site.

This report documents the first step in the 'remediation-to-restoration process being implemented at the **'40th Avenue West Habitat Complex,'** the development of an 'Ecological Design' for the project area, and a preliminary evaluation of those factors potentially limiting the realization of those habitat and other land use goals. This report is intended to serve as a basis for a subsequent feasibility study in which remediation alternatives will be evaluated along with restoration alternatives, which may achieve the habitat goals noted here. This project was funded under USFWS Cooperative Agreement Number 30181AJ68, and is part of the USFWS Environmental

Contaminants Program's goal to address contaminant-related needs of the St. Louis River Area of Concern as part of the Great Lakes Restoration Initiative.

To establish the basis of an 'ecological design' for the project area, researchers at the University of Minnesota Duluth's Natural Resource Research Institute (NRRI), in cooperation with USFWS, USEPA, MPCA, MNDNR, and other partners, sampled the project area from the late summer 2010 through spring 2011 to establish baseline information on sediment contamination, ecotoxicology, vegetation, sediment types, benthic macroinvertebrates, fish assemblage, and bird usage of the area. Vegetation, macroinvertebrates, and sediment characterization were also completed for five reference areas selected by project cooperators. These reference areas represent less disturbed locations having high or low wind and wave exposure that can serve to demonstrate restoration potential for the project area.

Figure 1. 40th Avenue West remediation-to-restoration project area in the St. Louis River estuary, Duluth, Minnesota.

Aquatic Vegetation Model Development

As a part of the ecological design, NRRI developed a model to predict the probability of aquatic communities under particular combinations of depth, wave energy, and substrate. The model was based on an assessment of vegetation, sediment types, benthic macroinvertebrates, and bird usage at the 21st and 40th Avenue West habitat complex areas, along with reference locations at other sites (Brady *et al.* 2010). These data were integrated with existing aquatic vegetation data, bathymetry, wind fetch, and other environmental variables. Classification and regression tree (CART) and logistic regression approaches were used to develop predictive models for dominant aquatic vegetation communities based on environmental factors. These relationships were then incorporated into a GIS modeling framework to map the predicted distribution of aquatic vegetation across these restoration sites.

The model was then used to simulate the outcome of a series of restoration scenarios which could be implemented after or in conjunction with remediation activities. Scenario results were summarized by mapping predicted aquatic vegetation communities, along with tabular summaries of habitat areas for macroinvertebrates, fish, and birds.

Aquatic plant communities

Aquatic plant communities were derived from an analysis of an integrated data set, consisting of sites sampled within the 40th Avenue West Complex project area, a set of reference sites collected in high quality habitat areas, and an extensive MNDNR survey of the overall St. Louis River estuary (Brady *et al.* 2010). The combined data set had 856 records, with 67 records in the emergent marsh (EM) class, 145 in floating leaf aquatic bed (FL) and 312 as submerged aquatic bed class (SAV); 332 points had no vegetation present. Sites were sampled up to 12.2 m in depth, but few aquatic plants were found at depths > 2.5 m. Sites deeper than this were mapped as disphotic, and the 172 samples > 2.5 meters were excluded from modeling.

While the aquatic plant communities are named for the dominant growth form, they are in fact more complex associations of plants, with species of submerged aquatic vegetation also in the emergent marsh and floating leaf classes:

> Emergent marsh (EM): the most diverse of the three aquatic plant communities, the emergent marsh is a mix of emergent, floating-leaf, and submerged aquatic plants, with 22 plant taxa occuring in at least 5% of the sample points in estuary. Water depths range from 0.03 to 2.32 m, with an average water depth of 0.63 m. The most frequent plant taxa are algae, arrowheads (*Sagittaria* spp.), water marigold (*Megalodonta beckii*), northern milfoil (*Myriophyllum sibiricum*), and bulrushes (*Schoenoplectus* spp).
>
> Floating-leaf aquatic bed (FL): the second most diverse of the three aquatic plant communities, the floating-leaf aquatic bed is a mix of submerged, floating-leaf, and free-floating aquatic plants, with the submerged aquatic plants often dominant in this type. Floating-leaf aquatic bed has 12 plant taxa occurring in at least 5% of the sample points in the estuary. Water depths range from 0.09 to 2.04 m, with an average water depth of

1.09m. The most frequent plant taxa are water celery (*Vallisneria americana*), algae, water meal (*Wolffia* spp.), clasping-leaf pondweed (*Potamogeton richardsonii*), Canada waterweed (*Elodea canadensis*), and bushy pondweed (*Najas flexilis*).

Submerged aquatic bed (SAV): the least diverse and often very sparsely vegetated of the three aquatic plant communities, the submerged aquatic bed is dominated by submerged aquatic plants mixed with occasional free-floating plants, with only 6 plant taxa occurring in at least 5% of the sample points in the estuary. Water depths range from 0.12 to 2.68 m, with an average water depth of 1.44 m. The most frequent plant taxa are water celery (*Vallisneria americana*) and Canada waterweed (*Elodea canadensis*).

The predominant plant communities varied by depth, with EM found from the surface to 1.2 m, FL at maximum abundance between 0.4 and 1.6 m depth, and SAV widely abundant but predominating at depths of 1.0 to 1.8 m (Figure 2). A CART analysis selected depth >=1.859 as the first split in partitioning SAV presence/absence

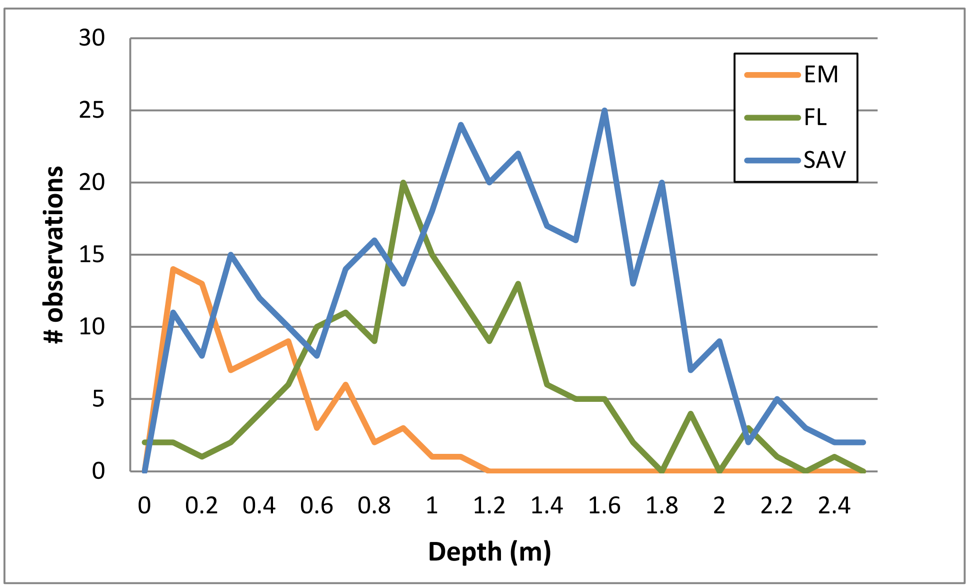

Figure 2. Frequency of aquatic plant community occurrences by depth.

Substrate Analysis

Depth and substrate data were collected during April and May of 2010 by the Fond du Lac Resource Management Department using data from a hydroacoustic echosounder. Substrates were classified into 13 classes. There were difficulties in using the hydroacoustics signal to discriminate the woody debris and organic 'coffee grounds' (finely divided wood waste particles) type substrates. To develop a predictive model, we aggregated the Fond du Lac substrate classes into three simpler classes: 'sand', which included coarse materials and other hard substrates, 'clay/silt', which included finer-textured substrates, and 'muck,' for fine and coarse organic materials (Table 1).

In NRRI field sampling, a combination of up to three substrate types were reported to describe the sediment at each sample point, with one type rated as dominant and others as second or third most prominent textures. Sediment types were classified by feel. Sediment data were converted to approximate proportions or percentages based on the three most prominent textures. If a single texture was present, it was recorded as 100%; two textures were recorded as 65/35 and three textures recorded as 55/30/15. For modeling purposes, only the dominant texture was used.

The aggregated Fond du Lac and NRRI substrate point data were used to generate a map of dominant substrate for the entire project area (Figure 3). The map was made using the ArcGIS tessellation technique NIBBLE, in which data is 'grown' from each point to fill in a complete map. As a result, the resolution of the map varies with point density. Since we had few data points in the shallow back bays where the Fond du Lac boat could not go, the substrate map has a much lower resolution (more highly generalized) compared with the more closely-spaced samples.

Table 1. Bottom type classification from Fond du Lac Natural Resources (FDL) and reclassification for modeling.

Bottom type	FDL description	Reclassified substrate
1	Clay / sand	Sand
1.5	Sand / coffee grounds mix	Sand
1.75	50% Chance of coffee grounds, approx. 25% fine sand, rest gravel or a sand / clay mix	Muck
2	Softer clay	Clay
2.5	Med soft clay	Clay
2.75	50% Hard clay, 50% med hard clay	Clay
3	Soft gelatinous goo	Muck
3.5	54% Soft clay, 34% harder clay, 12% coffee grounds	Clay
4	Harder clay	Clay
4.25	75% Hard clay, 25% sand	Clay
5	Rock	Sand
5.5	Gravel	Sand
6	Cobble	Sand

40th Ave West Substrates

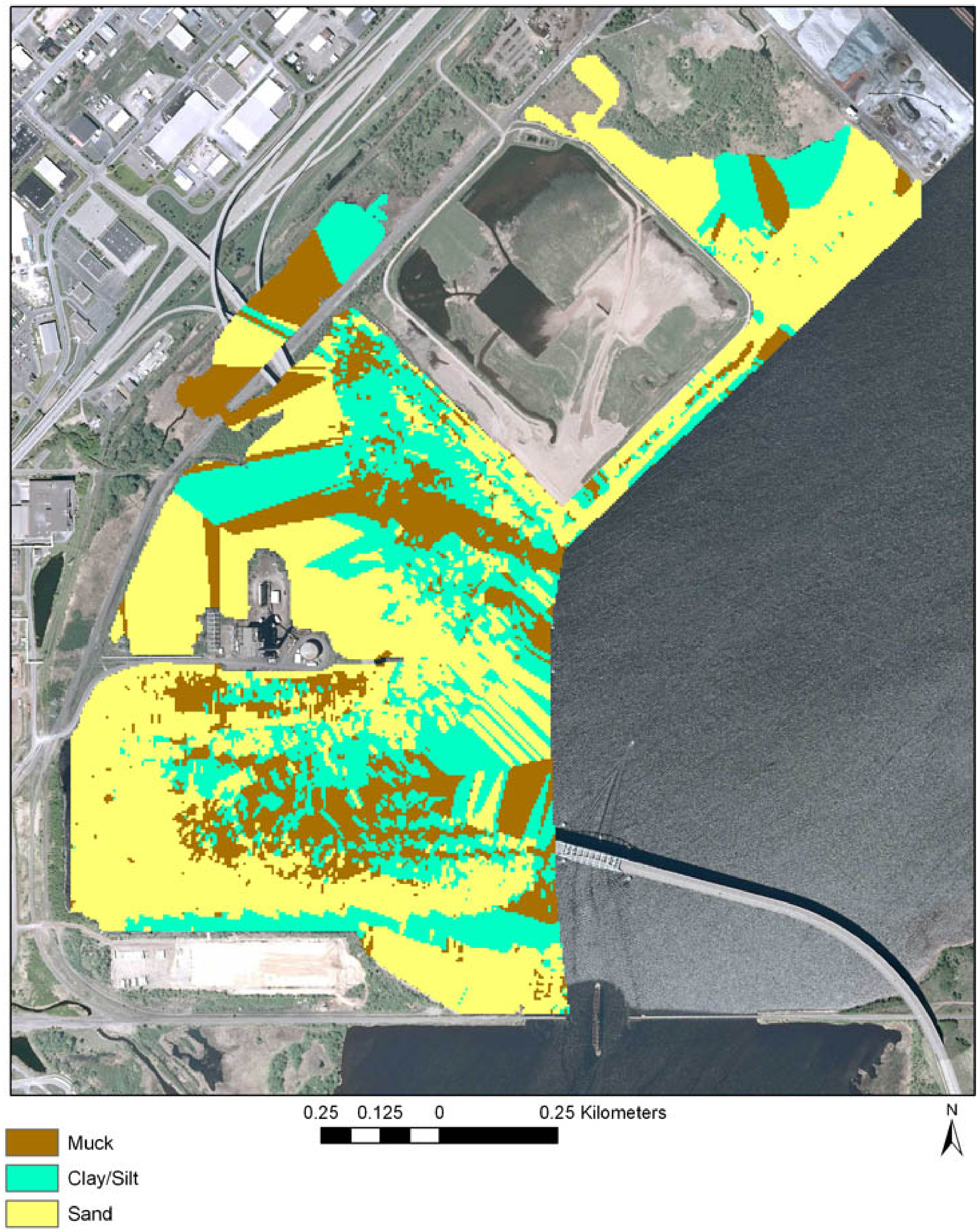

Figure 3. Substrate classification, interpolated from Fond du Lac and NRRI point sample data.

Wind Fetch Analysis

Wind fetch was used as a surrogate for wave energy, which is known to influence the presence and abundance of aquatic vegetation. Wind fetch is the unobstructed distance that wind can travel over water in a constant direction, with longer fetches resulting in greater wave energy. Obstructions such as barriers or islands can disrupt wind fetch, and can provide sheltered area.

The USGS Wind fetch model (Rohweder *et al.* 2008) was applied to the St. Louis River estuary. A binary map indicating water and land is used to calculate wind fetch from multiple directions. The different directions modeled were specified in 10-degree increments; the model creates a fetch map for each of the 36 possible directions.

An assessment of a decade of wind data records was used to identify the predominant wind directions: NE, W, and SW (T. Hollenhorst, US EPA, pers. comm.) (Figure 4). Single direction wind fetch, e.g. West or Northeast, were often associated with individual groups of sample points, depending on where they were located in the estuary. Points near the shore at 40th Ave do not receive a strong west fetch, even though the west fetch is generally important when considered over the entire estuary. For this reason, we used weighed-fetch based on 12 compass directions, which has less directional bias, and allows effects from any wind direction, although the effects are weighted by the historical record of wind directions. Weighted wind fetch was calculated by multiplying individual fetch outputs by the proportion of wind observations from a particular direction (from the collected weather data) and then summed to create a final wind fetch model that represents the prevailing winds in the area.

The specific formula, based on 12 wind directions, was:

```
wtd_fetch = ([fet_015] * 0.0667) + ([fet_045] * 0.3512) + ([fet_075] * 0.1010) + ([fet_105] * 0.0178) + ([fet_135] * 0.0165) + ([fet_165] * 0.0218) + ([fet_195] * 0.0601) + ([fet_225] * 0.1287) + ([fet_255] * 0.1083) + ([fet_285] * 0.0614) + ([fet_315] * 0.0363) + ([fet_345] * 0.0304)
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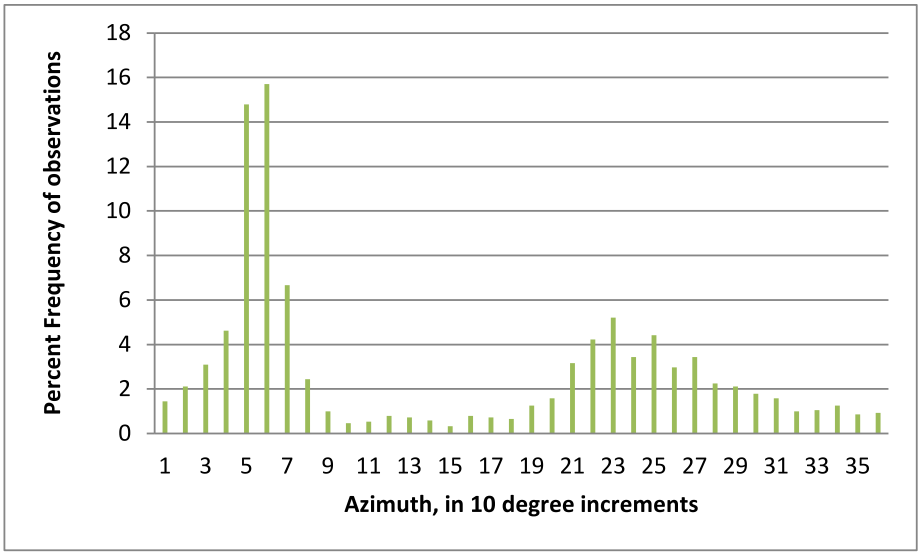

Figure 4. Frequency of wind observations by 10-degree azimuth classes.

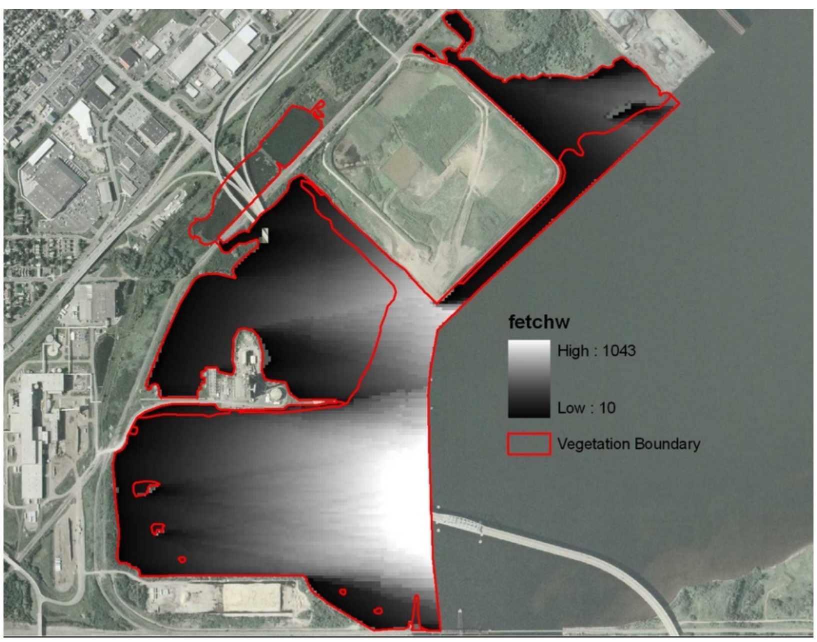

Figure 5. Westerly wind fetch (m) for project area.

Aquatic Vegetation Modeling

Predictive relationships between environmental and plant community data were developed using a combination of CART and logistic regression. CART was used for an initial screening of the large number of environmental variables to determine which were mostly closely correlated with the presence or absence of the three aquatic community classes. These variables were used as inputs to logistic regression. Logistic regression predicts the probability of outcome for a categorical variable, for example, the probability of finding emergent vegetation under particular depth and wind fetch conditions. Individual models were developed for each of the aquatic communities (EM, SAV, FL), as well as the general presence of aquatic vegetation (VP).

Since the FL community reached its greatest abundance at 0.4 to 1.6 m, we derived a synthetic depth variable [WatDepFLOpt] to use as an input to the model:

```
If Depth < 1
  WatDepthFLOpt = 1 + (1- WatDepth)
Else
  WatDepthFLOpt = Depth
End
```

Individual models were developed for EM, FL, SAV, and VP. While the models for FL and SAV were significant, the relationships were weak ($r2 < 0.1$). For this reason, we used the EM and FL models to map those two communities. SAV was modeled as the difference between VP and EM or FL communities. The following tables provide the inputs and parameter values for the three models.

Table 2. Logistic model results for Emergent Marsh (EM).

Depth_LT_2.5 2 - Fit Nominal Logistic - JMP Pro

Nominal Logistic Fit for EM

Converged in Gradient, 8 iterations

Iterations

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	104.66100	4	209.322	<.0001*
Full	114.60362			
Reduced	219.26462			

RSquare (U)	0.4773
AICc	239.296
BIC	261.847
Observations (or Sum Wgts)	684

Measure	Training	Definition
Entropy RSquare	0.4773	1-Loglike(model)/Loglike(0)
Generalized R-Square	0.5570	(1-(L(0)/L(model))^(2/n))/(1-L(0)^(2/n))
Mean -Log p	0.1675	∑ -Log(ρ[j])/n
RMSE	0.2285	√ ∑(y[j]-ρ[j])²/n
Mean Abs Dev	0.1037	∑ |y[j]-ρ[j]|/n
Misclassification Rate	0.0673	∑ (ρ[j]≠ρMax)/n
N	684	n

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	644	99.51073	199.0215
Saturated	648	15.09289	**Prob>ChiSq**
Fitted	4	114.60362	1.0000

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-1.5095054	0.5473322	7.61	0.0058*
WatDep_m	5.38954829	0.7339736	53.92	<.0001*
wtd_fetch	0.00086717	0.0005672	2.34	0.1263
SandGT30	1.18442719	0.485465	5.95	0.0147*
MuckGT30	-1.5791344	0.4155801	14.44	0.0001*

For log odds of 0/1

Covariance of Estimates

Effect Likelihood Ratio Tests

Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
WatDep_m	1	1	110.664152	<.0001*
wtd_fetch	1	1	2.39057607	0.1221
SandGT30	1	1	6.1553708	0.0131*
MuckGT30	1	1	15.551497	<.0001*

Table 3. Logistic model results for Floating Leaf community (FL).

Depth_LT_2.5 3 - Fit Nominal Logistic - JMP Pro

Nominal Logistic Fit for FL

Converged in Gradient, 6 iterations

Iterations

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	67.17456	4	134.3491	<.0001*
Full	282.18704			
Reduced	349.36160			

RSquare (U)	0.1923
AICc	574.463
BIC	597.014
Observations (or Sum Wgts)	684

Measure	Training	Definition
Entropy RSquare	0.1923	1-Loglike(model)/Loglike(0)
Generalized R-Square	0.2787	(1-(L(0)/L(model))^(2/n))/(1-L(0)^(2/n))
Mean -Log p	0.4126	∑ -Log(ρ[j])/n
RMSE	0.3618	√ ∑(y[j]-ρ[j])²/n
Mean Abs Dev	0.2643	∑ |y[j]-ρ[j]|/n
Misclassification Rate	0.1857	∑ (ρ[j]≠ρMax)/n
N	684	n

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	652	270.91324	541.8265
Saturated	656	11.27380	**Prob>ChiSq**
Fitted	4	282.18704	0.9994

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-3.3562405	0.5867753	32.72	<.0001*
WatDepFLOpt	2.624395	0.3667887	51.19	<.0001*
wtd_fetch	0.0020484	0.0003153	42.21	<.0001*
SiltGT30	-0.4934362	0.2449107	4.06	0.0439*
MuckGT30	0.43660786	0.2554801	2.92	0.0875

For log odds of 0/1

Covariance of Estimates

Effect Likelihood Ratio Tests

Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
WatDepFLOpt	1	1	64.4322101	<.0001*
wtd_fetch	1	1	49.9632644	<.0001*
SiltGT30	1	1	4.21968657	0.0400*
MuckGT30	1	1	2.99385737	0.0836

Table 4. Logistic model results for Vegetation Presence (VP).

Depth_LT_2.5 - Fit Nominal Logistic 4 - JMP Pro

Nominal Logistic Fit for VegPres

Converged in Gradient, 6 iterations

Iterations

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	138.98848	3	277.977	<.0001*
Full	236.60768			
Reduced	375.59616			

RSquare (U)	0.3700
AICc	481.274
BIC	499.327
Observations (or Sum Wgts)	684

Measure	Training	Definition
Entropy RSquare	0.3700	1-Loglike(model)/Loglike(0)
Generalized R-Square	0.5010	(1-(L(0)/L(model))^(2/n))/(1-L(0)^(2/n))
Mean -Log p	0.3459	∑ -Log(ρ[j])/n
RMSE	0.3227	√ ∑(y[j]-ρ[j])²/n
Mean Abs Dev	0.2108	∑ |y[j]-ρ[j]|/n
Misclassification Rate	0.1433	∑ (ρ[j]≠ρMax)/n
N	684	n

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	263	116.54513	233.0903
Saturated	266	120.06255	Prob>ChiSq
Fitted	3	236.60768	0.9079

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-7.1770337	0.6131625	137.01	<.0001*
WatDepFLOpt	4.07415144	0.3361161	146.93	<.0001*
SandGT30	0.73042822	0.2599197	7.90	0.0050*
SiltGT30	-0.9250639	0.2648721	12.20	0.0005*

For log odds of 0/1

Covariance of Estimates

Effect Likelihood Ratio Tests

Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
WatDepFLOpt	1	1	261.400623	<.0001*
SandGT30	1	1	8.12169695	0.0044*
SiltGT30	1	1	12.2639084	0.0005*

Mapping Vegetation Modeling Results

The equations of the logistic model were programmed into ArcGIS and grid algebra was used to generate maps of predicted vegetation. The maps were made in stages by integrating the EM, EM-FL and VP maps. Outputs of the logistic model are probabilities of finding the specific community under particular combinations of depth, wind fetch, and/or substrate (Figures 6-8)

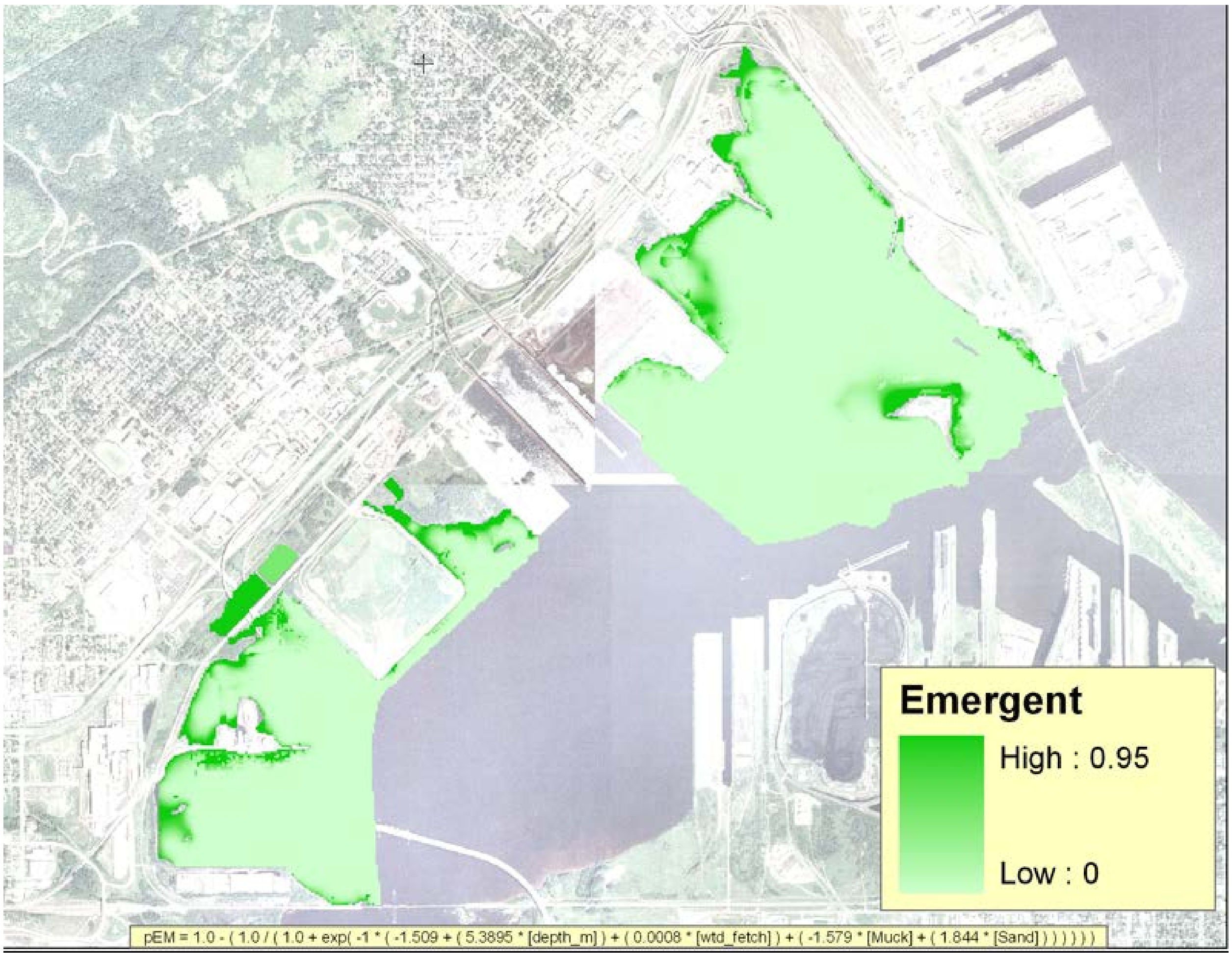

Figure 6. Predicted probability of Emergent Marsh community in project area.

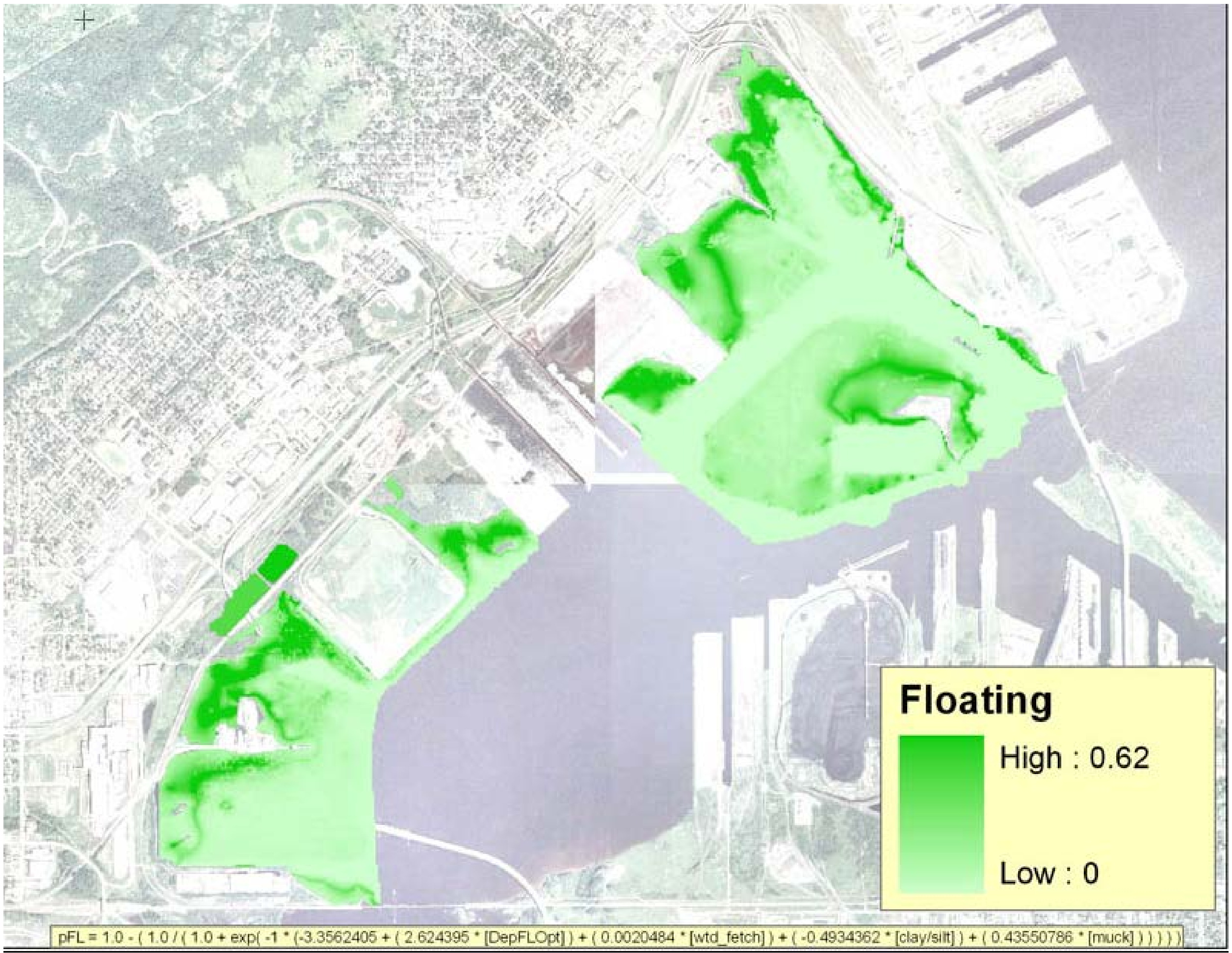

Figure 7. Predicted probability of Floating Leaf Aquatic Beds in the 40th Avenue West Complex project area.

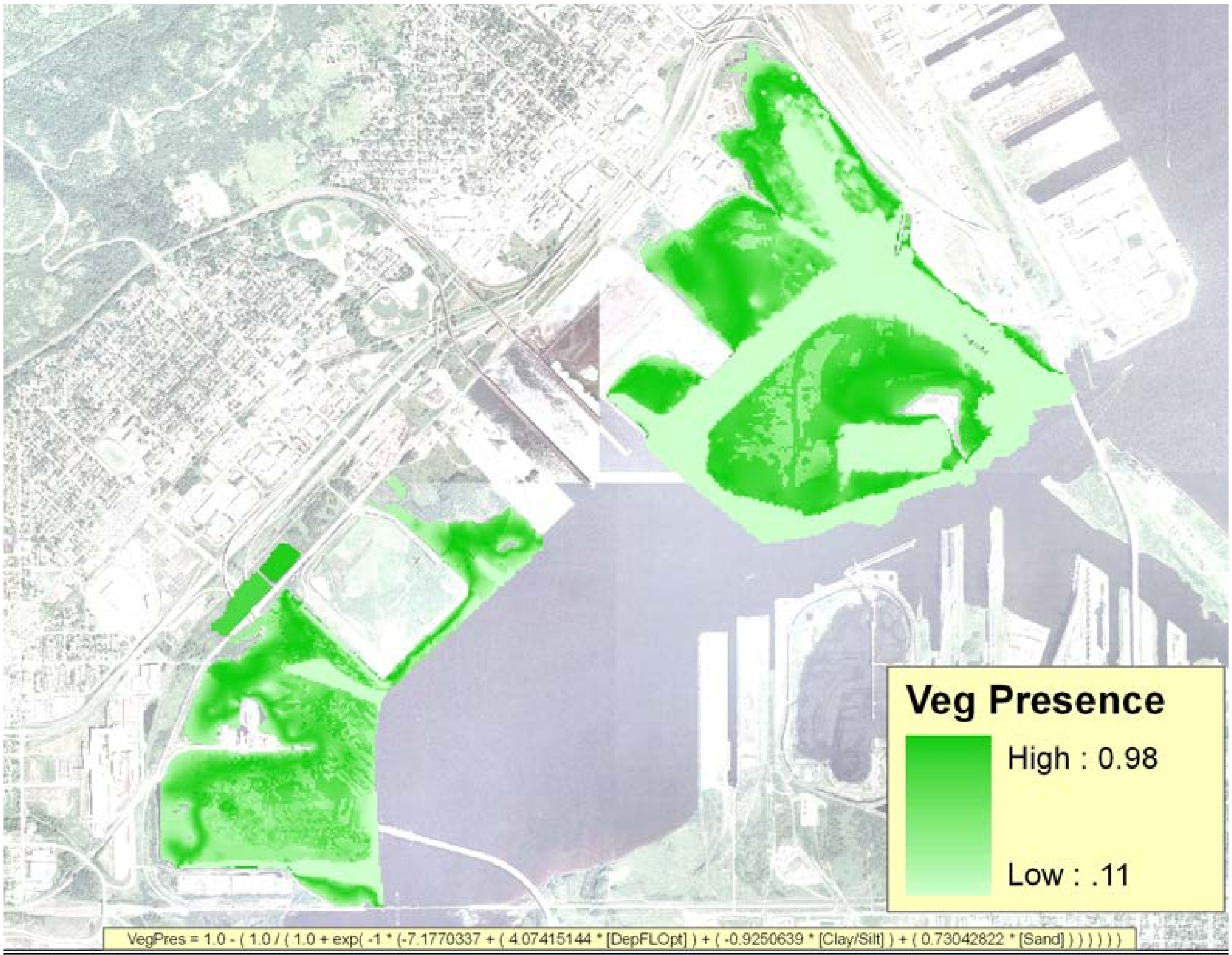

Figure 8. Predicted probability of aquatic Vegetation Presence in project area.

The probability maps were converted to aquatic plant community patches by identifying the p-values that best fit the sample data. Because there was no significant model for SAV, we subtracted the EM and FL communities from the veg presence model; the remaining grid cells were classified as SAV. Figure 9 shows the predicted distribution of vegetation based on current conditions.

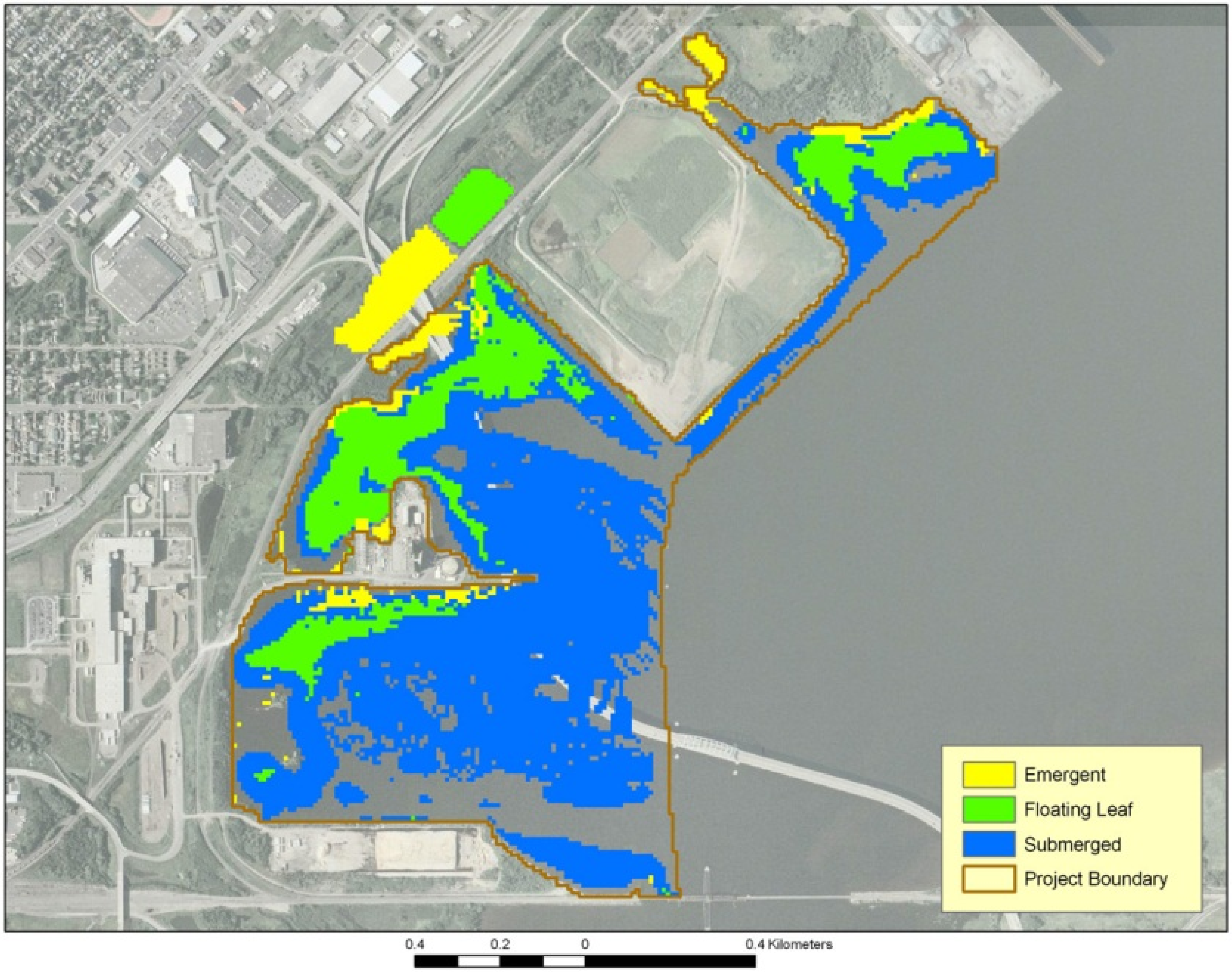

Figure 9. Model predictions of aquatic vegetation beds in project area – current conditions.

Habitat Classes

In addition to the vegetation maps, thresholds of depth and wind energy identified in the CART and logistic modeling were used to create a map of habitat classes for the project area (Figure 10). The resulting map identifies 4 depth classes – shallow (0- 0.65 m), intermediate 0.65 – 1.65 m, deep (1.6-2.5 m), as well as a disphotic zone, below which no vegetation occurs. We also discriminated low energy sites (< 100 m of a windbreak) from higher energy locations. These classes were used to assess the changes in acreages of particular habitat for the plant, macroinverbrate, bird, and other ecological response data collected in this study.

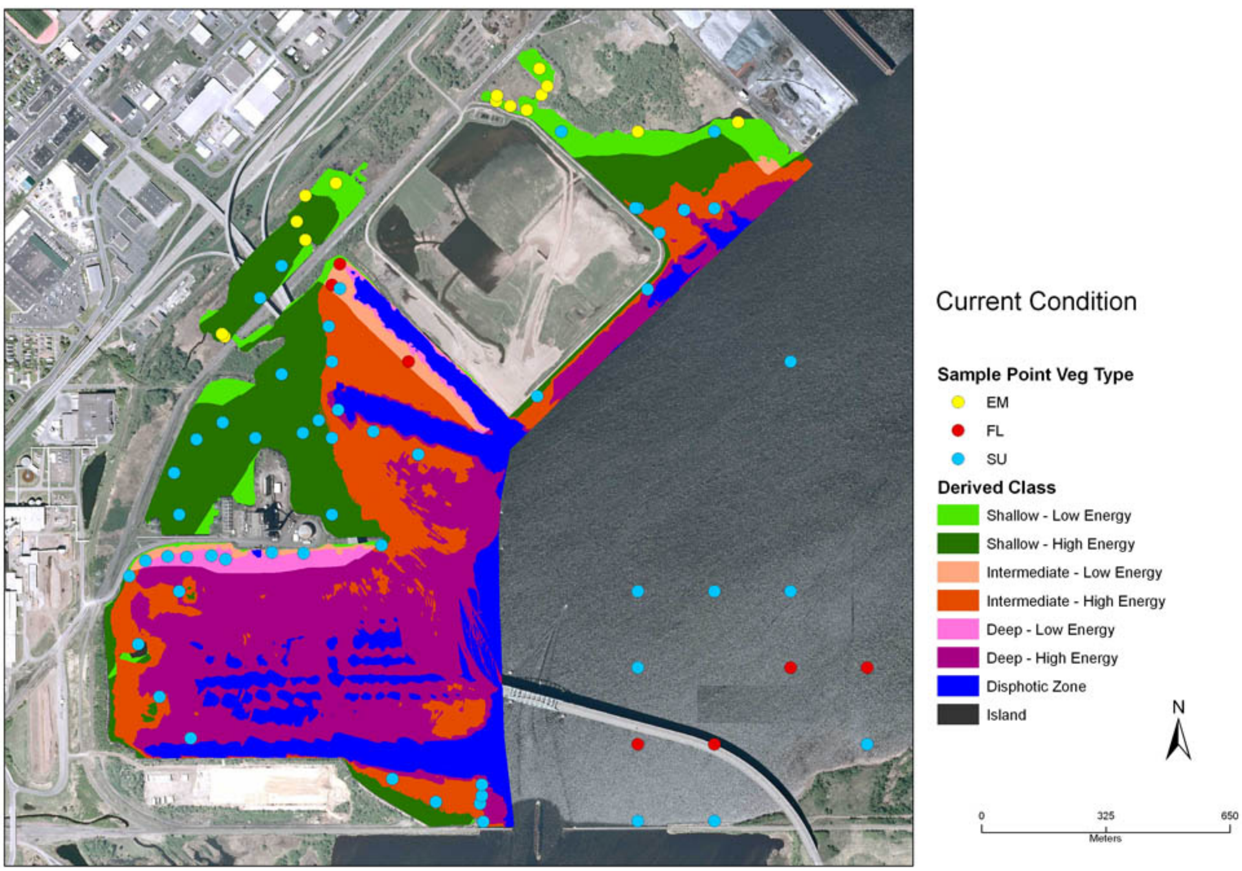

Figure 10. Habitat classes based on depth/energy environments in project area.

Habitat Restoration Scenarios

NRRI and the SLRA habitat team met for a session to develop a series of ecological design scenarios to assess potential outcomes of plants, macroinvertebrates birds, and fish within the 40th Ave W Project Area. These scenarios were designed to represent a range of potential restoration scenarios that follow remediation at the site, and demonstrate how the model can be used to predict the response of aquatic vegetation. Scenarios include alterations to substrate or bathymetry to provide more suitable habitat for emergent, floating-leaf or submerged aquatic vegetation beds, along with the creation of islands or breakwalls to disrupt wind fetch and dissipate wave energy (Figure 11). Several of the scenarios represent real plausible restoration activities that could be implemented in the estuary, while others, such as the re-creation of the 1861 conditions mapped by William Hearding, provide a theoretical baseline to allow comparison with historic conditions.

Scenarios 1-3 involve creation of islands and increased shallow habitat adjacent to the islands. Scenario 4 is a replication the William Hearding 1861 map, prior to development of the harbor. Scenario 5 has no islands but increases shallow habitat to create fringing wetlands and aquatic habitat. This scenario also includes some excavation of existing land in the northern portion of the study area, replacing it with submerged silt and clay substrates.

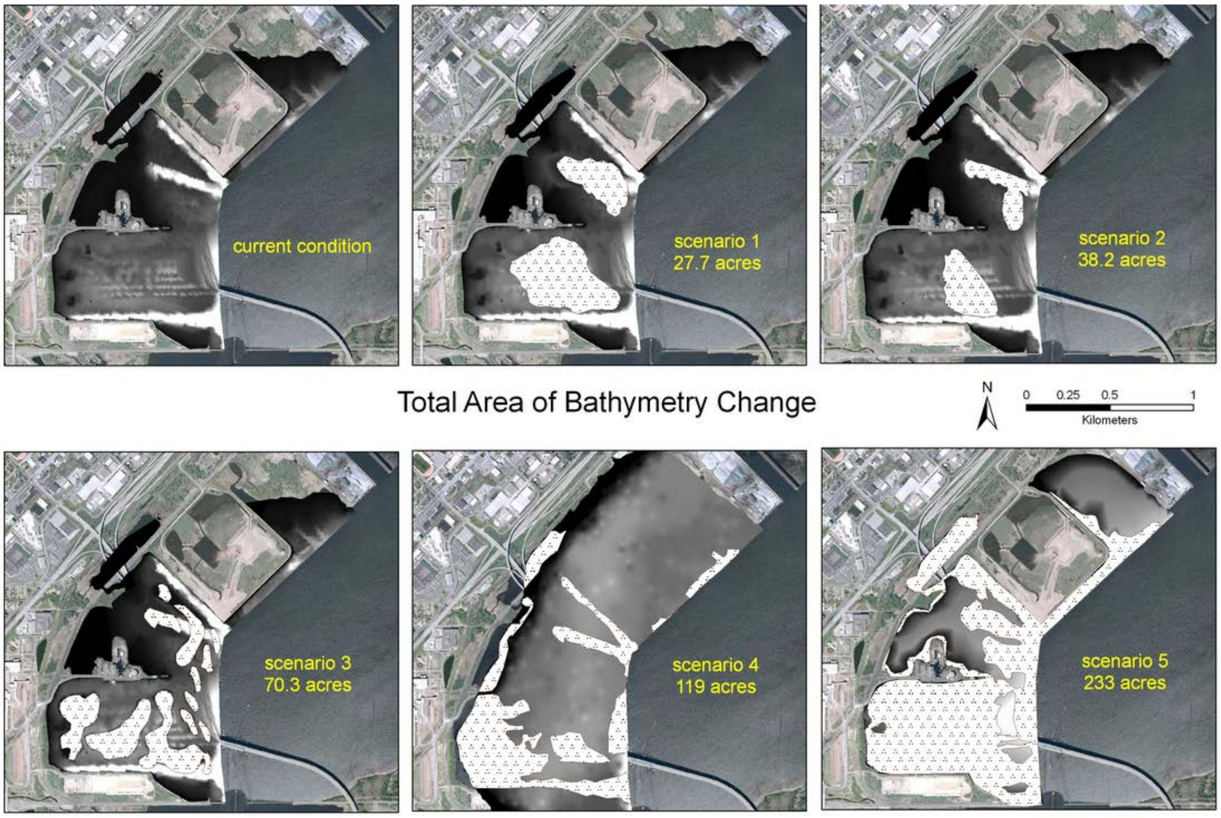

Figure 11. Area of substrate modified in each of the five scenarios.

Aquatic Plant Communities: Current Condition and Predicted Response to Ecological Design Scenarios

Figures 12 through 16 show the distribution of the three aquatic plant communities based on model predictions. For each scenario, new input maps of bathymetry, substrate, and weighted wind fetch (the product of 12 separate wind grids) were calculated. The models for the three aquatic plant communities were then applied to the new set of grids, resulting in new probability maps. As a final step, the three plant community maps were integrated into a final predictive map of discrete communities, and areas of each community type were calculated (Table 5). Refer to Figure 11 for the design of each restoration scenario.

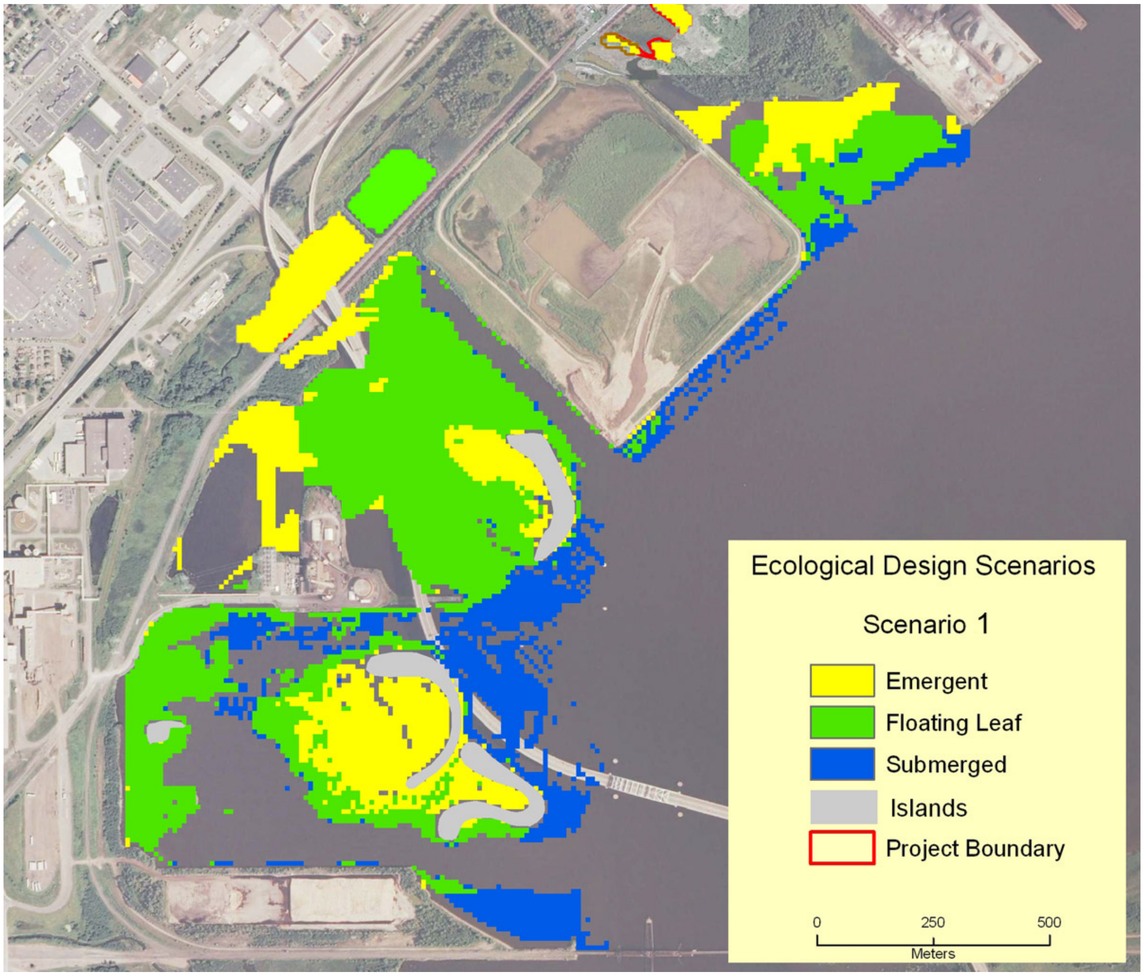

Figure 12. Scenario 1 results depicting the distribution of aquatic vegetation communities.

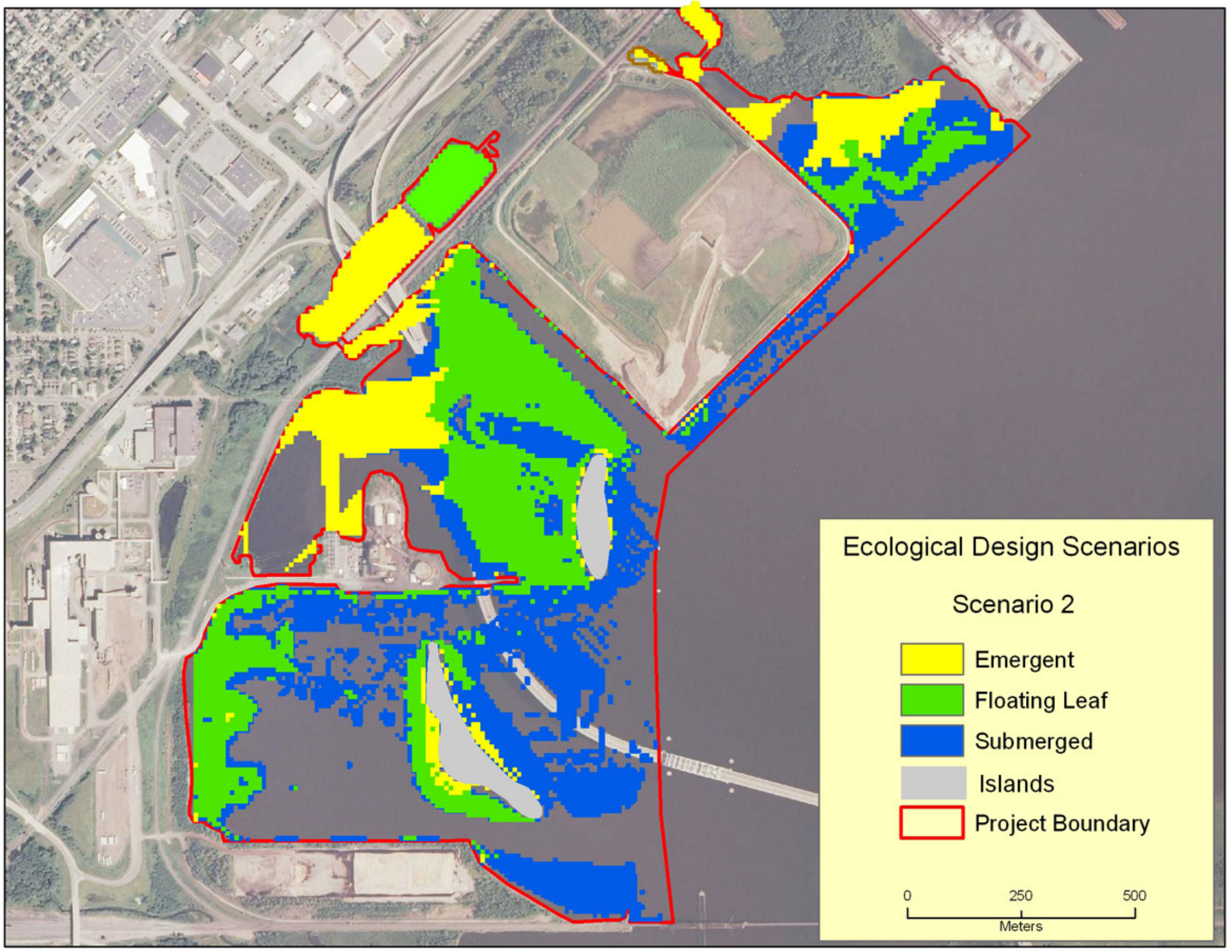

Figure 13. Scenario 2 results depicting the distribution of aquatic vegetation communities.

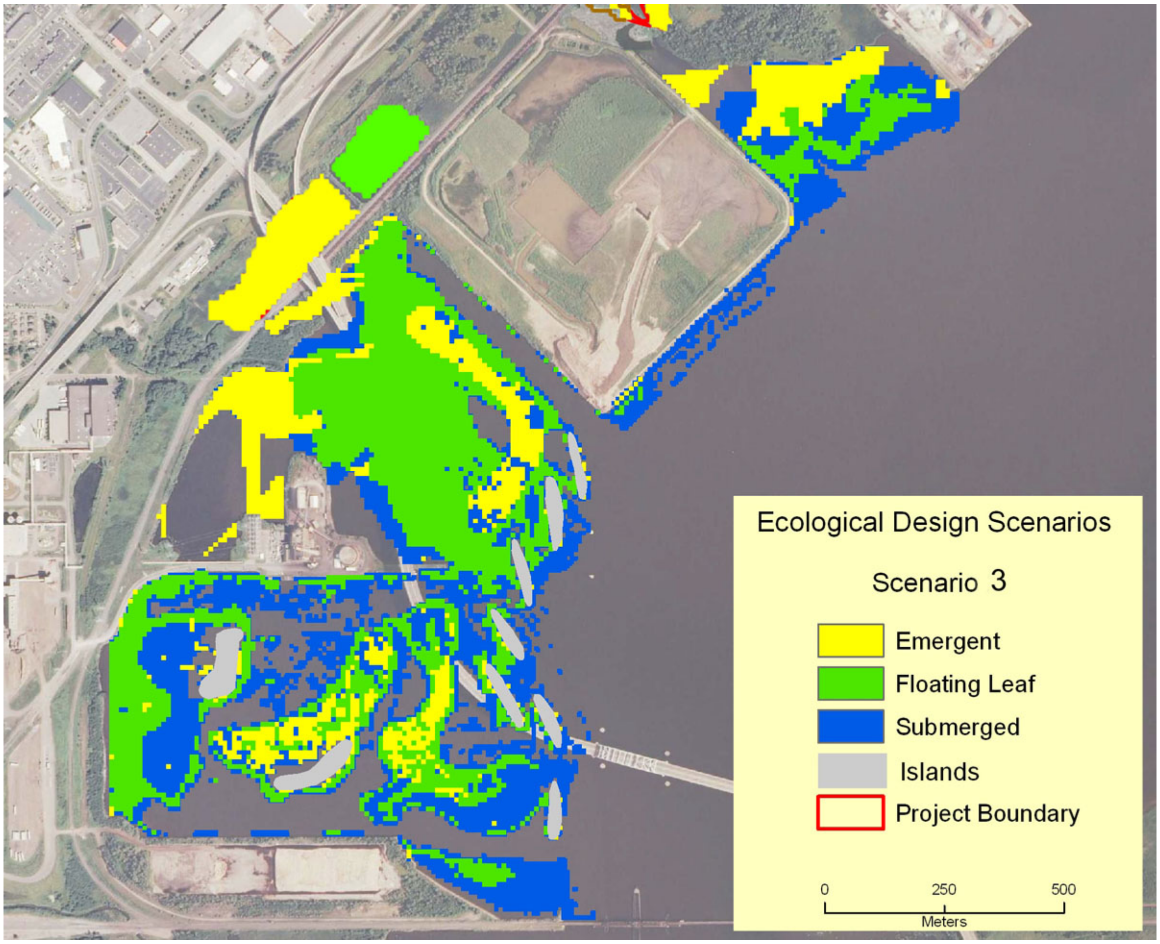

Figure 14. Scenario 3 results depicting the distribution of aquatic vegetation communities.

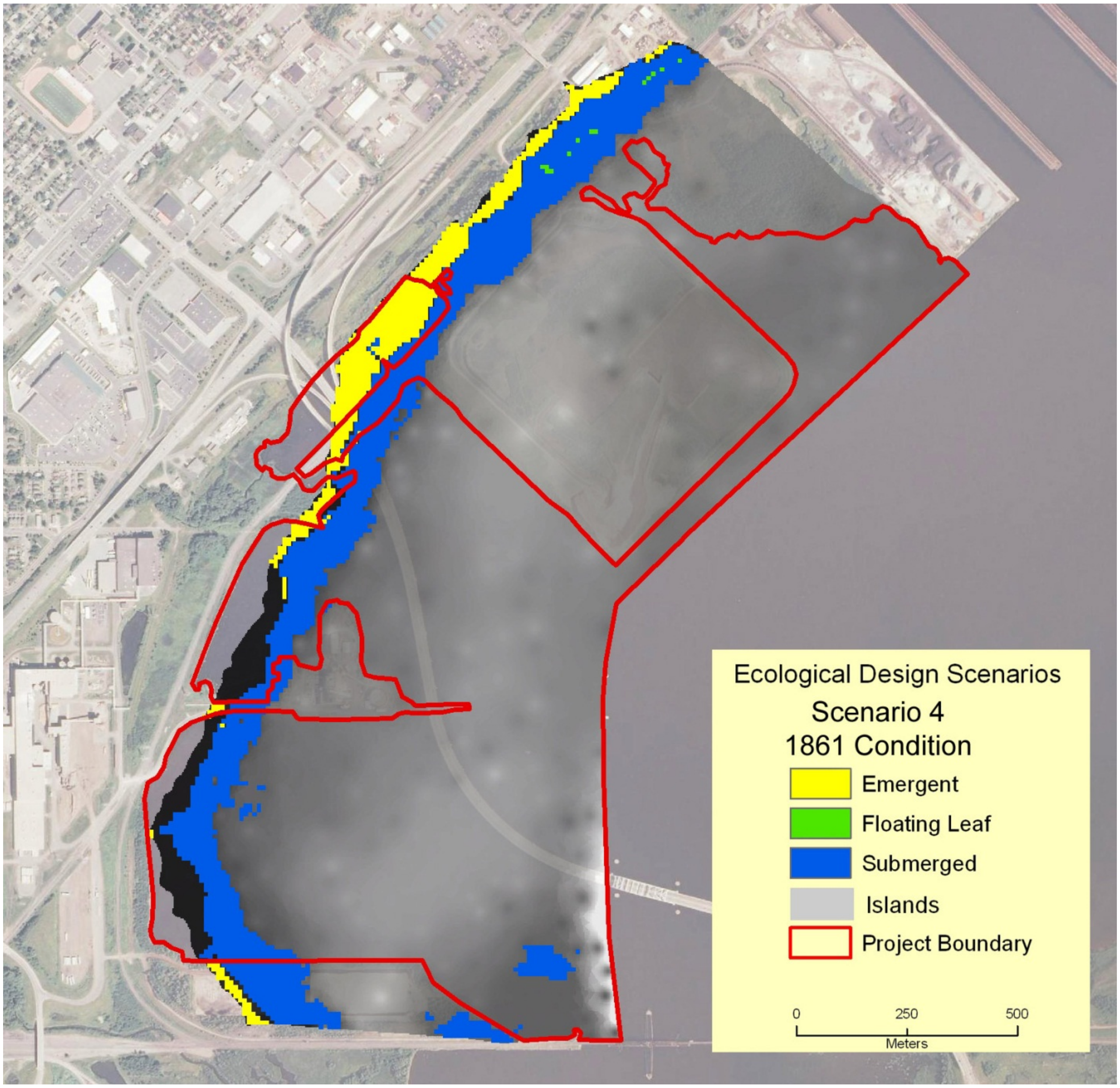

Figure 15. Scenario 4 (1861) results depicting the distribution of aquatic vegetation communities.

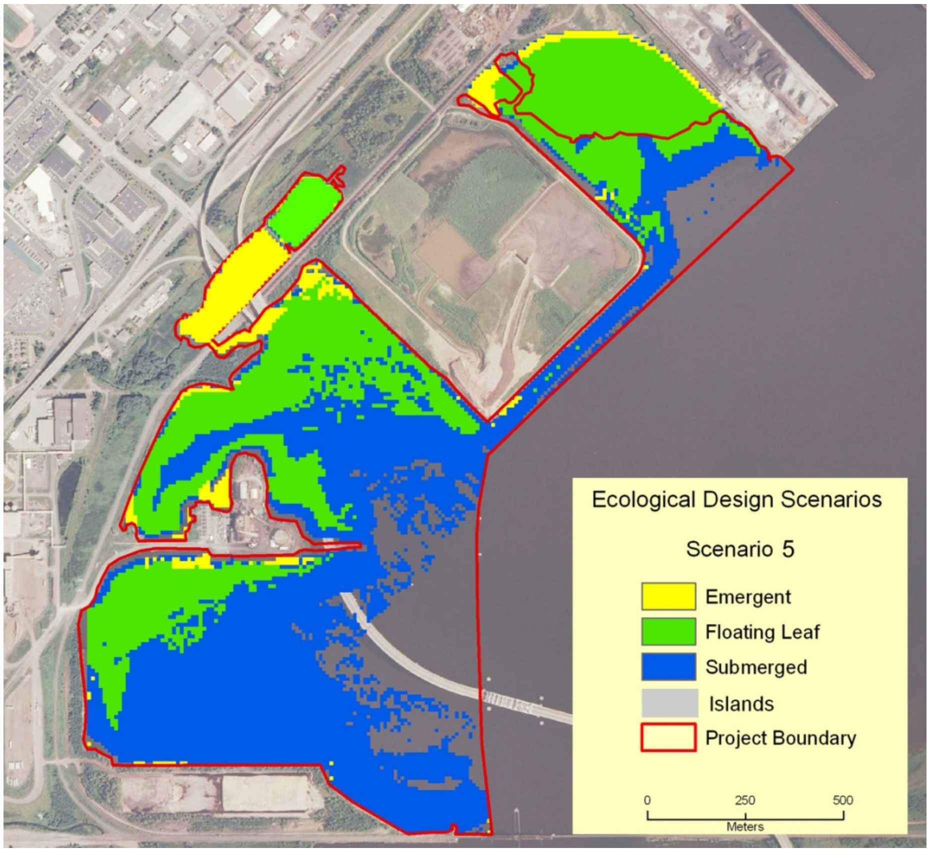

Figure 16. Scenario 5 results depicting the distribution of aquatic vegetation communities.

Table 5. Summary of the areas of aquatic vegetation communities predicted under the current condition and scenarios 1-5.

Scenario	Emergent marsh (ac)	Floating leaf (ac)	Submerged aquatic beds (ac)	Total vegetation area (ac)
Current condition	24.6	29.2	104.5	158.3
Scenario 1	58.8	130.6	70.6	260.0
Scenario 2	37.4	73.4	84.5	195.3
Scenario 3	46.8	96.1	78.8	221.7
Scenario 4	17.1	0.3	67	84.4
Scenario 5	20.8	113.0	152.8	286.6

We also summarized the total area for each of the habitat classes based on depth and wind energy, as shown in Figure 10 for the current conditions. The results of each scenario are shown in Figures 17-21, and the habitat class areas are summarized in Table 6.

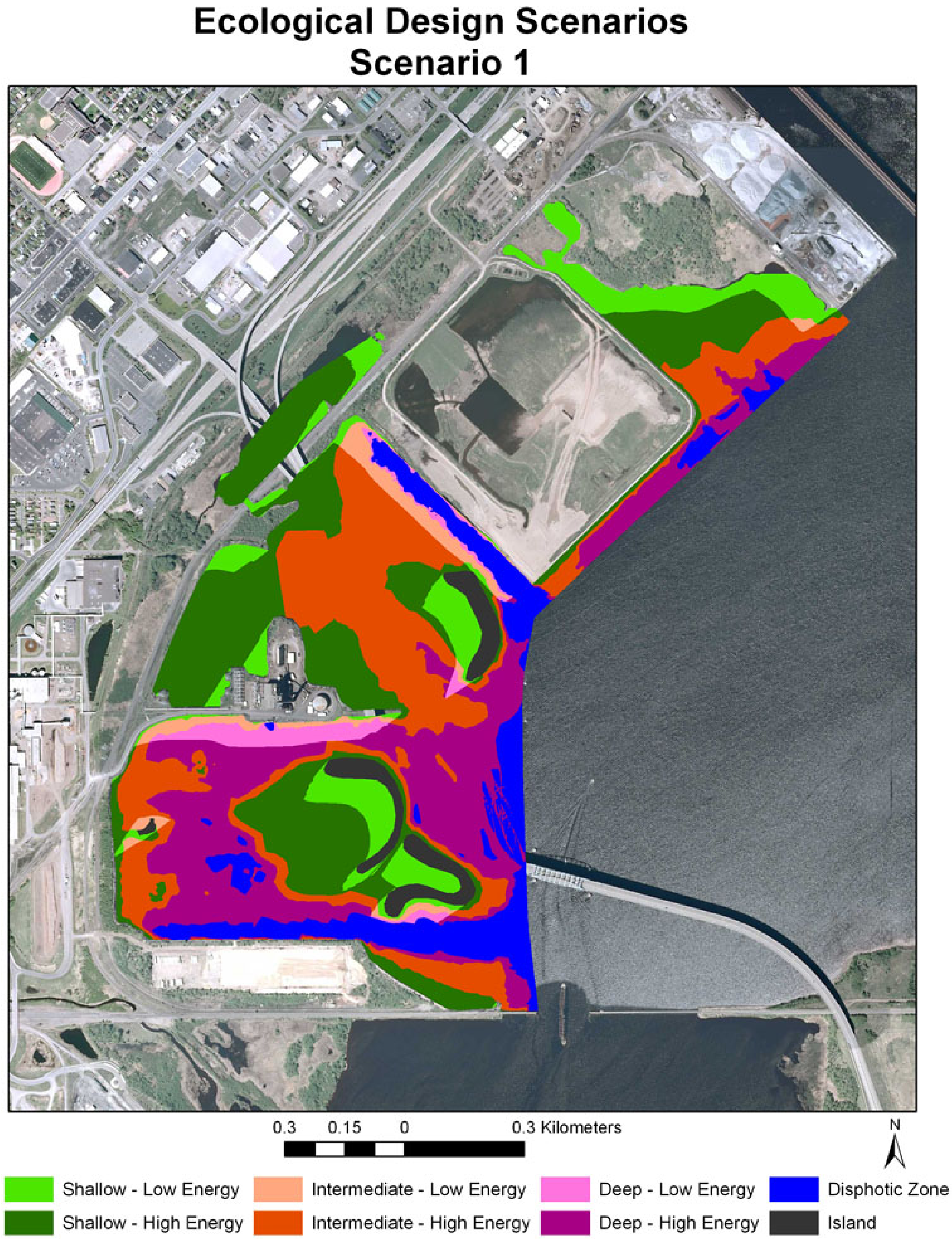

Figure 17. Summary of habitat types based on depth and potential energy: Scenario 1.

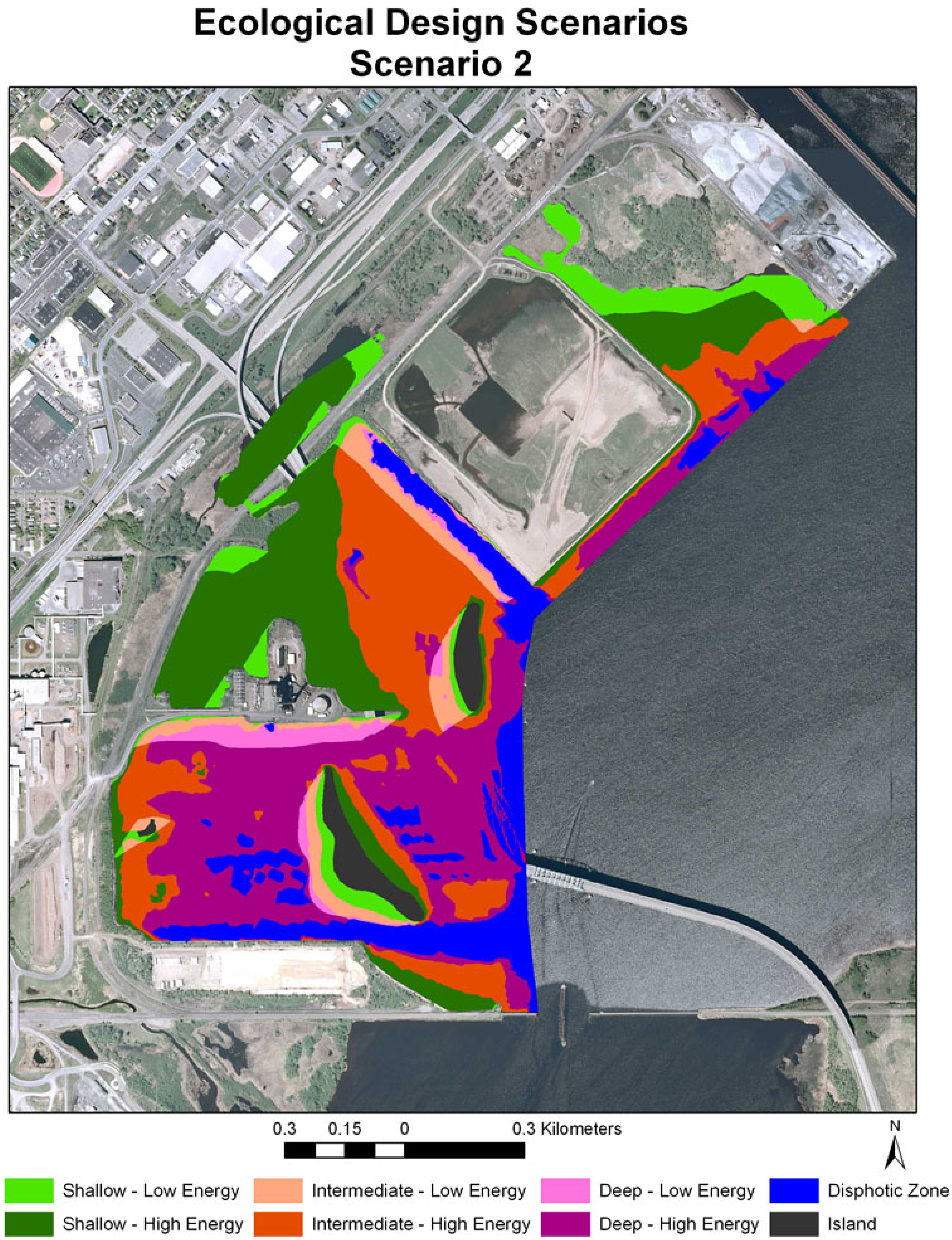

Figure 18. Summary of habitat types based on depth and potential energy: Scenario 2.

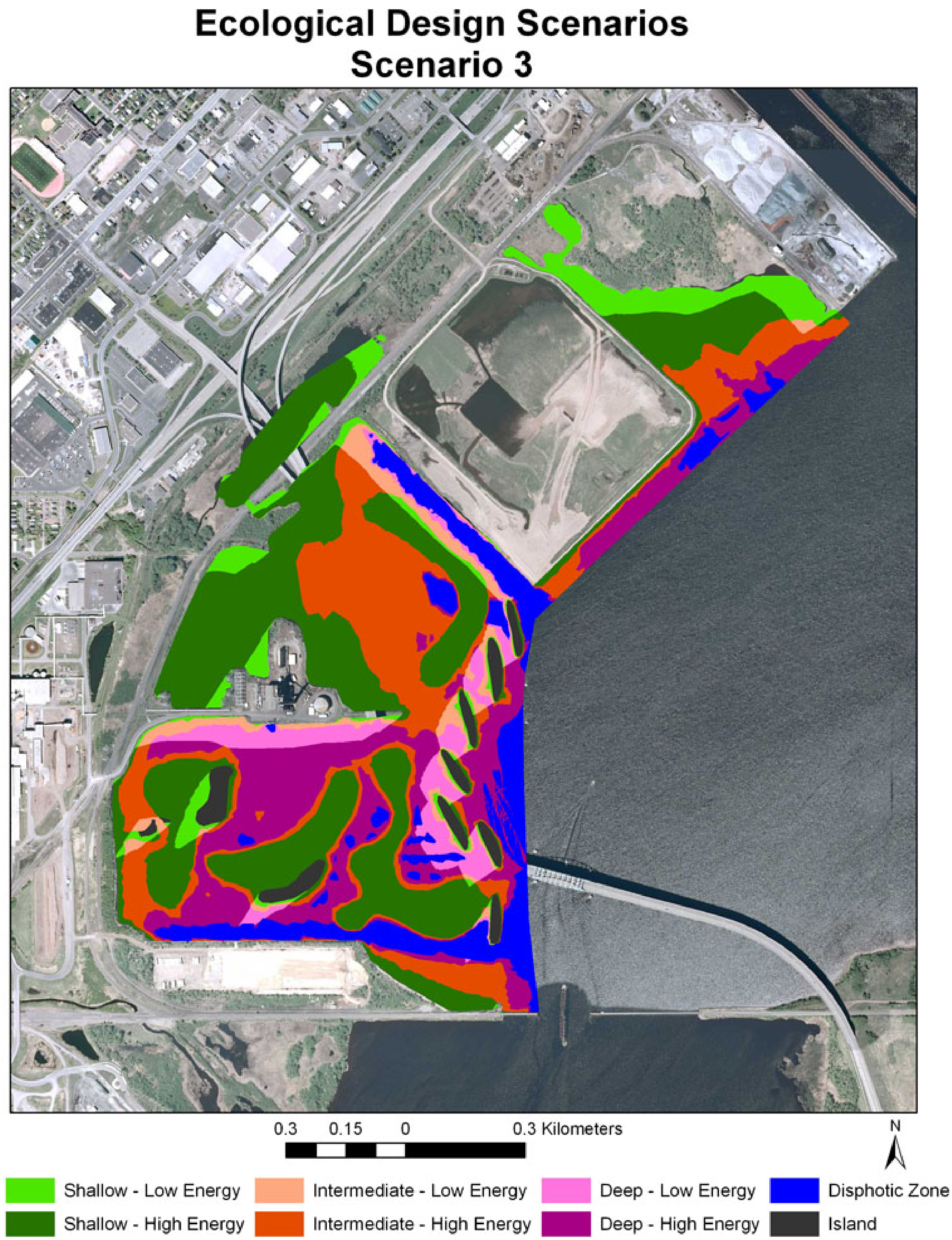

Figure 19. Summary of habitat types based on depth and potential energy: Scenario 3.

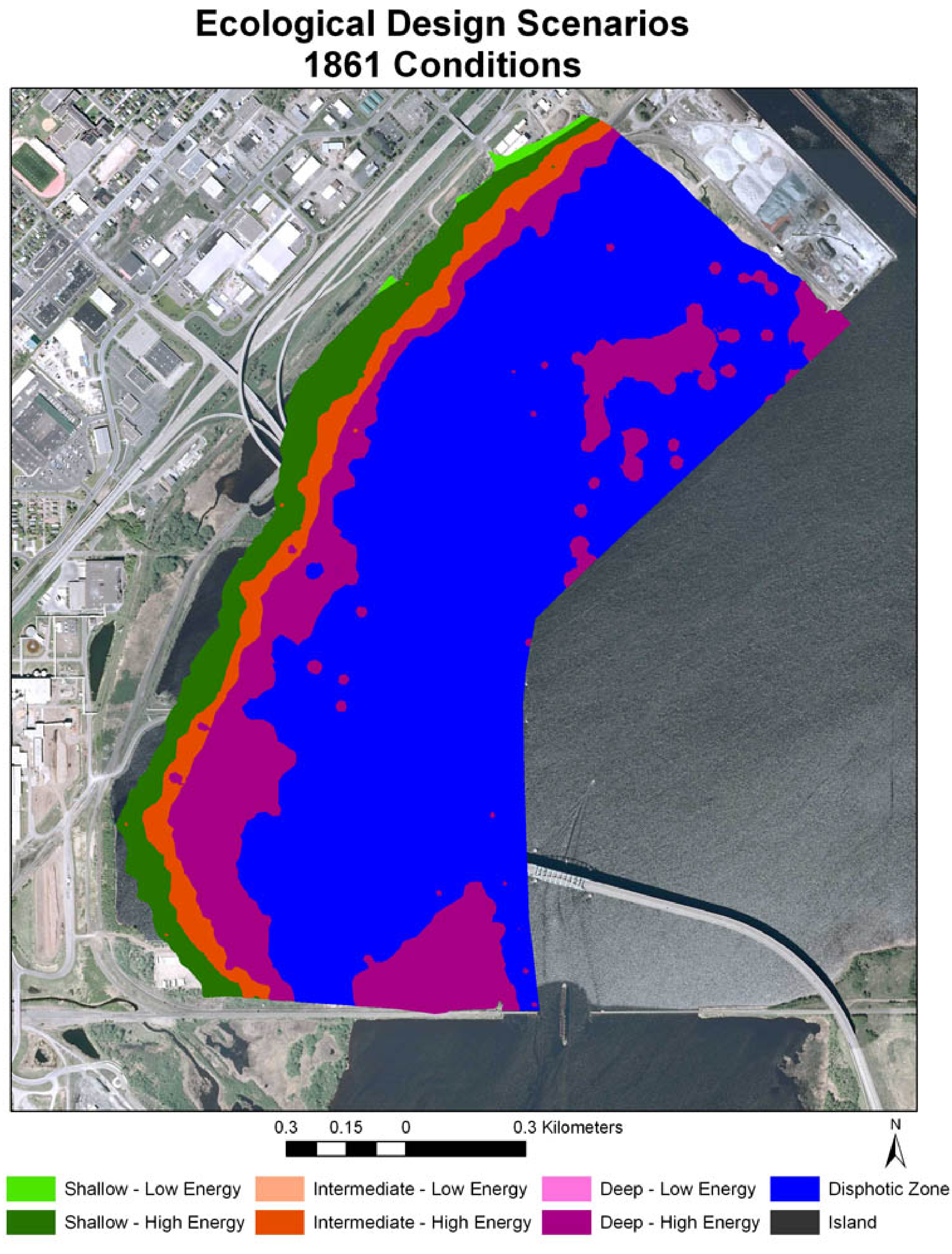

Figure 20. Summary of habitat types based on depth and potential energy: Scenario 4 (1861)

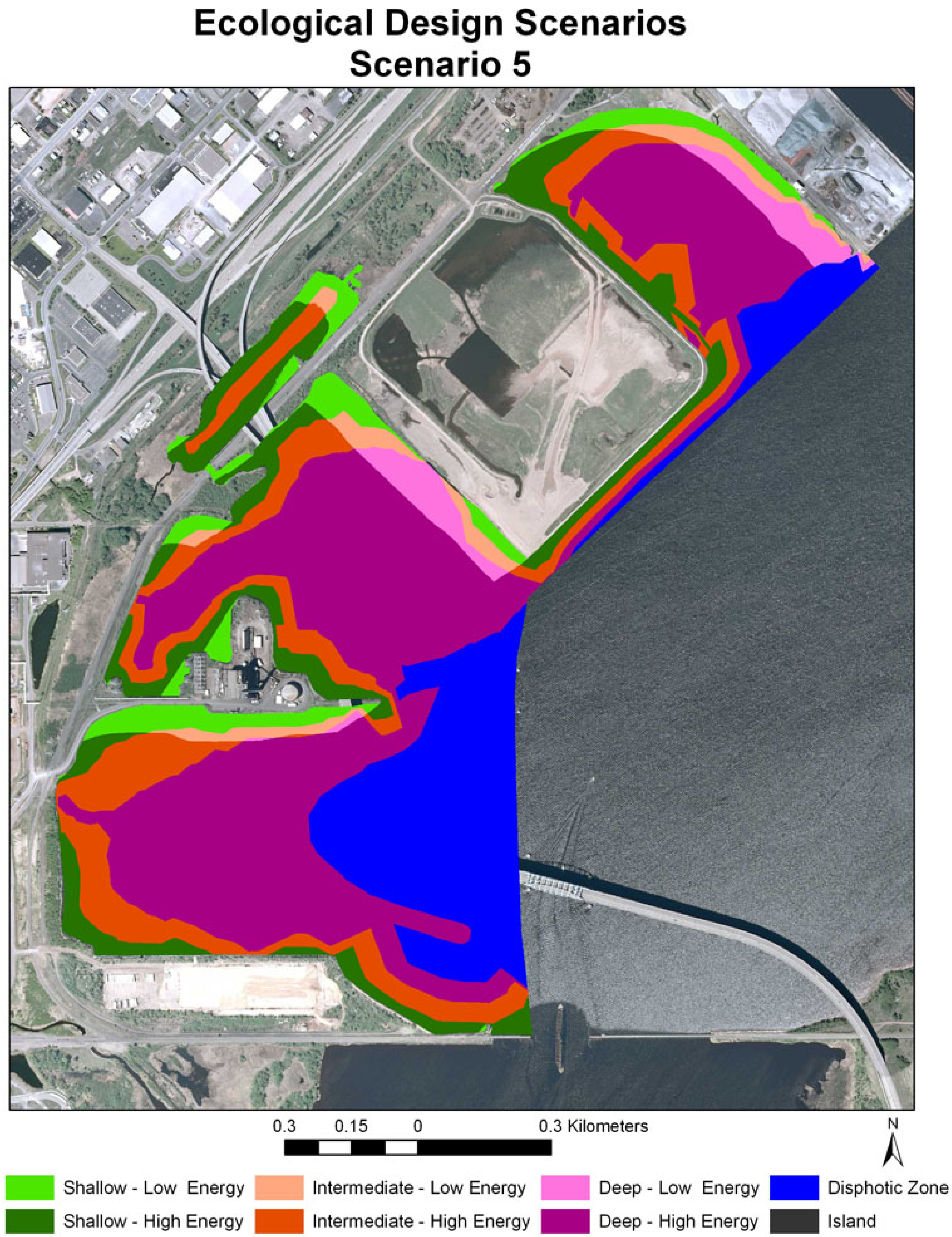

Figure 21. Summary of habitat types based on depth and potential energy, Scenario 5

Island areas ranged from 0 to 12.3 ac. (Table 6). Maximum shallow/ low energy habitat was achieved with Scenario 3, approximately 30% more than the current condition. Maximum intermediate/low energy habitat was achieved with the two-island Scenario 2. The 1861 levels based on the Hearding Map placed most of the project area in the deep-high energy or disphotic zone. This is likely due in part to amounts of fill added to create the current shoreline and the lack of fetch-disrupting features.

Table 6. Summary of ecological design scenarios for area (ac) of physical habitat.

Category	Physical Habitat	Current Condition (acres)	Scenario 1 - 3 island	Scenario 2 - 2 island	Scenario 3 - 9 island	Scenario 4 1861 level	Scenario 5 Land Trust
1	Shallow (< 0.65 m) - Low Energy	19.3	30.5	20.8	20.7	1.7	22.2
2	Shallow (< 0.65 m) - High Energy	70.4	85.6	75.0	112.5	45.2	42.0
3	Intermediate (< 0.65 - 1.6 m) - Low Energy	8.4	9.5	14.7	12.1	0.0	10.8
4	Intermediate (< 0.65 - 1.6 m) - High Energy	61.0	75.2	69.8	65.9	30.0	56.8
5	Deep (1.6 - 2.5) - Low Energy	7.7	8.4	9.3	15.5	0.0	11.6
6	Deep (1.6 - 2.5) - High Energy	105.7	67.5	83.9	53.9	103.9	150.8
7	Disphotic zone (> 2.5 m)	52.2	37.1	41.5	35.2	335.0	69.8
8	Island area	0.5	11.3	10.0	12.3	0.0	0.0
	TOTAL ACRES	325.2	325.1	325.0	328.1	515.8	364.0

Benthic Macroinvertebrates: Current Conditions and Predicted Response to Ecological Design Scenarios

Current status of the benthic macroinvertebrate community in the project area and reference area has previously been reported (Brady *et al.* 2010). We used Spearman Rank Order correlations (SigmaPlot ver. 11) to assess benthic community responses to physical habitat types. Habitat variables of interest include the aquatic plant community (emergent, floating leaf, or submergent), percent vegetative cover (continuous variable); water depth (as a categorical variable of shallow, deep, or disphotic [Table 6]; and as a continuous variable); substrate type (categorical), fetch distance (a continuous variable and a categorical variable of low energy, intermediate energy, and high energy); and finally an overall habitat category using the depth-exposure classes as shown in Table 6.

Unfortunately, there were too few data points and/or insufficient variability in our benthos data set from the 40th Avenue West Complex project and reference area locations to test some of these relationships. In particular, there were almost no benthos samples dominated by emergent or floating leaved vegetation types, and almost all substrate types were silt or sand.

We did, however, find some interesting relationships with habitat (depth-exposure) categories, percent vegetative cover, and fetch distance. For example, taxa richness is significantly positively correlated with increasing westerly fetch distance (Figure 22), but the relationship is largely driven by three reference area points. These points may have better benthos habitat for reasons other than westerly fetch.

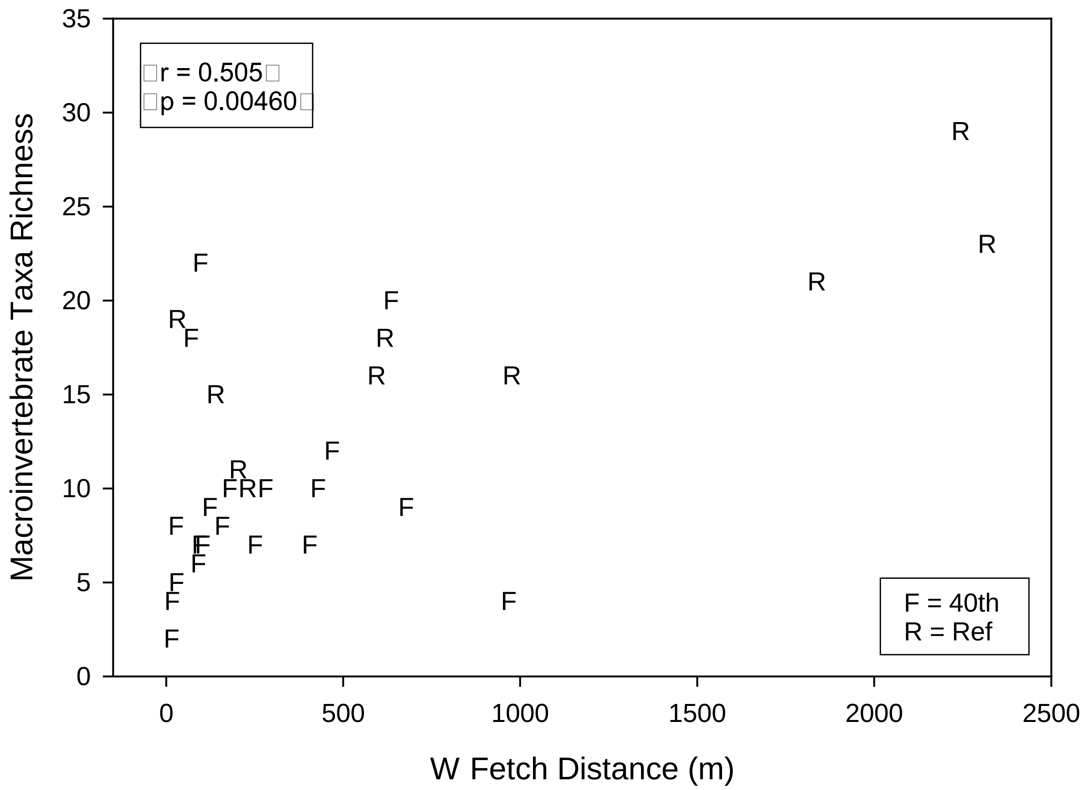

Figure 22. Taxa richness is significantly positively correlated with increasing westerly fetch distance. Project area locations at 40th Ave W. are indicated by an F, while reference area locations are indicated by an R.

Abundance of taxa (as measured by number of individuals per square meter) has the opposite relationship with exposure, and this is shown most strongly in the depth-exposure categories. Macroinvertebrate abundance is higher in shallow depths with low exposure (category 1, Figure 23), and decreases to lower abundances at deep depths with high exposure (category 6). Note that only one sample was collected in the disphotic zone (category 7).

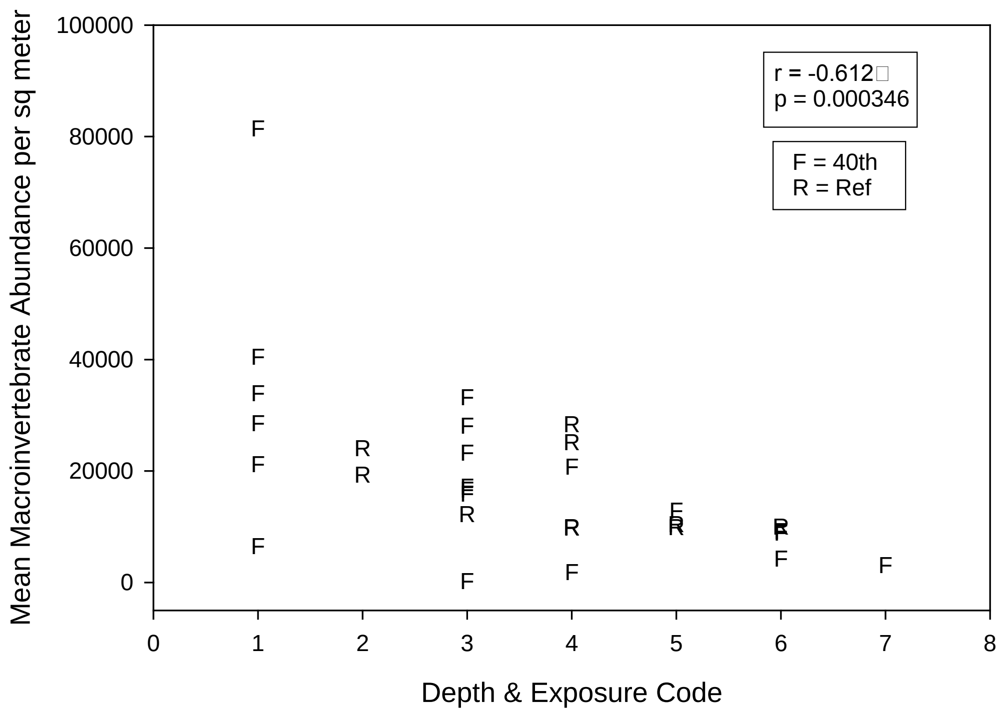

Figure 23. Maximum macroinvertebrate abundance values decrease with increasing depth and energy environments.

A wide range of species richness was found in many of the habitat types, and consequently there was no statistical difference in mean richness across categories. The upper boundary of species richness (i.e. greatest richness in each habitat type) at the 40th Ave sites however, does show a decline in species richness as the depth and energy environments increase (Figure 24). Specifically, there is a separation between sites 1-3, which had maxima above 20, and the high energy or deep sites (categories 4 and above) that had 12 or fewer taxa. Consequently, we can interpret scenarios that increase the area in classes 1 and 3 as conducive to promoting macroinvertebrate species richness (Table 7). With respect to restoration options, Scenarios 1 and 2 provide the greatest increases in these habitat types, at 11 and 6 acres of new habitat, respectively. It is important to note, however, that overall the macroinvertebrate community of the estuary will benefit most from having a wide variety of habitat types available.

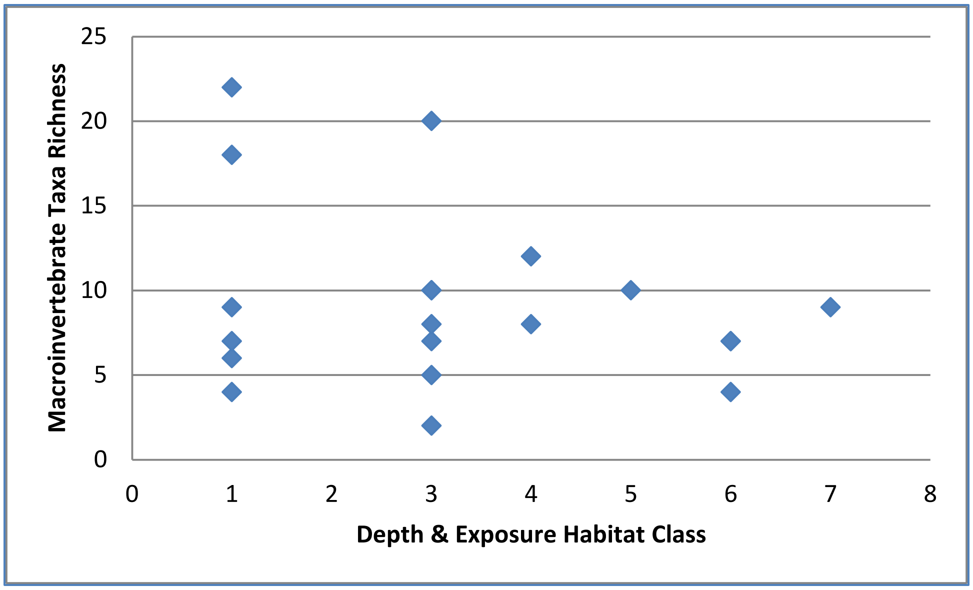

Figure 24 Maximum species richness decreases with increasing depth and energy environments.

Table 7. Change in habitat area (acres) by scenario to promote macroinvertebrate species richness (Low Energy)						
	Current Condition (acres)	Scenario 1 - 3 island	Scenario 2 - 2 island	Scenario 3 - 9 island	Scenario 4 1861 level	Scenario 5 Increased shallow habitat
Shallow (< 0.65 m) - Low Energy	19.3	**11.2**	**1.5**	**1.4**	**-17.6**	**2.9**
Shallow (< 0.65 m) - High Energy	70.4	15.2	4.6	42.1	-25.2	-28.4
Intermediate (< 0.65 - 1.6 m) - Low Energy	8.4	**1.1**	**6.3**	**3.7**	**-8.4**	**2.4**
Intermediate (< 0.65 - 1.6 m) - High Energy	61.0	14.2	8.8	4.9	-31.0	-4.2
Deep (1.6 - 2.5) - Low Energy	7.7	0.7	1.6	7.8	-7.7	3.9
Deep (1.6 - 2.5) - High Energy	105.7	-38.2	-21.8	-51.8	-1.8	45.1
Disphotic zone (> 2.5 m)	52.2	-15.1	-10.7	-17.0	282.8	17.6
Island area	0.5	10.8	9.5	11.8	-0.5	-0.5

There has been considerable interest in the burrowing mayflies of the family Ephemeridae, which contains the genera *Hexagenia* and *Ephemera* and represent an important food source to many fish species. Anecdotal evidence suggests that these mayflies are experiencing resurgence in the estuary. Burrowing mayflies tend to be large (for macroinvertebrates) and are of great interest to fly fishermen who like to 'fish the hatch', which is the emergence of the burrowing nymph as it floats to the surface and becomes an aerial sub-adult. The mayflies are quite vulnerable to fish predation during this short period. Burrowing mayflies are also quite sensitive to low dissolved oxygen levels, and are used as indicators of oxygen conditions in the Great Lakes and other areas, particularly in western Lake Erie (c.f., Krieger 1999). Because the nymphal stage of burrowing mayflies often lasts 1-2 years, presence of these mayflies is an indicator of acceptable oxygen conditions over that time period. The apparent recovery of burrowing mayflies in the estuary in recent years speaks well of dissolved oxygen conditions in these locations.

Only *Hexagenia* (the larger of the two burrowing genera) was collected in the St. Louis River estuary during this project (although we had some small and/or damaged individuals that we were unable to identify below the family level). Point locations of all benthos samples, with separate color-coding for points where *Hexagenia* was found, are shown in Figure 25. Habitat characteristics of points with *Hexagenia* versus all points sampled are shown in Table 8.

Table 8. Habitat characteristics of points containing the burrowing mayfly, *Hexagenia,* from project and reference areas.

Characteristic	*Hexagenia* locations	All locations
Sediment type	Silt or sand	92% of all points sampled were silt or sand
Depth	1.8 m (range 0.5 – 6 m)	2.5 m (0.1 – 10 m)
Vegetation percent cover	13% (range 0-75%)	11% (range 0-90%)

Other researchers have shown that *Hexagenia* has clear substrate preferences, preferring silt or silty mud to sandier substrates (Blouin *et al.* 2004). Larger nymphs appear to be unable to maintain their burrow structure in sand and larger particle sizes. Because we characterized substrate simply by feel, rather than doing a formal particle size analysis, our sediment classes are rather imprecise and may not accurately reflect the true substrate preferences of *Hexagenia* in the estuary. *Hexagenia* also shows a clear preference for large amounts of organic detritus in sediments, and substrate texture and organic matter content appear to be more important than depth (Blouin *et al.* 2004). Interestingly, *Ephemera* (the smaller burrowing mayfly genus) prefers coarser substrates (sand or even sandy gravel) with much less organic matter (Blouin *et al.* 2004), so coarser substrates may select for other burrowing mayfly taxa. However, we did not find *Ephemera* in any samples.

In our study, *Hexagenia* was less averse to vegetated substrate than expected. We found *Hexagenia* in up to approximately 75% vegetative cover (Table 8), although it made up a greater proportion of sample abundances at lower vegetative cover (Figure 25). Note that the negative correlation between proportion *Hexagenia* in samples and vegetative cover was not significant and is not particularly strong (Figure 26).

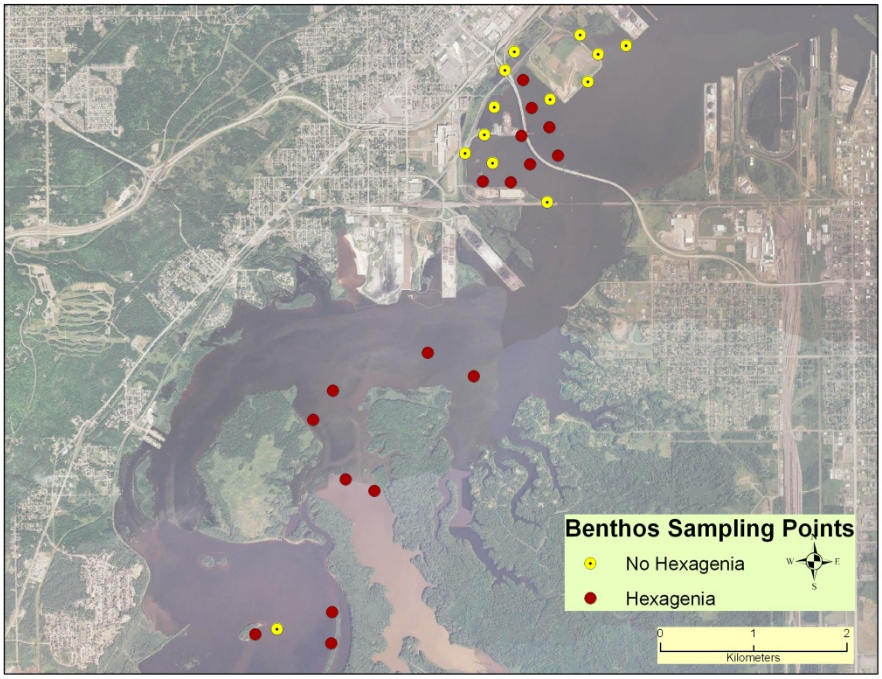

Figure 25. Benthos sampling points in the project area (top of picture) and the reference area (center and bottom). Locations are color-coded by presence or absence of the burrowing mayfly *Hexagenia*

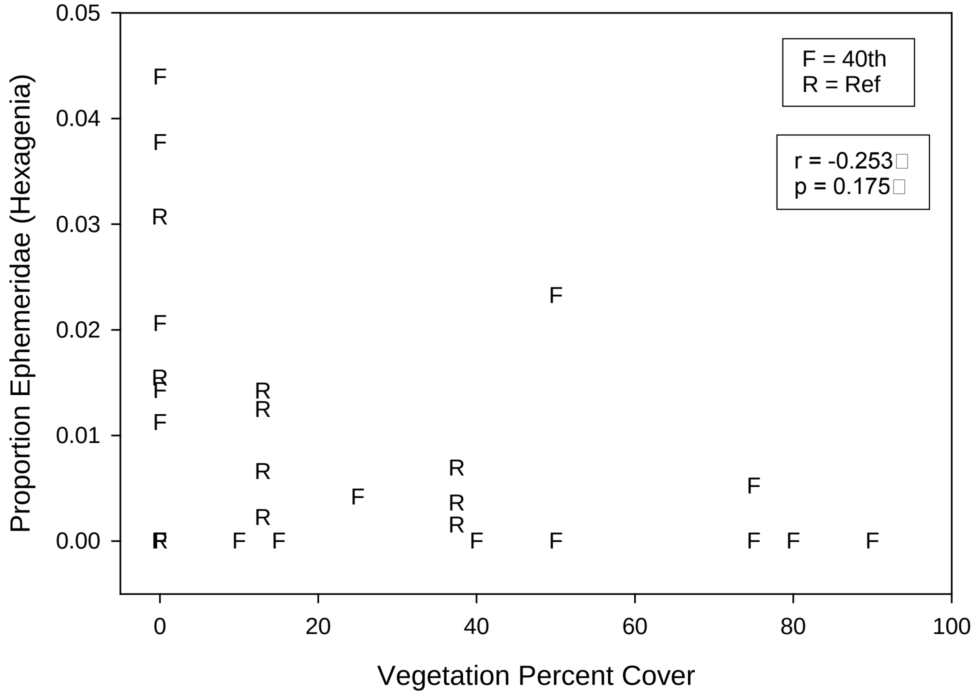

Figure 26. The mayfly genus *Hexagenia* exhibits a nonsignificant trend toward greater proportions of sample abundances at points with less vegetative cover. F =project area points; R = reference area points.

In spite of the overall increase in macroinvertebrate abundance at shallower depths, *Hexagenia* made up a significantly greater proportion of invertebrate sample abundance at points with greater depth and exposure, as shown in the correlation between proportion and depth-exposure categories (Figure 27). This correlation was strong (r = 0.62) and highly significant (p < 0.001). *Hexagenia* abundance was highest in the intermediate to deep water categories, relatively independently of the exposure regime (Figure 27). Restoration scenario 5, which increases both shallow and deep habitat, provides 66 acres of deep conditions favorable to *Hexagenia*. Scenario

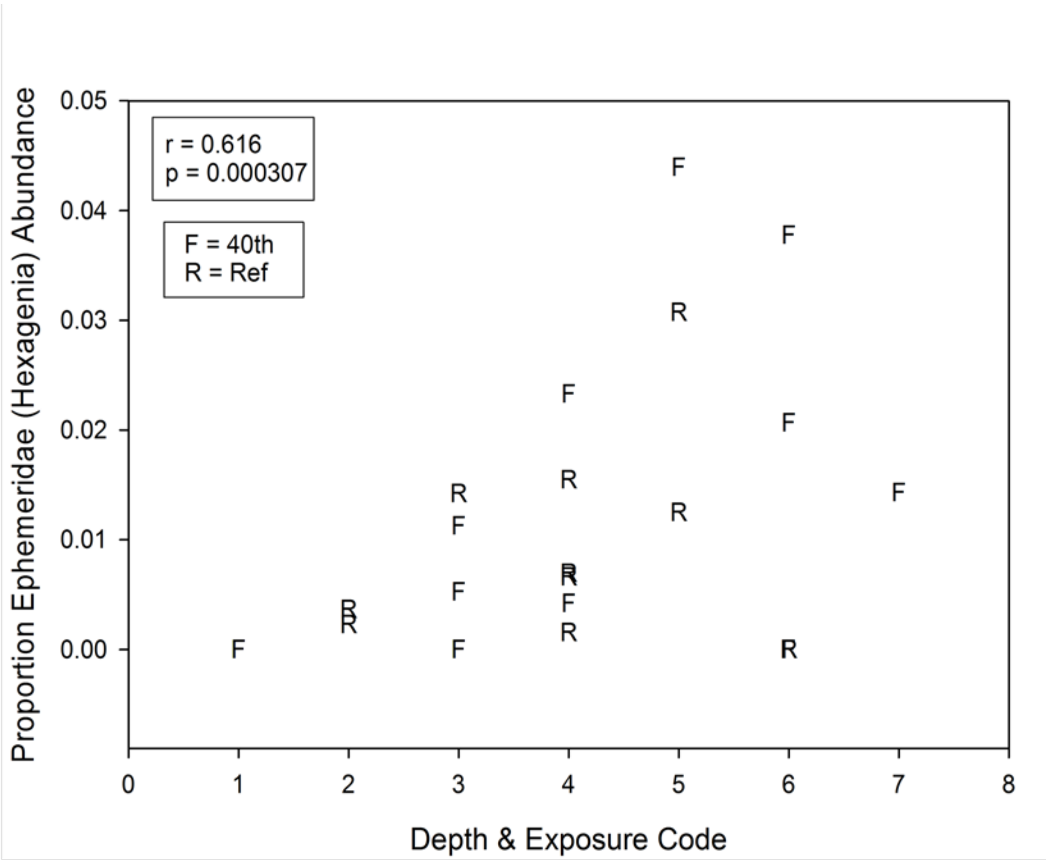

Figure 27. The mayfly genus *Hexagenia* makes up a greater proportion of the invertebrates at points with greater depths and more exposure. F = project area points; R = reference area points.

3 adds approximately 8 acres of deep habitat. Note that Scenario 4, which is based on 1861 conditions and removes the Erie Pier site, produces an additional 283 acres of deep water (> 2.5 m) habitat.

Taken together, the macroinvertebrate data suggest that a variety of depths and exposure amounts will provide a variety of habitats that many different invertebrates can use. This includes habitats often considered less desirable: deeper waters and greater exposure.

Table 9. Change in habitat area (acres) by scenario for favorable Hexagenia habitat. (Intermediate to Deep Habitat)						
	Current Condition (acres)	Scenario 1 - 3 island	Scenario 2 - 2 island	Scenario 3 - 9 island	Scenario 4 1861 level	Scenario 5 Increased shallow habitat
Shallow (< 0.65 m) - Low Energy	19.3	11.2	1.5	1.4	-17.6	2.9
Shallow (< 0.65 m) - High Energy	70.4	15.2	4.6	42.1	-25.2	-28.4
Intermediate (< 0.65 - 1.6 m) - Low Energy	8.4	1.1	6.3	3.7	-8.4	2.4
Intermediate (< 0.65 - 1.6 m) - High Energy	61.0	**14.2**	**8.8**	**4.9**	-31.0	-4.2
Deep (1.6 - 2.5) - Low Energy	7.7	**0.7**	**1.6**	**7.8**	-7.7	**3.9**
Deep (1.6 - 2.5) - High Energy	105.7	-38.2	-21.8	-51.8	-1.8	**45.1**
Disphotic zone (> 2.5 m)	52.2	-15.1	-10.7	-17.0	**282.8**	**17.6**
Island area	0.5	10.8	9.5	11.8	-0.5	-0.5

Avian Communities: Current Conditions and Predicted Response to Ecological Design Scenarios

The current status of the avian community was reported by Niemi et al (2011) based on weekly surveys of the 40th Avenue West Complex Project Area during the fall migration season (August to November 2010), breeding season (June 2011), and spring migration season (March to May 2011). The weekly surveys were designed to capture a complete count of birds using the area during each survey, which has been found to be a particularly useful technique for species associated with water, such as waterfowl, waterbirds and shorebirds, and less effective for songbirds, raptors and gulls that are often moving through the area, utilizing multiple locations and not necessarily associated with aquatic habitats.

Over 13,500 individual bird observations were made during fall, spring and breeding seasons. The pattern of observations show clear associations between different groups of birds and habitat features such as islands, the shallow points west of Erie Pier, and other nearshore areas (Figure 28).

We quantified the distribution of bird observation points with respect to the Depth/Exposure habitat types and aquatic vegetation communities mapped in the ecological design phase. As noted in Niemi et al (2011), species such as songbirds, raptors, and corvids associated with land, utilized both the coastlines as well as the existing islands in the project area. Shorebirds preferred shallow habitats, both high (63% of occurrences) and low energy (25% of occurrences); 13% of shorebird occurrences were found on land (Table 10). Waterbirds and waterfowl were preferentially found in shallow – high-energy conditions (46 and 35% respectively), but also in shallow-low energy habitats (22 and 27% respectively).

Table 10. Percent of total observations among bird communities by Depth-Exposure categories.

Species Group	shallow - low	shallow - high	intermediate - low	intermediate - high	deep - low	deep - high	disphotic	land
Corvid	0.12	0.12	0.00	0.03	0.03	0.00	0.03	0.67
Gull	0.08	0.45	0.00	0.18	0.00	0.04	0.03	0.22
Raptor	0.17	0.08	0.00	0.08	0.00	0.00	0.00	0.67
Shorebird	0.25	0.63	0.00	0.00	0.00	0.00	0.00	0.13
Songbird	0.13	0.10	0.00	0.00	0.00	0.00	0.00	0.77
Waterbird	0.22	0.46	0.01	0.12	0.00	0.12	0.01	0.06
Waterfowl	0.27	0.35	0.01	0.10	0.00	0.02	0.03	0.22

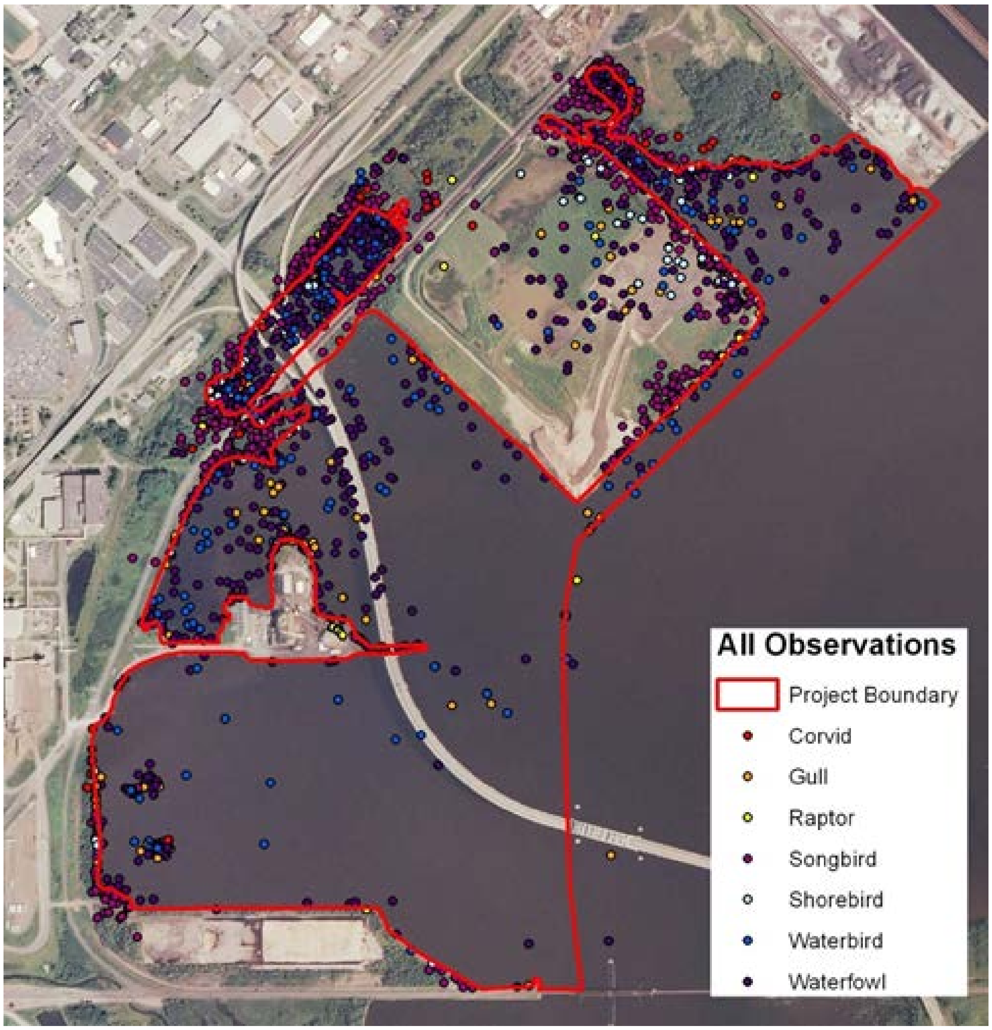

Figure 28. Distribution of all bird observations at the 40th Avenue West Complex project area site.

Scenarios 1, 2 and 3 all increased accessible land area in the form of islands, all on the order of 10 acres of new habitat which could promote songbird, shorebird, and waterbird occupancy Table 11). For example, this new habitat could potentially provide nesting habitat for the Common Tern, a threatened species in Minnesota, known to nest at nearby Interstate Island.

Increasing shoreline habitat will encourage use by a variety of shorebird species for both breeding birds and those using the area during migration. Scenario 3 provides the greatest increase – 42 acres in shallow, high-energy habitat preferred by shorebirds. Scenario 1 added approximately 26 acres of shallow habitat (low and high energy combined).

Table 11. Change in habitat area (acres) by scenario for favorable Songbird (land), Waterbird and Waterfowl (Shallow <0.65 m) habitat.

	Current Condition (acres)	Scenario 1 - 3 island	Scenario 2 - 2 island	Scenario 3 - 9 island	Scenario 4 1861 level	Scenario 5 Increased shallow habitat
Shallow (< 0.65 m) - Low Energy	19.3	**11.2**	**1.5**	**1.4**	-17.6	2.9
Shallow (< 0.65 m) - High Energy	70.4	**15.2**	**4.6**	**42.1**	-25.2	-28.4
Intermediate (< 0.65 - 1.6 m) - Low Energy	8.4	1.1	6.3	3.7	-8.4	2.4
Intermediate (< 0.65 - 1.6 m) - High Energy	61.0	14.2	8.8	4.9	-31.0	-4.2
Deep (1.6 - 2.5) - Low Energy	7.7	0.7	1.6	7.8	-7.7	3.9
Deep (1.6 - 2.5) - High Energy	105.7	-38.2	-21.8	-51.8	-1.8	45.1
Disphotic zone (> 2.5 m)	52.2	-15.1	-10.7	-17.0	282.8	17.6
Island area	0.5	**10.8**	**9.5**	**11.8**	-0.5	-0.5

Current Status of the Fish Assemblage Current Conditions and Predicted Response to Ecological Design Scenarios

Based on available trawl net, fyke net, electro-fishing, and fixed gill net catch data, the fish assemblage comprises 27 fishes species (J. Hoffman, J. Lindgren pers. com.). Catches from the combined trawl net, fyke net, and electro-fishing data are dominated by spottail shiner (*Notropis hudsonius*). Catches from the gill net were co-dominated by rock bass (*Ambloplites rupestris*), white sucker (*Catostomus commersonii*), walleye (*Sander vitreus*), and yellow perch (*Perca flavescens*), ranging from 14% to 22% of the catch. Together, the two data sets indicate that most fish in the project area are using sandy flats, rocky margins, and deeper, channel habitat, and that a smaller portion of fishes present rely on vegetated habitat. This interpretation is consistent with the current habitat conditions within the project area.

To describe the fish assemblage, catch data from the joint US EPA and USFWS aquatic invasive species early detection surveys from the sampling years 2006, 2008, and 2009 were combined following Peterson *et al.* (2011). In those three years, 11 sampling events within the project area or adjacent shipping channel were conducted (5 electro-fishing samples, 3 fyke net samples, and 3 trawling samples). Sampling was conducted as described by Peterson *et al*. (2011). Based on combined data from three gears, the four most common fish comprised 75% of the assemblage (by abundance). These fish were (in descending rank order) spottail shiner, young-of-year sunfish (both bluegill, *Lepomis macrochirus*, and pumpkin seed, *Lepomis gibbosus*), mimic shiner (*Notropis volucellus*), and troutperch (*Percopsis omiscomaycus*). Three of these species, spottail shiner, mimic shiner, and troutperch, prefer sandy environments. Fish species that prefer aquatic habitat with intermediate vegetation, yellow perch, and northern pike (*Esox lucius*) were less abundant or rare (<5%) in the project area. Fish that prefer rocky margins (rock bass and smallmouth bass, *Micropterus dolomieu*), and deep channel habitat (walleye and channel catfish, *Ictalurus punctatus*) were rare. Ruffe were the most abundant non-native species; in total, all non-native species captured comprised 8.3% of the catch. On a pooled basis, 91 fish were caught per sampling event, whereas 196-311 fish per sampling event using a similar gear mix were sampled estuary-wide during the same time-frame (based on over 200 samples; Hoffman *et al.* 2011). This implies that the project area supports fewer fish than the estuary taken as a whole.

To describe the large-bodied, adult fish assemblage, catch data from the Minnesota Department of Natural Resources annual gillnet survey for the same years (2006, 2008, and 2009; two gillnets per year) were combined. The survey uses a fixed, graded-bar mesh gillnet (graded-mesh was 1.9, 2.5, 3.2, 3.8, and 5.1 cm). In those three years, six sets were conducted and 119 fish captured. Compared to the joint US EPA and USFWS data, fish that prefer rocky margins (rock bass, shorthead redhorse, *Moxostoma macrolepidotum*), and deep channel habitat (walleye, Eurasian ruffe) were slightly more abundant whereas fish that prefer vegetated habitat (yellow perch) comprised a similar portion of the catch. Ruffe were again the most abundant non-native species captured; all non-native species comprised 12.6% of the catch.

Framework for Projecting Restoration Effects on the Local Fish Assemblage

To qualitatively predict fish assemblage change as a function of habitat availability and primary production the following strategy was used. Common, index fish species were grouped into habitat type affiliations by life stage, focusing on adult fish habitat and nursery habitat (spawning and juveniles). Corresponding metrics were proposed that measure habitat availability as area or linear distance (e.g. length of perimeters) and primary production as the area of habitat suitable for benthic primary production (<1.5 m depth). These metrics can readily be summarized from the outputs of the aquatic vegetation model. Under the framework, relative composition of the fish assemblage varies directly with the amount of each habitat type. Affiliations for adult fish and spawning fish are as follows (* = fish species that utilize the habitat type for spawning):

> *Sand affiliated* - species positively associated with sandy, non-vegetated, open areas within the photic zone: spottail shiner*, trout perch, mimic shiner, Johnny darter, and emerald shiner*.
>
> > Metric: sum of areas within the photic zone (<1.5 m depth) and that are non-vegetated (shallow-high energy + intermediate-high energy). The models predicted approximately 80 ac of sand affiliated habitat under the current condition.
>
> *SAV affiliated* –species positively associated with the interior of submerged and emergent vegetation beds: yellow perch*, bluegill, pumpkinseed, largemouth bass, juvenile bass and sunfish (incl. black crappie). The invasive, non-native tubenose goby is also known to positively associate with this habitat type (Table 12).

Metric: sum of areas within the photic zone (<1.5 m depth) and that are vegetated (shallow-low energy + intermediate-low energy + deep-low energy + deep-high energy).

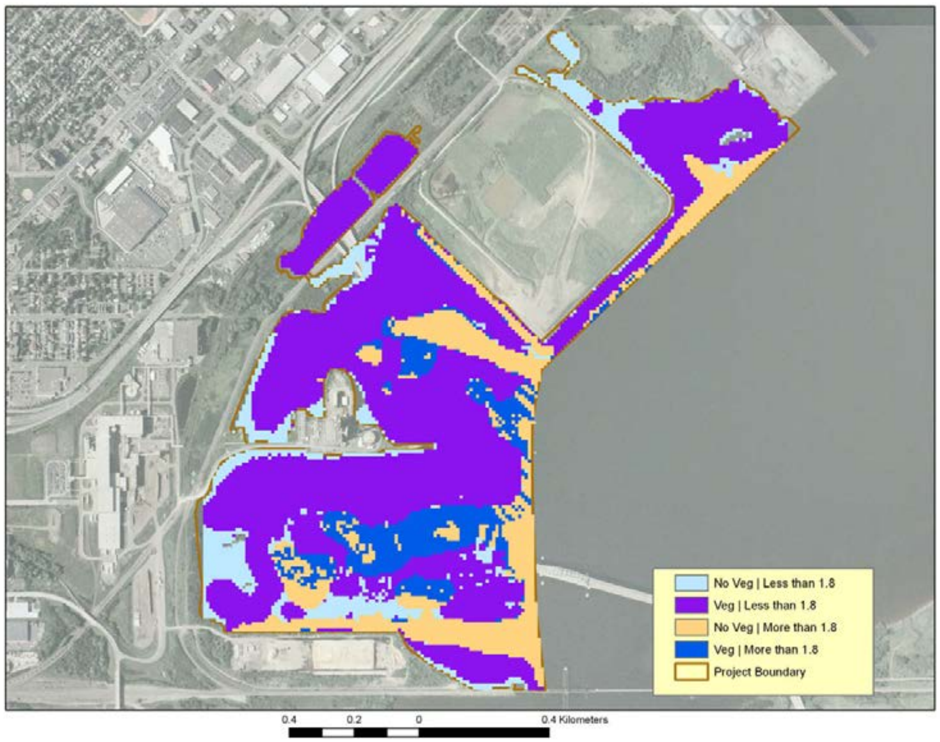

Figure 29. Habitat for sand and aquatic vegetation-affiliated fish communities.

Edge affiliated –species positively associated with the transition between vegetated and non-vegetated areas within the photic zone: muskellunge, northern pike, juvenile smallmouth bass, largemouth bass, bluegill (spawning only)*, black crappie (spawning only)*.

Metric: sum of the perimeters of all vegetation polygons within photic zone. Estimate for current conditions is 7403 m.

Physical structure affiliated –species positively associated with boulder clusters, root wads, and other 'hard' features: smallmouth bass*, walleye, black crappie, largemouth bass (spawning only)*.

Metric: sum of the perimeters surrounding all hard structures (rip-rap, structure footings).

Deepwater and channel affiliated –species positively associated with utilizing the disphotic zone: walleye and channel catfish.

Metric: sum of areas at depths >2.5m, length of line separating channel and deep habitat (<3 m) from shallow habitat. The area for the current condition is 285.7 ac

Benthic production – a proxy for total energy available to higher consumers.

Metric: sum of areas at depths <1.5 m. The area for the current condition is 536.4 ac

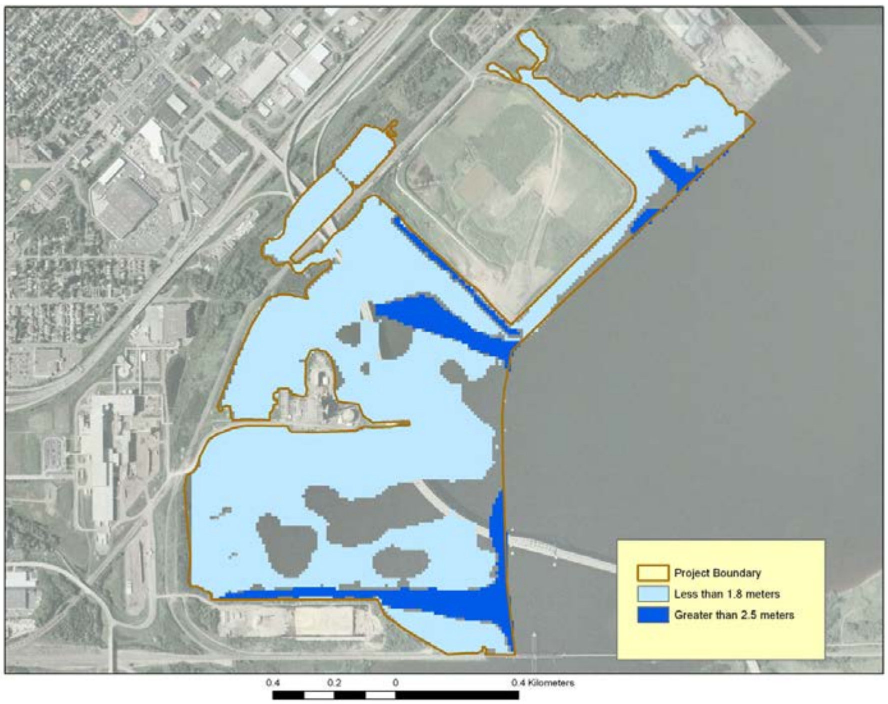

Figure 30. Deepwater and channel affiliated habitat, and shallow areas for benthic production.

Table 12. Change in habitat area (acres) by scenario for aquatic vegetation affiliated fish species (yellow perch, bluegill, pumpkinseed, bass and sunfish).

	Current Condition	Scenario 1 - 3 island	Scenario 2 - 2 island	Scenario 3 - 9 island	Scenario 4 1861 level	Scenario 5 Increased shallow habitat
Emergent Marsh	24.6	34.2	12.8	22.2	-7.5	-3.8
Floating Leaf Aquatic Beds	29.2	101.4	44.2	66.9	-28.9	83.8
Submerged Aquatic Beds	104.5	-33.9	-20	-25.7	-37.5	48.3
Total Vegetation Area	158.3	101.7	37	63.4	-73.9	128.3

A desired output of the restoration at 40th Avenue West Complex is an increase in fish abundance. To realize an increase in fish biomass, the overall (gross) primary production associated with the site must also increase. The difference in area for which the bottom depth is

<1.5 m between a restoration alternative and the present condition can serve as a proxy to compare relative primary production because it represents the area available to support benthic primary producers (benthic algae, submersed vegetation, and emergent vegetation). With respect to the fish assemblage, an increase in recruitment (rather than biomass) is expected to be greatest for those species that are provided increased spawning habitat within the site.

Example Application of the Fish Assemblage Framework

The framework is applied by comparing projected effects on an index group (for example, sand affiliated species) under the four restoration alternative outcomes that are possible when comparing the restoration project to the current condition (Table 8). The four outcomes are increased benthic primary production (BPP) and habitat; decreased BPP and habitat; increased BPP and decreased habitat; and decreased BPP and increased habitat. Benthic primary production is measured by the relative amount of area <1.5 m in depth (see rationale and definition above). The qualitative framework characterizes a direction of change: ++ likely increase in fish number or biomass (relative to current conditions), + possible increase in fish number or biomass, - possible decrease in fish number of biomass, -- likely decrease in fish number or biomass. In the framework application, an increase in number is associated with stages directly related to greater fish reproductive success (spawning, nursery habitat), whereas an increase in biomass is associated with the adult life stage.

Table 8. Example of framework application with respect to sand-affiliated species.

Restoration alternative outcome	*Increased sand habitat*	*Decreased sand habitat*
Increased benthic primary production	++	-
Decreased benthic primary production	+	--

Ecotoxicology at 40th Avenue West Complex: Sediment and Fish Tissue

One of the major reasons for the listing of the St. Louis River as an area of concern (AOC) is because of the existing sediment chemical pollution. The project area has previously shown elevated levels of chemicals (heavy metals, polycyclic aromatic hydrocarbons [PAH], polychlorinated biphenyls ([PCB]) in the sediment) (Crane 2006). To help inform site characterization for the 40th Avenue West Complex project area, the US Fish and Wildlife Service completed a preliminary ecotoxicological evaluation by collecting additional surficial sediment and fish samples for chemical analysis. Results from this evaluation are intended to provide an initial understanding of three aspects: 1) are there elevated levels of chemicals in the 40th Avenue West Complex; 2) if so, where are these areas with elevated chemical levels; and 3) are these chemicals bioaccumulating in animals in the area? Addressing these questions will help further evaluate and design remedial alternatives necessary to achieve the final ecological design. In addition to this preliminary ecotoxicological evaluation, MPCA coordinated sediment sampling in the project area for chemical analyses in 2010 (47 locations) as part of a larger St.

Louis River-wide study. Results are pending and will be incorporated for further consideration as plans for the remediation and restoration continue.

Toxicology Methods

In 2011, 7 white suckers (*Catostomus commersonii*, WS) and 7 smallmouth bass (*Micropterus* dolomieu, SMB) were collected from locations within the project area and analyzed for whole-body chemical levels. Six surface sediment samples were also collected and analyzed for chemical levels (Figure 30). Fish tissue and sediment samples were analyzed for a suite of chemicals, including: heavy metals, organochlorines, aliphatic compounds, and aromatic compounds.

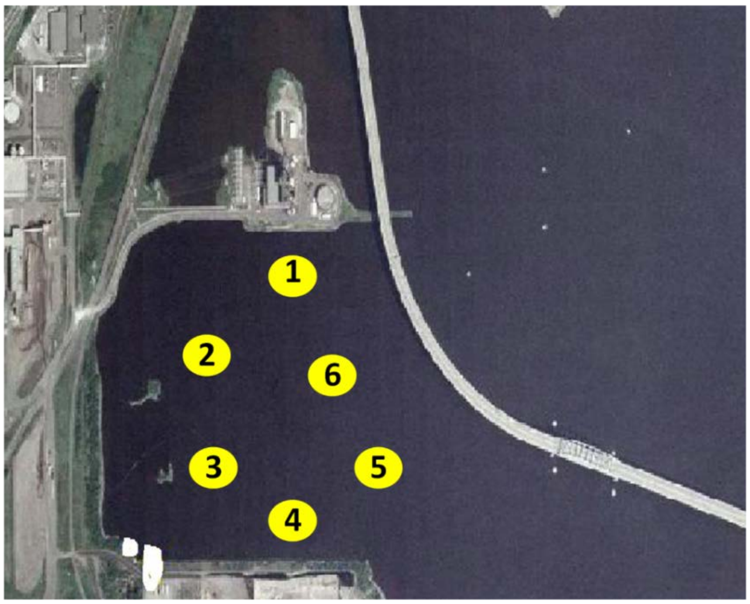

Figure 31. Sediment sample locations in the 40th Avenue West Complex project area.

Ecotoxicology Results

Sediments

Analyses of the six sediment samples from 2011 showed elevated levels of select chemicals in the 40th Avenue West Complex project area (Appendix 1). Where appropriate, chemicals were compared to sediment quality targets (SQT) that were developed for the St. Louis River AOC (Crane *et al.* 2000, 2002; Crane and MacDonald 2003). Concentrations above the Level II SQTs are anticipated to have harmful effects on sediment-dwelling organisms. Concentrations below Level I SQTs are anticipated to have no effects on sediment-dwelling organisms, and the effects of concentrations between Level I and Level II SQTs are unknown. Within the 40th Avenue West Complex site there were numerous chemicals had concentrations that exceeded Level II SQTs, and a majority of chemicals exceeded Level I SQTs.

The polycyclic aromatic hydrocarbons (PAHs) were the chemicals most often measured at elevated levels and were the only chemicals found above Level II SQT values. Concentrations of

PAHs as compared to SQT levels varied by PAH and location. The PAH 2-methylnapthalene exceeded Level II SQTs at all six locations. This would indicate that at all locations 2-methylnapthalene would be anticipated to have a harmful effect on sediment-dwelling organisms. Acenaphthalene, benzo(a)anthracene, naphthalene, phenanthrene and pyrene were all measured at concentrations above Level II SQTs at all locations except one. Other chemicals that were measured at concentrations between Level I and Level II SQTs include: Total PCBs, Total DDTs, O,p' DDD, dieldrin, zinc, mercury, nickel and lead.

Out of the six locations, Site 1 consistently showed the highest chemical concentrations. For all chemicals that had at least one measurement above Level II SQTs, Site 1 was always one of the elevated concentrations. For certain chemicals Site 1 was at levels well above Level II SQTs. Concentrations were approximately four times higher than Level II SQTs for 2-methylnapthalene and acenaphthalene, and over twice as high for benzo(a)pyrene and fluorene. Site 3 consistently showed the lowest chemical concentrations. For the remaining sites the concentration levels varied by chemical. These sediment results show similar varied chemical patterns as has been previously reported (Crane 2006).

Fish Tissue

Chemical analyses of fish tissues showed similar results to sediment chemical concentrations; concentrations varied both by chemical and by fish (Appendix 2). Chemical concentrations in fish tissue were compared to two other data sets. One data set is the U.S. Geological Survey Biomonitoring of Environmental Status and Trends Program (BEST). The BEST biomonitoring program collected and analyzed a select suite of chemicals in 1378 fish from 22 species at 47 different locations along the Mississippi River and its tributaries in 1995, along with one reference location. Chemical concentrations of fish from the St. Louis River were compared to the 50th percentile and 90th percentile levels from the BEST biomonitoring program. For evaluation of PAH concentrations, white suckers collected from the 40th Avenue West Complex were compared to white suckers (total of 9) collected from Stryker Bay in 2001 and 2002 (U.S. Fish and Wildlife Service unpublished data), a Superfund Site prior to remediation.

Average total PAH concentrations in white suckers from the 40th Avenue West Complex were slightly lower than white suckers from the Stryker Bay location, but also elevated as compared to the North Bay (reference) location. These high concentration levels in fish from the 40th Avenue West Complex indicate that PAHs are readily available to fish and potentially other ecological receptors for uptake and/or bioaccumulation, which supports the results of the sediment chemistry. The average concentration of Total PCBs in the fish was around the 50th percentile concentration from the BEST biomonitoring program. However, 4 of the fish had concentrations near the 90th percentile concentration, and one fish was measured at a concentration higher than the 90th percentile. While arsenic, copper, mercury and nickel measured in individual fish were at concentrations near or above the 90th percentile concentration, most of the chemicals were measured at average concentrations near the 50th percentile concentration.

Ecotoxicology Study Conclusions

From this preliminary ecotoxicological evaluation, it appears that the primary contaminants of ecological concern within the 40th Avenue West Complex are PAHs. Data also indicate that PCBs, mercury and nickel may be affecting ecological resources. These results from the limited sediment chemistry data also indicate that additional data (both surficial and deep) are necessary for select locations in the 40th Avenue West Complex in order to complete feasibility studies to accomplish ecological design goals. It is critical that the results from the 2010 sediment sampling coordinated by the MPCA be evaluated and incorporated into this analysis as soon as possible. These evaluations should focus on further defining the lateral and vertical extent of sediment contamination in the 40th Avenue West Complex, as well as addressing the potential for bioaccumulation and food chain effects of PAHs, PCBs, mercury, and nickel. Further, evaluations should follow the preferred ecological design alternative(s) for the project area; accordingly, results should support preliminary remediation goals for specific sites within the project area developed as part of a subsequent feasibility study.

Public /Stakeholders Outreach Efforts

Outreach Planning

The St. Louis River Habitat Team worked with Community GIS Services, Inc., Duluth, to produce a map of property ownership adjacent to and near the 40th Avenue West project site. The team used the property ownership map to identify stakeholders. All ownership adjacent and near the site consists of private business and public entities. Each of the businesses and public groups were contacted to identify key personnel who would best represent the interests of the stakeholders. Once the contact list was compiled, key personnel were contacted and offered the opportunity to meet with the design about the project and their interests in further involvement in the ecological design phase. A list of corporations, public entities, and businesses and detailed contact information are included with this report.

For the purpose of coordinating communications and combining presentations when possible, stakeholders were divided into three categories:

- Major corporations with land and/or operations adjacent to the site;
- Public entities and agencies with land and/or operations adjacent to or near the site;
- Small businesses operating near the project site

The ecological design team chose to meet individually with major corporate landowners to allow ample time for concerns and questions relevant to their operations. The design team presented to all public ownership groups at one meeting. Businesses from the third category (near the site) were invited to attend the public ownership stakeholders meeting.

Prior to each of the meetings, the property ownership map, a document describing the St. Louis River Estuary restoration efforts and a one-page introduction to the 40th Avenue West project were mailed to stakeholder key personnel. These materials are included with this report.

Meetings with Stakeholders

The ecological design team met individually with the major corporate landowners. Meetings were held with representatives from New Page Corporation, Duluth; Hallett Dock Company, Allete/Minnesota Power, CN Railroad, and BNSF Railroad. Prior to each of the meetings, a letter was sent with the property ownership map and a brief overview of the 40th Avenue West restoration project. Representatives of the corporation were asked to review the map for ownership accuracy and to consider the project from their perspective and to use the meeting time to ask questions or express concerns.

Following are the concerns and questions raised at the meetings with the five corporate property owners:

New Page
Diane Gobin, Environmental Supervisor; Matt Christenson, Communications Coordinator

- New Page has a water intake along Berwind slip used to make snow to pile on logs. Restoration designs should ensure adequate intake capacity for this operation.
- New page offered that they would like to maintain the option of for using the deep-water slip along the pier where they now store logs. This pier, the Berwind Dock, is owned by Minnesota Power and leased to New Page.
- New page has a ground water monitoring well system used to monitors\ for contaminants from Well 7, a superfund site.

Hallet Dock
Mike McCoshen, President; Jerry Fryberger, Chairman

- Hallett does not expect the project would impact their operations as their operations are on the other side of the dock.
- Hallett uses some of the railroad tracks but do not own them.
- Hallett mentioned that much of the wetlands and creak outfall south of Hallett are all growing on wood waste.

Aerial images indicate there maybe dumping on the site, but no mention was made of this. Ownership of the wetland area needs to be verified.

MN Power

Dave Pessenda, Renewable Business Operations Manager; Blake Francis, Supervisor, Water Quality & Waste Management

- MN Power has concerns regarding potential impacts to intake and outfall water-cooling system. Restoration design alternatives need to provide enough water depth and flow for the cooling system to operate.
- MN Power also stated the federal rules on entrainment are being updated and any changes may affect their current –or any future- intake entrainment protocol
- MN Power mentioned that they had evaluated the potential for expanding the footprint of the peninsula with Army Corps of Engineers by using dredge material, but decided against it at the time.
- Ownership question – MN Power owns the Berwind Dock but are not sure if they own the deepwater slip. *Legal ownership needs to be determined.*
- MN Power would consider utilizing removed wood waste as a renewable fuel.
- MN Power owns the Berwind Dock which is being used by New Page. MN Power suggested that the other half of the dock could potentially be considered for stockpiling removed waste from the project.

BNSF Railroad
Chuck VonRueden, Roadmaster

- Questions about the accuracy of the map of land ownership – BNSF suggested the team communicate with BNSF property management company to determine legal ownership and property boundaries.
- BNSF raised a concern, though not related to the 40th Avenue West Complex restoration project, about wood and other debris washing down Kingsbury Creek, affecting their culverts, bridges, and rail lines. It seems that there may be people clearing brush or trees along the creek and not removing the cut material from the floodplain.
- BNSF worked with the Hog Island project and experienced addressing the needs and issues related to access and property use during the restoration process.

CN Railroad -
Marl Erickson, Port Manager

- CN expressed no concerns at this time; would like to be informed as the project progresses

The following persons participated in a public stakeholder meeting.

Public Representatives

City of Duluth	Tim Howard, Facilities Manager
City of Duluth	Mark McShane, Property and Contract Manager
Duluth Seaway Port Authority	Jim Sharrow, Facilities Manager
MNDOT	Todd Campbell
MNDOT	Roberta Dwyer, Project Manager
St. Louis County	Mark Weber, Resource Management

	Supervisor	
St. Louis County	Karen Zeisler	

Business Invited *(attendance noted)*

Bayside Recycling	CJ (Chris) Goodwald	
Cedar Hill Partners	Gary Moline	
DMA & Associates (Demoliscious)	Diane Anderson	
ERA Labs	Bob Magnuson	*Attended*
Industrial Welders	Dawn Abernathy	
Eco Lab	Joe Kleiman	*Attended*
Kraus Anderson	Greg Wegler	
Lakehead Outdoor Advertising	Robert Brooks	
National Propane (Amerigas)	Manager	
Midwest Coca-Cola Bottling Co.	Greg Ladich	
WTW Construction	Weston Wehr	

Concerns and questions expressed by representatives:

- Public entities are interested in participating in planning and engineering of the conceptual plans – particularly in the re-use of dredge materials
- Concerns about the ownership of the bed by private entities; how jurisdiction (permissions and authority) are going to be addressed
- Design team suggested that the state of Minnesota needs to look into ownership of bed and jurisdiction issues

Questions Yet to Be Answered

Several issues were raised at the outreach meetings or in team discussions which require further investigation:

- Who is using the south side of the Hallett slip? (owned by Hallett but being used by another)
- Changes in federal rules on fish entrainment at water intakes and their potential impact to MN Power's cooling system.
- MN Power owns Berwind Dock but are not sure of the ownership of the deepwater slip
- Ownership of the river bed – who owns it, who has jurisdiction, how is this determined.

These outreach activities reached the major stakeholders and landowners in the Project Area, and raised the critical issues that needs to be address in order to move forward with restoration activities in the estuary. Coupled with the biological sampling information and the interpretations of the ecological design scenarios, we now have a suite of model-based results and public input that should effectively facilitate the decision-making process for developing and implementing a restoration design.

Putting it all Together: A Summary of Ecological Design Results

The scenario model runs and analyses derived from them provide guidance to inform future restoration options for the 40th Avenue West Remediation-to-Restoration site. The modeling effort identified which environmental factors were the best predictors of the occurrence of the three aquatic plant communities - depth, substrate, and wind fetch. The observed data showed relatively consistent depth thresholds for the three aquatic plant communities, providing a reliable basis for modeling conditions where a diversity of aquatic habitat is desired. Aquatic plant communities were more strongly associated with silt/clay or organic substrates, and less associated with sand, providing guidance on the type of materials that should be used for different restoration endpoints.

The model is based on empirical relationships, but was calibrated to fit the actual occurrence of aquatic communities observed at 40th Avenue West Complex. As a result, it may over-predict occurrence of vegetation at other sites, such as 21st Ave West. The model identifies the combinations of conditions that are most conducive to plant establishment and growth: low energy, appropriate substrates and optimal depths. But for many reasons outside the scope of the data used in the model (e.g. sediment contamination, grazing by geese and other water birds, individual extreme events, lack of seed source), the results are best interpreted as potential habitat. Understanding potential habitat, and the effects of the bathymetric changes, fetch disruption, and substrate alterations presented in the five scenarios, should prove useful for devising remediation strategies to restore aquatic plant communities 40th Avenue West Complex, with corresponding increases in habitat for macroinvertebrates, fish and birds.

Initial results from a limited sampling of sediments and fish indicate that remediation of sediment contamination will be an important step on the R-to-R process. PAHs were found at concentrations that impact sediment-dwelling organisms at each of the six sample sites. PCBs, DDT, mercury and lead were among the chemicals above Level I SQT concentrations. Analysis of PAH and other chemicals in fish tissues corroborates the results from the sediment sampling, and it is reasonable to infer that these toxins are present in the other key parts of the food chain, such as macroinvertebrates and birds. Since many of the restoration techniques involve dredging or other disturbance to sediments, it will be critical to understand the concentrations and spatial distribution of sediment-borne contaminants prior to initiating restoration activities that involve sediment disturbance. Of the scenarios presented above, scenarios 4 and 5 involve creation of additional deep habitat, and are most likely to have associated toxicological problems. Scenarios 1-3 create islands or increase depth, but toxin issues with materials used in restoration and disturbance to existing sediments during restoration activities will be important considerations.

Additional data (both surficial and deep) is needed to develop a better understanding as to the extent of sediment contamination, as well as the potential for bioaccumulation and food chain effects of specific contaminants. The additional data will support preliminary remediation goals for specific sites (as developed by a subsequent feasibility study) and direct remediation needs within the project area, which will be incorporated along with the restoration goals.

The model outputs based on the various scenarios predict that changes in depth and energy environments will have diverse effects on increasing or decreasing habitat for biota of the estuary. Macroinvertebrate diversity is predicted to increase if low energy environments are increased at both shallow and intermediate depths. Scenarios 1 and 2, which add 2 or 3 islands to the Project Area respectively, are predicted to provide the greatest increases in macroinvertebrate diversity (Table 13). *Hexagenia*, the burrowing mayflies that are important source of food for fish and, consequently, important to sport fisheries, occur at sites with greater depth and exposure. Scenarios 3 and 5 increased potential *Hexagenia* habitat, as did the Scenario 4, which reproduces conditions at the time of the 1861 Hearding survey. Substrate type and amount of organic material incorporated into substrates use for fill or re-shaping of the project area will also affect which particular macroinvertebrates colonize the restored areas.

In terms of waterfowl and water birds species, the 9-island Scenario 3 produced the greatest amount of habitat, creating 43 additional acres of shallow habitat. Scenario 1 produced 26 ac and Scenario 2 produced 6. In addition, all three of these scenarios create additional land surface through islands – these ranged from 9-12 additional acres of land to provide habitat for songbirds, corvids and gulls. However, Niemi *et al.* (2011) point out the conflicts with increasing songbird and shorebird habitats in a location with active nesting peregrine falcons.

Fish use a broad range of habitats, from emergent marsh to deep channels. For this reason, most of the scenarios resulted in an increase in some types of habitat and a reduction in others. Since many of the scenarios were designed to increase the amounts of all three aquatic community types, most scenarios provided increased habitat for young fishes (Table 13). The substrates chosen for remediation will also have an influence on fish composition, e.g. sand fill for shiners, darters and perch. Scenarios 4 and 5 also provide an increase in deepwater habitat, used by walleye and channel catfish.

Table 13. Summary of increased habitat for macroinvertebrates, fish and birds.

	Scenario 1 - 3 island	Scenario 2 - 2 island	Scenario 3 - 9 island	Scenario 4 1861 level	Scenario 5 Increased shallow habitat
Shallow (< 0.65 m) - Low Energy	Waterbird Waterfowl Macroinvertebrate Richness, SAV affiliated fish	Macroinvertebrate Richness	Macroinvertebrate Richness, SAV affiliated fish	Macroinvertebrate Richness	Macroinvertebrate Richness, SAV affiliated fish
Shallow (< 0.65 m) - High Energy	Waterbird, Waterfowl	Waterbird, Waterfowl	Waterbird Waterfowl	Waterbird Waterfowl	
Intermediate (< 0.65 - 1.6 m) - Low Energy	Macroinvertebrate Richness	Macroinvertebrate Richness	Macroinvertebrate Richness		Macroinvertebrate Richness
Intermediate (< 0.65 - 1.6 m) - High Energy					
Deep (1.6 - 2.5) - Low Energy			Hexagenia		Hexagenia
Deep (1.6 - 2.5) - High Energy					Hexagenia, Deepwater and channel affiliated fish
Disphotic zone (> 2.5 m)				Hexagenia, Deepwater and channel affiliated fish	Hexagenia, Deepwater and channel affiliated fish
Islands	Songbirds, Corvids, Gulls	Songbirds, Corvids, Gulls	Songbirds, Corvids, Gulls		

These restoration scenarios provide some guidance toward understanding how plant and animal communities might change with the creation of wind barriers, changes in substrate and alterations to bathymetry. The most pronounced effects are predicted to come from scenarios that increased the amounts of low energy environments, in both shallow and intermediate depths. These scenarios would increase habitat for macroinvertebrates, fish and birds – effects that will be further amplified by the trophic relationships among these communities. Increased deep habitat may lead to increases in *Hexagenia* as well as walleye and other fish that use deeper waters as refugia.

The scenarios are an example of the types of restoration techniques that are available to be incorporated with remediation design and implementation, and a mix of the design elements illustrated in the scenarios can be used to provide the diversity of aquatic vegetation beds, substrates and range of depths needed to promote the development of healthy and self-sustaining plant and animal populations at 40th Avenue West Complex. The many stakeholders, both in the adjacent private lands and the public at large, can use this ecological design approach to access data and information from a broad spectrum of scientific disciplines to inform this important decision-making process.

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