21st Avenue West Remediation to Restoration Project: Biological Survey and Hydrodynamic Modeling Results

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Introduction

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 **"21st Avenue West Habitat Complex"** (approximately 215 ha; Map 1), was identified by a focus group within the SLRA Habitat Workgroup as a priority for a "remediation-to-restoration" project. The focus group subsequently developed a general description of desired future ecological conditions at the 21st Avenue West Habitat Complex, hereafter referred to as the 'Project Area', including known present conditions and 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.

As the next step toward the creation of an "Ecological Design" for the Project Area, Natural Resource Research Institute researchers, in cooperation with USFWS, USEPA, MPCA, MnDNR, and other partners, sampled the 21st Avenue West site in late summer of 2011 to establish baseline information on vegetation, sediment types, benthic macroinvertebrates, toxins and bird usage of the area. This work will inform development of an ecological design that will allow assessment of restoration scenarios in the Project Area. The project will build on the 40th Ave West Remediation to Restoration effort, which developed an aquatic vegetation model based on depth, energy environment (predicted from a fetch model), water clarity, and other environmental factors. The model allows the evaluation of restoration scenarios involving changes in bathymetry, remediation or enhancement of substrate, reduction in wave energy, and other strategies.

In this report we also incorporate a hydrodynamic model of the estuary to inform the ecological design process. Relationships between vegetation and the macroinvertebrate and avian communities will provide information on the efficacy of these strategies in remediating and restoring overall habitat and biological productivity in the 21st Avenue West Habitat Complex. This project was funded under USFWS Cooperative Agreement Number F11AC00517; full details of the project can be found in Attachment 1 of that Agreement.

Map 1. 21st Ave West remediation-to-restoration Project Area in the St. Louis River estuary, Duluth, Minnesota.

Task 1. Aquatic Vegetation Surveys & Plant Community Classification, and Wetland Characterization/Assessment

Aquatic Vegetation Survey Methods

Field survey methods for sampling the aquatic vegetation in the 21st Avenue West Project Area followed the sampling protocol used in 2010 in the 40th Avenue West Project Area. A wetland survey following the meander methodology described by Millar (1973) was completed, and an assessment of wetland functions was completed following the Minnesota Routine Assessment Method (MnRAM) for Wetlands, (MN BWSR 2009). Since all portions of the Project Area were open water, we used a variation of the point-intercept method described in Chapter 2 (MN DNR 2009) for sampling the aquatic plants. When we surveyed the area in late August and early September 2011, there were no aquatic plants visible at the water surface in the entire project area. There were no apparent beds of aquatic plants visible from the boat. We were unable at that point to map aquatic plant community boundaries for vegetation sampling. So instead we used a grid of points that were evenly spaced across the Project Area for vegetation sampling, and when we started finding aquatic plants, we added intermediate points to increase the density of sampling in areas that had some aquatic vegetation underwater (Map 2). The grid of evenly spaced points included the points where benthic macroinvertebrates were being sampled. We navigated the boat to each sampling point using GPS location measurements (accuracy ± 3 m). At each sampling point we recorded any submerged aquatic plants pulled up by a rake tossed into the water and allowed to float down until it hit bottom. All plants were identified to the level of genus and species when practicable. For plants such as narrow-leaved pondweeds, which are difficult to identify to species, genus-level categories were used. Plant nomenclature followed the MN DNR County Checklist (MnDNR 2010). Any algae collected by the rake were noted, but not identified to species. Vegetation sampling was completed by September 9, 2011.

In addition to plant species identification, we also recorded the following environmental conditions at each sampling point: (1) water depth, (2) Secchi disk depth, and (3) substrate type (muck, detritus, silt, sand, clay, gravel, rubble, boulder). A combination of up to three substrate types was reported to describe the conditions at each sampling point, with one type rated as dominant and the others as second or third most prominent. Bulk samples for substrate characterization were collected from the upper 8 cm of the bottom.

In order to produce a map of submerged aquatic vegetation (SAV) present in the Project Area, we relied on bathymetric data produced during recent surveys by the Fond du Lac Natural Resources staff using a hydroacoustic sensor. They used a BioSonics Digital Echosounder System in combination with BioSonics VBT (Visual Bottom Typer) data processing software to provide bathymetric measurements and sediment textures. For the vegetation study we used only the bathymetric data. In ArcView GIS we followed the 1.8 m depth contours to delineate shallow water polygons in the Project Area. This "shallow water" area represents the area where SAV beds are most likey to occur. Within this shallow water area in Map 2, the sample points where SAV occurred are indicated with green symbols.

Map 2. Vegetation sample points, 21st Ave West remediation-to-restoration Project Area in the St. Louis River estuary, Duluth, Minnesota.

A single qualitative field assessment of wetland functions was completed for the entire shallow water area (or "Assessment Area") within the Project Area (Map 2) following the Minnesota Routine Assessment Method (MnRAM) for Wetlands, Version 3.4 beta (Microsoft Access Database version). Field work for the wetland assessment was completed at the same time as the vegetation surveys in the Project Area.

Narrative Description of Project Area and Plant Community Classification
The aquatic vegetation present in the Project Area was very sparse and variable. In late summer of 2011 there were no aquatic plants visible at the water surface, but we did pull up submerged aquatic plants on the sampling rake. The total sample size was 64 points scattered through the Project Area; of those 13 points were in water too deep (over 2 m) to be likely to support aquatic vegetation, and no plants were found at those points. Out of 51 points sampled in shallow water (under 2 m depth), 59% had some aquatic plants present, and 41% had no vegetation. The most abundant plants (those with the highest relative frequency) were water celery (*Vallisneria americana*), which was present at 29.4% of sample points, and algae (mostly filamentous) present at 15.7% of sample points. Each of the other aquatic plants present were found in fewer than 6% of the total sample points in shallow water. Three different portions of the bay had slightly different vegetation.

Near Interstate Island there were 24 shallow sample points, and 13 points (54%) had SAV present. The only plants found near Interstate Island were scattered sparse patches of wild celery (*Vallisneria americana*), and some sparse algae. At three sample points near Interstate Island we gathered wild celery from water depths of 2.0-2.1 m, which is slightly deeper than our 1.8 m contour line for delineating shallow versus deep water. Average water depth at vegetated sample points was 1.41 m, and average Secchi depth was 0.67 m. Sediments near Interstate Island were mostly sand and silt, with some clay.

In the central and western parts of the bay near WLSSD there were 16 shallow sample points, and only 2 points (12%) had SAV present; plants identified were Nuttall's waterweed (*Elodea nuttallii*) and a narrow-leaved *Potamogeton* sp. The narrow-leaved *Potamogeton* was not fruiting and so we were unable to identify the species. Average water depth at vegetated sample points was 1.1 m, and average Secchi depth was 0.59 m. Sediments near WLSSD were mostly silt and detritus with a little clay. The water in this area stays ice-free longer than adjacent areas of the harbor, due to effluent water from WLSSD; and therefore it often has a large population of waterfowl, especially Canada geese. The abundant detritus at this part of the bay may be due to waterfowl concentrations, or from runoff or effluent from WLSSD.

Near the eastern shore of the bay along the Garfield Street point of land there were 11 shallow sample points, and 6 points (55%) had SAV present, although one of those had only algae. The plants along the Garfield Street point of land included water celery, two species of waterweed (*E. nuttallii* and *E. canadensis*), a narrow-leaved *Potamogeton* sp. (not fruiting), and algae. Average water depth at vegetated sample points was 0.75 m, and average Secchi depth was 0.62 m. Sediments near the Garfield Street shore were mostly sand and silt, with some detritus and gravel; at one point the "gravel" included taconite pellets.

Overall aquatic plant diversity was very low in the Project Area, especially when compared to other sites recently sampled for remediation to restoration projects. A comparison of number of aquatic plant taxa and sampling intensity is shown in Figure 1.1. Even with a much higher number of sample points in the shallow portions of the Project Area (21stSH), the number of aquatic plant taxa present was in the very low end of the range for open water sample points.

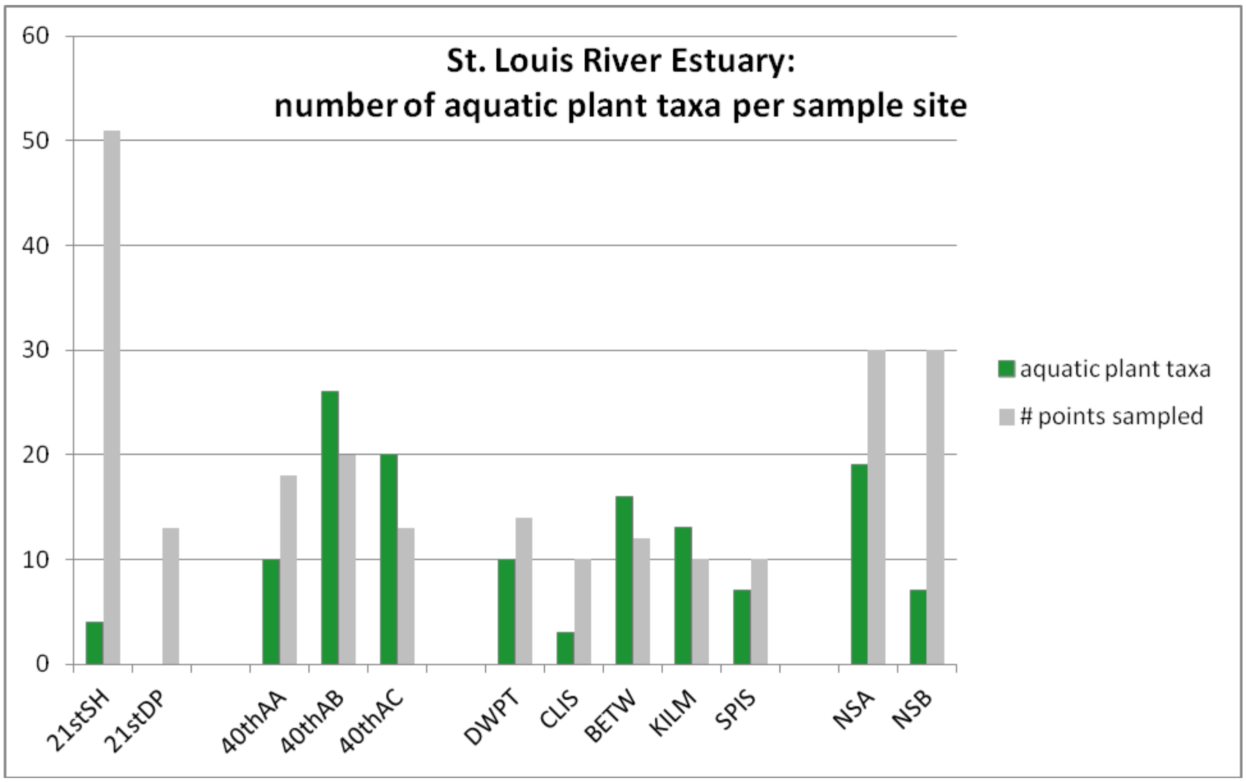


Figure 1.1 Comparison of number of aquatic plant taxa found in 2011 at 21st Ave W shallow and deep sample points, to 2010 samples from 40th Ave W (AA, AB, AC), open water reference areas (N of Dwight's Point, NE of Clough Island, Between Clough Island and Dwight's Point, W of Kilchlis Meadow Island, and near Spirit Island), and near shore reference areas (NSA: E of Clough Island, and NSB: N of Clough Island).

The low diversity of plant taxa in the shallow portions of the Project Area is not explained by water clarity as expressed by average Secchi depth, nor by water depths. The range of water depths and Secchi depths are similar to the reference areas. The low diversity of the deep portions of the Project Area may be due to much deeper water depths in the dredged channels, since they have depths much greater than in the comparable reference areas. A comparison of aquatic plant diversity with average Secchi depths and average water depths for the same set of sample sites is shown in Figure 1.2.

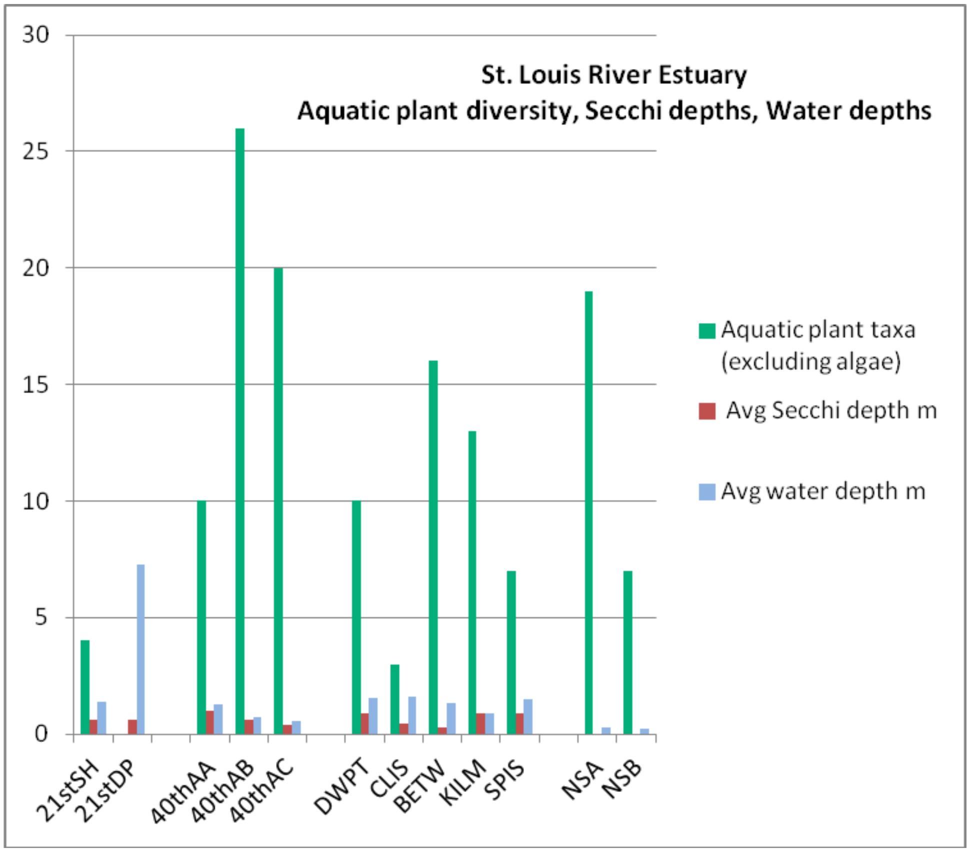


Figure 1.2 Comparison of aquatic plant diversity with average Secchi and water depths. Samples from 2011 at 21st Ave W shallow and deep sample points, and from 2010 at 40th Ave W (AA, AB, AC), open water reference areas (N of Dwight's Point, NE of Clough Island, Between Clough Island and Dwight's Point, W of Kilchlis Meadow Island, and near Spirit Island), and near shore reference areas (NSA: E of Clough Island, and NSB: N of Clough Island).

For this very sparse aquatic vegetation, the closest community class in the Minnesota Department of Natural Resources Ecological Land Classification System (MNDNR 2003) is the Lake Superior Coastal Marsh community class (MRu94). This class is described as emergent marshes that occur in estuaries and embayments near river mouths along the shore of Lake Superior, in settings influenced by fluctuating water levels caused by lake seiches. This class is present in tributaries of Lake Superior upstream as far as water levels are influenced by seiche-mediated Lake Superior water level fluctuations. Seiches, which are wind-driven changes in local water levels in Lake Superior, have significant influence on the vegetation of MRu94. These changes in local water level, which occur regularly as water levels oscillate back and forth, normally range between 1-10 in (3-25 cm) and can reverse the flow of tributary rivers of Lake Superior and flush sediments and nutrients back upstream. Water levels in coastal marshes are also influenced by river flooding from runoff following snowmelt or heavy precipitation.

The plant community "Estuary Marsh (Lake Superior)" with the code MRu94a is the only MN DNR native plant community type currently recognized in the Lake Superior

Coastal Marsh class, and there are no subtypes recognized (MNDNR 2003). Estuary Marsh (Lake Superior) is broadly defined to include a variable mixture of species, typically with a dense layer of submerged plants under and between floating-leaved and emergent aquatic plants. So portions of that plant community may include open water areas with submerged aquatic plants (lacking emergent and floating-leaf plants) similar to the sparse aquatic beds found in the Project Area. But the MNDNR classification does not currently include a classification of strictly aquatic vegetation types, so Estuary Marsh plant community type is the closest plant community type available. In past MNDNR maps of the St. Louis River estuary, the Project Area was not mapped as an example of the Estuary Marsh (Lake Superior) type.

Wetland Type/Characterization in Assessment Area

In the Eggers and Reed classification (1997) the shallow wetlands in the Project Area are all classified as "Shallow, Open Water Communities", which are described as follows:

> Shallow, open water plant communities generally have water depths of less than 6.6 feet (2 meters). Submergent, floating and floating-leaved aquatic vegetation including pondweeds, water-lilies, water milfoil, coontail, and duckweeds characterize this wetland type. Size can vary from a one-quarter acre pond, to a long oxbow of a river or shallow bay of a lake. Floating vegetation may or may not be present depending upon the effects of the season, wind, availability of nutrients, and aquatic weed control efforts.
>
> Shallow, open water communities differ from deep and shallow marshes in that they are seldom, if ever, drawn down. As a result, emergent aquatic vegetation cannot become established.
>
> Shallow, open water communities provide important habitat for waterfowl, terns, furbearers, fish, frogs, turtles, and aquatic invertebrates. For example, the submergent plants and aquatic invertebrates provide food for waterfowl, which is especially important during migration. The permanent to semi-permanent water regime of these deep-water wetlands results in their being especially important for waterfowl production in drought years when other wetlands have become dry. Also provided is habitat for spawning beds and nursery areas for both game and nongame fish. Finally, these areas of open water provide a valuable aesthetic resource important to municipalities and landowners.

In the Cowardin et al. (1979) classification of wetlands, the wetlands in the Project Area consist of two classes in the Riverine system, Lower Perennial subsystem, which are described as follows:

> The Riverine System is bounded on the landward side by upland, by the channel bank (including natural and man-made levees), or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. The Riverine System terminates at the downstream end where the concentration of ocean-derived salts in the water exceeds 0.5 ‰ during the period of annual average low flow, or where the channel enters a lake. It terminates at the upstream end where tributary streams originate, or where the channel leaves a lake. Springs discharging into a channel are considered part of the Riverine System.
>
> The Lower Perennial subsystem has a low gradient, and water velocity is slow. There is no tidal influence, and some water flows throughout the year. The substrate consists mainly of sand and mud. The gradient is lower than that of the Upper Perennial Subsystem and the floodplain is well developed.

Applying the Cowardin et al. classification, there are two classes present in the Project Area: "unconsolidated bottom" and "aquatic bed". The shallow areas that have submerged aquatic plants are classified as "aquatic bed", and the unvegetated shallow areas are classified as "unconsolidated bottom".

Assessment of Wetland Functions in Assessment Area (from MnRAM reports)

The shallow water portions of the Project Area are estimated to cover 295 acres. Site conditions in June 2011 were cooler than usual, so the growing season for aquatic plants may have been shorter than usual. This may partly explain the lack of aquatic vegetation visible at the water surface: it may have been too short a growing season in 2011 for the water celery (*Vallisneria americana*) to reach the water surface in this site. Patches of this plant have been reported near Interstate Island in previous years. At other sites further upstream in the estuary, including 40th Avenue West, Radio Tower Bay, and Pokegama River, water celery was visible at the surface in 2011. So conditions for water celery to reach the water surface existed in other parts of the estuary in 2011, but it may not have been as dense in 2011 as it was in 2010. The very sparse aquatic vegetation at 21st Ave West seems unusual for the estuary, and may be due to some other environmental factor specific to the Project Area such as water pollution or sediment contamination.

Hydrogeomorphology

The maximum water depth in the shallow water portions of the Project area is 86 inches (2.18 m), with 100% inundated. With an immediate drainage area of approximately 125 acres, it is doubtful that the current wetland is sustainable given its small catchment area. As a Riverine wetland, this site is within the river or stream banks. As such, its vegetation may serve to protect the banks from erosion, and may harbor fish, amphibian, bird, and mammal species. As a Lacustrine Fringe wetland, this site is located at the edge of deepwater areas and may be considered shoreland. As such, it protects from possible erosive wave effects and may be used as a spawning area for fish. This wetland has the unique characteristics of a freshwater estuarine wetland; it is subject to the irregular water level fluctuations and currents caused by seiches on Lake Superior. This wetland has been altered approximately 45% from its historical size of 534 acres.

Soils

The soils in the immediate wetland area are primarily under water. The adjacent upland, to about 500 feet is Urban land-Udorthents-Aquents complex, with 0 to 8% slopes.

Vegetation and Upland Buffer

The extent of vegetation in this wetland is about 33% and the naturalized buffer width averages 60 feet. Vegetated buffers around wetlands provide multiple benefits including wildlife habitat, erosion protection, and a reduction in surface water runoff. This buffer not only provides a good buffer for wetland water quality, it also serves as an important resource for wildlife habitat.

As a shoreline wetland, this site has the potential to protect from erosion and provide spawning and nursery habitat for fish and wildlife. Wetlands located in areas with strong currents and wave action have the greatest potential for protecting shoreline. Shorelines composed of sandy or erodible soils will benefit the most from shoreline wetland protection.

Special Features

The tributaries flowing into this wetland are designated trout streams; so the fish habitat rating is exceptional. This wetland is part of a high priority wetland complex and environmental corridor identified in a local water management plan (Lower St. Louis River Habitat Plan). This area is a local shoreland management plan area; and it is part of a federally identified special area management plan (the St. Louis River AOC).

Vegetative Communities

The only plant community observed was “Shallow, Ow Communities, Type 5”. This community had a vegetative index of low, and comprised 33% of the entire area; it was rated at 1. The vegetative diversity and integrity of this wetland is low. The majority of vegetation at this site, such as it is, does not contribute to wetland function beyond water retention and flow resistance.

Summary of Functional Ratings

Function	Rating
Vegetative diversity	Low
Additional stormwater treatment needs	Low
Maintenance of hydrologic regime	Low
Provision of flood/stormwater attenuation	Moderate
Downstream water quality	Moderate
Maintenance of wetland water quality	Low
Shoreline protection	Moderate
Maintenance of characteristic wildlife	Low

habitat structure	
Maintenance of characteristic fish habitat	Exceptional
Maintenance of characteristic amphibian habitat	Low
Aesthetics/Recreation/Education/Cultural	Moderate
Wetland restoration potential	Moderate
Wetland sensitivity to stormwater and urban development	Moderate

Sediment Summary

Sediment samples were collected by the macroinvertebrate survey crew August 24-26, and by the vegetation crew Sept 8-9, 2011. The bug crew collected three samples at each point, and the majority of these were identical, occasionally with one exception. The vegetation crew collected one sample at each point. For the following summary, we used only one of the three bug crew samples, and avoided using the odd sample when there was one different from the other two. The combined group of sediment samples from both sample crews was 100 sediment samples, including sediments from 28 deep sample points, and 72 shallow sample points.

Sediment data were converted to approximate proportions or percentages as follows. The three variables on the field form: sediment 1, sediment 2, and sediment 3 represent the most prominent sediment texture, the second most prominent texture, and the third most prominent texture, respectively. These three variables were converted into 9 variables, one for each sediment texture class. For each sample, a proportion was entered for each texture reported at a sample. If three sediment types were reported for a sample point or plot, then the sediment type entered for sediment 1 was assigned an estimated proportion of 0.55, sediment 2 was assigned a proportion of 0.30, and sediment 3 was assigned a proportion of 0.15, so that the total of the three proportions would add to 1. If only two sediment types were reported for a sample point or plot, then sediment 1 was assigned an estimated proportion of 0.65, and sediment 2 was assigned a proportion of 0.35. If only one sediment type was reported for a sample point or plot, then that type was assigned a proportion of 1 (or 100%). These estimated sediment proportions were then summarized across all the samples for each of the 12 sample sites: AA, AB, and AC in the 40th Ave W project site, BETW, CLIS, DWPT, KILM, SPIS are open water reference areas, NSA and NSB near-shore reference areas, 21-SH and 21-DP are the shallow and deep portions of the 21st Ave West Project Area. In general, sediments at the shallow sample points in the Project Area were primarily silt and sand, with lesser amounts of clay and detritus. Sediments at the deep sample points were primarily silt, with lesser amounts of muck, detritus, and clay. The relative proportions of the different sediment types in each sample site are presented in Figure 1.3.

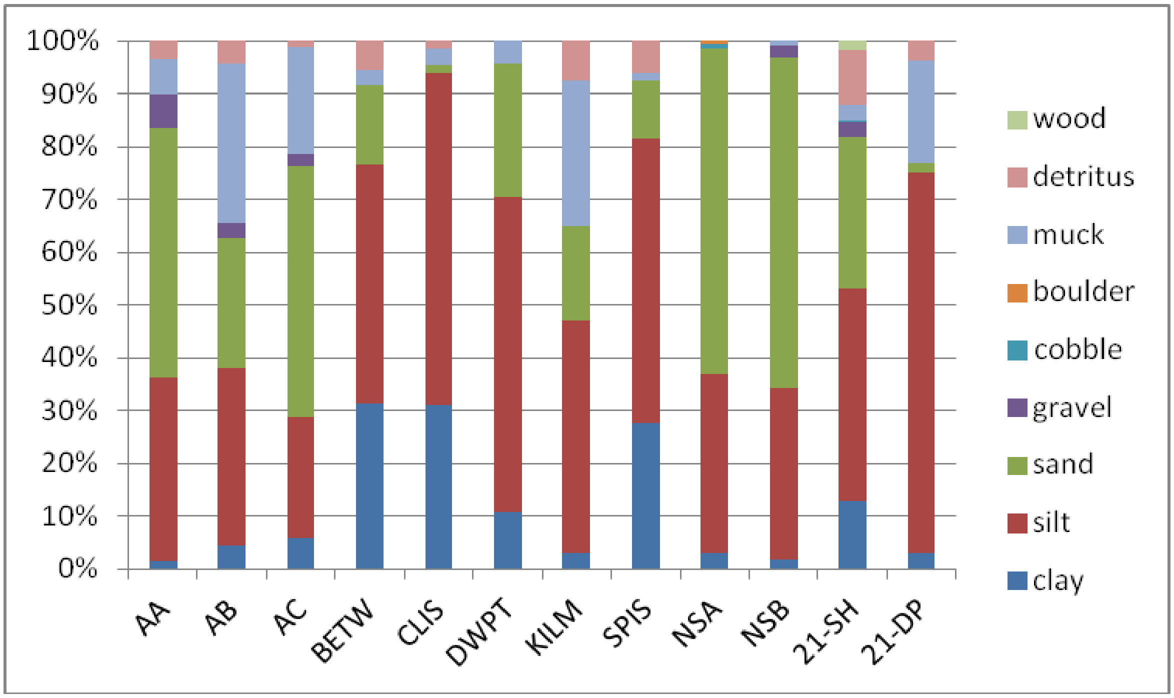


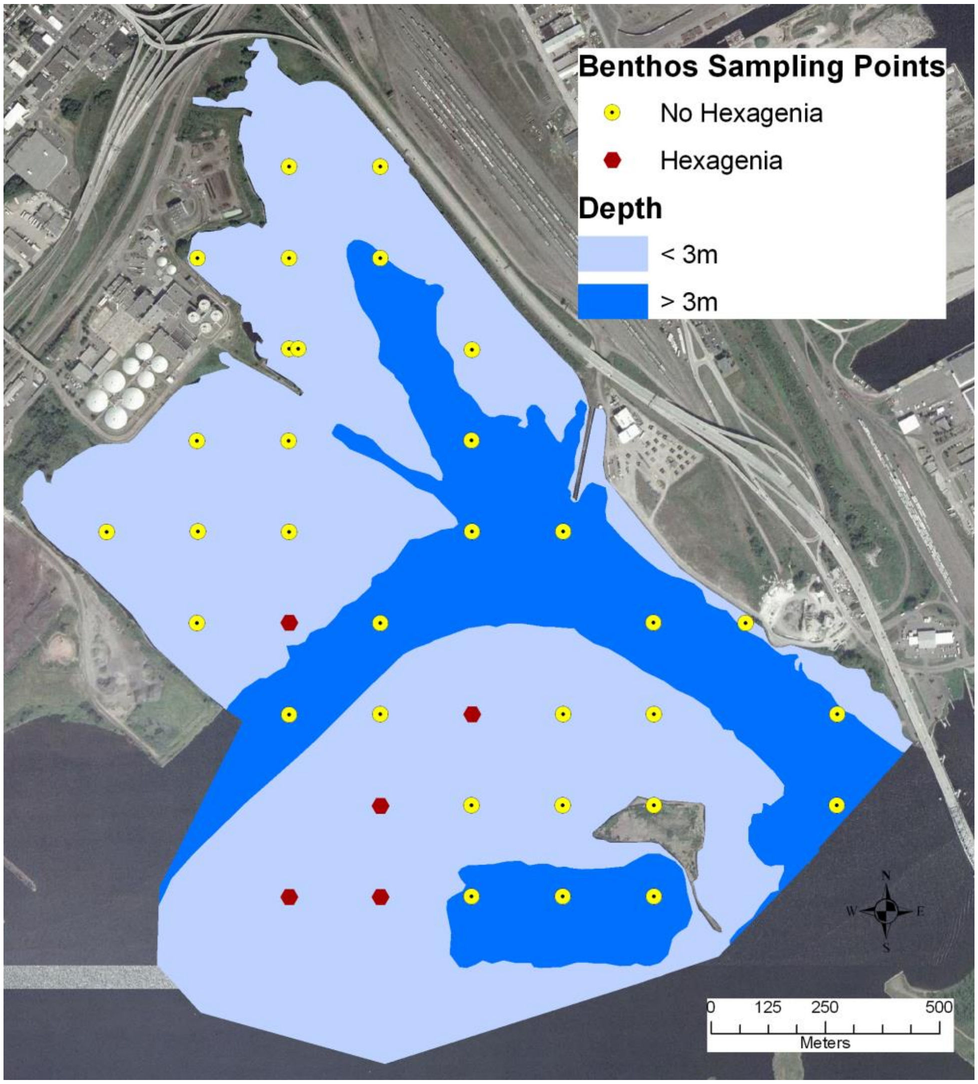
Figure 1.3. Summary of approximate proportions of sediment classes in each sample area.

Acknowledgements
Pat Collins of the USFWS provided field assistance and use of a USFWS boat for field surveys. Paul Meysembourg provided assistance with GIS datasets.

Task 2. Benthic Macroinvertebrate Surveys

Macroinvertebrate Sampling

The benthic macroinvertebrate community was sampled within the 21st Avenue West project area between 24 and 26 August 2011 (Map 3). Coordinates for 35 sample points were stratified by depth contours with 11 points ('deep', > 3 m) targeting the abandoned shipping channel, and 24 in 'shallow' ($\leq$ 3m) habitats (Appendix BA1). Sampling points were recorded on-site using a hand-held GPS (NAD 83 UTM, accuracy $\pm$ 3 m) and downloaded to a project file at the NRRI-GIS Laboratory. Field crews double-anchored the boat after obtaining the coordinate, adjusting the boat position in order to establish appropriate sampling depths, obtain optimal sediment content, or to avoid debris interfering with proper sample retrieval.



Map 3. Benthic macroinvertebrate sampling locations within the 21st Ave. West project area. Background coloring shows the 3 m depth contour. Dark red hexagons show where the mayfly genus *Hexagenia* was found.

Samples were collected in triplicate using a Petite Ponar dredge. Dredge samples were hand-washed through a 250 µm mesh according to methods outlined in NRRI Microscopy Laboratory standard operating procedures (Breneman 1999) and subsequent Great Lakes Environmental Indicators (GLEI) project reports (NRRI 2010, USEPA 2003). Procedures were adapted specifically for the 21st Ave West project in accordance with USFWS recommendations, and as outlined in the 40th Avenue West project report (Brady *et al.* 2011). Those recommendations outside the standard procedures briefly describe that 1) ponar samples brought on-board be considered representative, and subsequently retained, only if the device content was at least 25 percent of full capacity, 2) primary laboratory processing to physically separate invertebrates from sample detritus would conclude within an 8-hour duration, and 3) macroinvertebrate identifications could be limited to family-level rather than the typical genus-level for most aquatic insects.

Invertebrate samples were preserved in the field using Kahle's solution and labeled both internally and externally with unique identification. Additional site information including water and Secchi disc depth, substrate type, vegetation presence, and sample quantity were recorded in field books. Sample information was recorded on site and transferred to a chain-of-custody document as samples were archived after returning to NRRI.

Sample processing

Benthic samples were processed at NRRI following standard protocols. Invertebrates were identified to an appropriate level by a qualified NRRI invertebrate taxonomist using standard identification guides (e.g., Merritt *et al.* 2008, Thorp and Covich 1991, 2010). Although the protocol specified family-level identification of Class:Insecta, many organisms were identified to genus without adding additional time to the identification process. Chironimidae:Diptera were the exception, and this group was identified to sub-family. However, data were summed at the family-level for statistical analyses to better compare with the reference site and 40th Avenue West data. Remaining invertebrates, such as Oligochaeta and Nematoda, typically remained at a phylum or class-level because of the difficulty and cost of further identification. Macroinvertebrate and point data were entered into electronic spreadsheets and incorporated into an Access database in accordance with USFWS guidelines.

Quality Control

Laboratory personnel from NRRI re-check every sample, with 34 of 106 (over 30%) sample from this project being randomly selected to evaluate processing efficiency. On average, 95% of the organisms from each sample were extracted during the primary processing effort, ranging from 82 to 100% complete, depending on sample conditions and individual staff performance. Representative individuals from each taxa were retained during identification procedures to complete a project-specific voucher collection. No organisms remained unidentified following laboratory processing, and no samples were subject to outside expert identification.

Data entry was double-checked for all field and laboratory data sheets. Suspicious and missing values were double-checked against field and laboratory data sheets. Taxonomic information was merged by taxonomic number with the Integrated Taxonomic Information System database to ensure current information.

Biotic metrics
Respective counts of each taxonomic category per sample were merged with a trait characteristic database to organize individuals by functional feeding behaviors, trophic status, and mechanistic processes. A host of metrics were then generated and compared among sample locations. These metrics were used to help uncover differences among sites that are less apparent when looking solely at the taxonomy and raw population numbers.

Analysis
Individual taxa counts and raw abundances for each sample were log transformed, with metrics expressed as proportions undergoing an arcsin square root transformation prior to analysis. Trait categories among the 21st Avenue West sites were grouped by deep and shallow habitats as separate locations, and compared with 40th Ave West and the Reference location near Clough Island (see Brady *et al.* 2011). Data were analyzed with location as the class variable using a general linear model procedure in SAS (PROC GLM, SAS, 1988). Mean comparisons by locations was performed using Duncan's Multiple Range Test.

Results and Discussion

Benthic Habitat
Benthic macroinvertebrates respond strongly to their habitat, particularly substrate type and composition, presence and type of aquatic macrophytes, and water quality. Substrate at sampling points was predominantly silt, with some sand, clay, organic matter, and wood thrown in (Appendix BA1). Aquatic vegetation was quite scarce in this area and rarely noted in ponar samples. Water depths at 21st Shallow averaged 1.6 m, with the average depth increasing to 7.7 m for 21st Deep (Appendix BA1).

Water quality measurements were collected in conjunction with a separate project and are only available for the 21st and 40th Avenue West sites (Table 2.1). This project focused on shallow-water sites, so water quality represents only the shallow portion of 21st. Secchi disc depths are quite shallow (average 0.6 m, Appendix BA1) and turbidity is relatively high (Table B1), as is typical in the estuary. This may be one factor that limits aquatic vegetative growth in the 21st Ave West area. Another factor may be burial due to sedimentation of fine materials entering from tributaries, but we do not have sedimentation rates available to evaluate this possibility. Finally, it is also possible that sediments may still contain toxic substances that affect both vegetation and aquatic invertebrates.

Table 2.1. Water quality data collected as part of a separate project from the general vicinity of the 21st and 40th Ave West sites.

	21st Ave W	21st Ave W	40th Ave W	40th Ave W	40th Ave W
Habitat	Open water 1	Open water 2	Open water 3	Submergent veg	Typha
Date	8/25/2011	8/25/2011	8/29/2011	8/29/2011	8/30/2011
Mean Depth (cm)	46.0	62.7	84.0	89.0	11.0
Alkalinity (as $CaCO_3$ mg/L)	86.226	77.568	64.880	67.105	119.418
Chlorophyll a (ppb)	0.9	5.9	3.0	5.2	8.0
Phaeophytin (ppb)	1.9	2.9	5.5	4.9	13.7
Total Phosphorus (mg/L)	0.075	0.072	0.07	0.052	0.07
Ortho Phosphorus (mg/L)	0.031	0.031	0.028	0.015	0.011
Total Nitrogen (mg/L)	1.686	1.531	1.16	1.029	1.037
Ammonium (mg/L)	0.6	0.472	0.053	0.036	0.02
Nitrate-nitrite (mg/L)	0.263	0.274	0.227	0.08	0.003
Color (pt-co)	227	237	274	271	174
Turbidity (NTU)	7.2	8.0	7.7	7.4	12.6
Chloride (mg/L)	34.6	21.0	10.5	22.5	36.0
Trans. Tube (cm)	62.0	55.8	51.0	56.0	54.0
DO (mg/L)	11.8	12.1	6.5	9.1	4.7
DO (%)	146.2	143.9	74.5	108.6	55.6
Temperature (C)	23.4	21.7	19.8	21.2	20.1
pH	7.1	7.1	6.9	7.5	6.8
Specific Cond. (µS cm-1)	314.3	269.6	154.6	175.3	342.8

Invertebrate Community

The shallow water benthic macroinvertebrate assemblage contained 31 taxa, while the deep water assemblage contained only 21 taxa (Appendix BA2). In comparison, 38 taxa were collected from the reference site, and 32 taxa from the 40th Avenue West site. It is important to note that twice as many ponar samples were collected from the 21st Avenue West shallow water area, and it is well-documented that numbers of taxa increase with increased sampling effort. Thus, the taxonomic richness of 21st Shallow should be compared to the other sites with caution.

Comparing macroinvertebrate assemblage composition (Table 2.2, Figure 2.2) reveals that the most abundant invertebrate at all sites, except Reference, was aquatic earthworms (Oligochaeta). Non-biting midges (Chironomidae) were the dominant group at Reference, with aquatic earthworms the subdominant group. Tube worms (Polychaeta) were the subdominant group at both the shallow and deep 21st locations. A perusal of the top ten most abundant invertebrates at all sites shows that most taxa are non-insects such as various types of worms (Oligochaeta, Polychaeta, Turbellaria, and Nematoda), mussels

(Sphaeriidae, Dreissena), snails (Hydrobiidae, Gastropoda, Lymnaeidae, Planorbidae, Ferrissia), leeches (Glossiphoniidae), aquatic sowbugs and scuds (Caecidotea, Gammarus), and mites (Acari). Insects within the top ten list are non-biting midges (Chironomidae), mayflies (Ephemeridae), and caddisflies (Phylocentropus, Oectis). These results are not atypical of soft-sediment benthic assemblages.

Table 2.2. Top ten most abundant benthic macroinvertebrates found in samples at each location sampled by NRRI in the St. Louis River Estuary. Reported are sample mean abundances ± one standard deviation.

Reference Area		21st-Deep		21st-Shallow		40th Ave W	
Chironomidae	**138±124**	**Oligochaeta**	**522±286**	**Oligochaeta**	**494±503**	**Oligochaeta**	**189±197**
Oligochaeta	**104±71**	**Polychaeta**	**307±301**	**Polychaeta**	**155±441**	**Chironomidae**	**118±151**
Nematoda	**39±24**	**Nematoda**	**101±66**	**Nematoda**	**112±113**	**Nematoda**	**109±126**
Polychaeta	**32±29**	**Sphaeriidae**	**58±50**	**Chironomidae**	**57±65**	**Ferrissia**	**29±57**
Caecidotea	**18±2**	**Hydrobiidae**	**42±39**	**Dreissena**	**21±324**	**Glossiphoniidae**	**24**
Hydrobiidae	**14±21**	**Chironomidae**	**13±12**	**Sphaeriidae**	**13±18**	**Dreissena**	**24±43**
Dreissena	**14±19**	**Turbellaria**	**11±11**	**Acari**	**10±9**	**Lymnaeidae**	**13±13**
Sphaeriidae	**12±18**	**Gastropoda**	**8**	**Glossiphoniidae**	**6±5**	**Oecetis**	**13±10**
Phylocentropus	**9±9**	**Acari**	**4±2**	**Hydrobiidae**	**6±6**	**Polychaeta**	**12±18**
Gammarus	**9±9**	**Phylocentropus**	**4±4**	**Ephemeridae**	**5±2**	**Planorbidae**	**12±6**

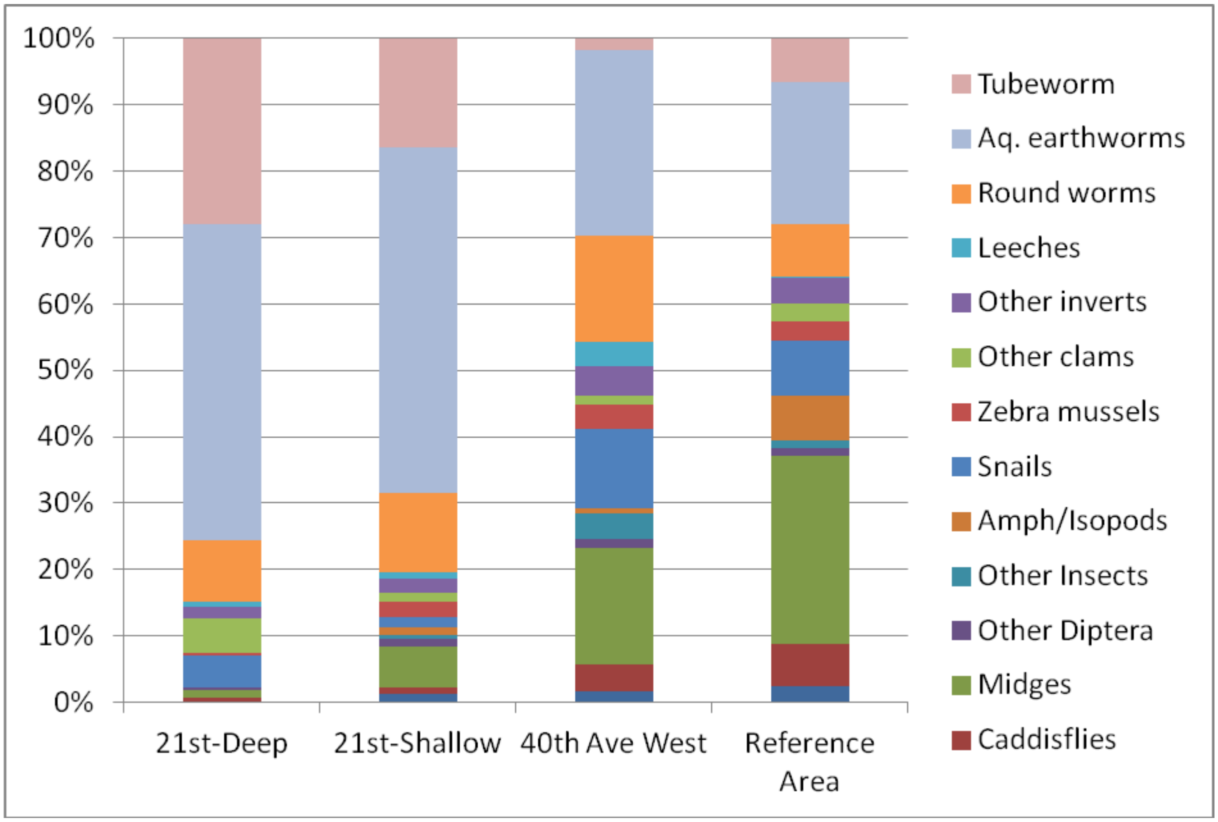


Figure 2.2. Benthic macroinvertebrate assemblages from the four sites NRRI sampled in the St. Louis River estuary. Common names of invertebrates are used for ease of interpretation.

Sites also had invertebrates unique to them and found at none of the other three sites. For the 21st Deep site, this was only the single taxon of leech Piscicolidae (Table 2.3). However, at 21st Shallow, 6 unique taxa were collected. This compares to 15 unique taxa for Reference, and 9 for 40th Avenue West. Other interesting taxa found at sites include the burrowing mayfly *Hexagenia*, which was found at all sites except 21st Deep (see Appendix BA2 and Figure map), and the burrowing caddiflies *Phylocentropus* and *Polycentropus*.

Table 2.3. List of unique taxa for the sites NRRI has sampled in the St. Louis River Estuary as part of the overall remediation-to-restoration work. "Unique" thus means found at only that location of the 4 separate locations we have sampled. Note that the 21st Avenue West site was separated into shallow (≤ 3 m) and deep (> 3 m) sampling points.

Location	**Taxa**	**Class**	**Order**	**Family**
21st-Shallow	Corbicula	Bivalvia	Veneroida	Corbiculidae
21st-Shallow	Dubiraphia	Insecta	Coleoptera	Elmidae
21st-Shallow	Hyalella	Malacostraca	Amphipoda	Hyalellidae
21st-Shallow	Hydra	Hydrozoa	Anthoathecatae	Hydridae

21st-Shallow	Polycentropus	Insecta	Trichoptera	Polycentropodidae
21st-Shallow	Probezzia	Insecta	Diptera	Ceratopogonidae
21st-Deep	Piscicolidae	Clitellata	Rhynchobdellida	Piscicolidae
40th Ave W.	Bezzia	Insecta	Diptera	Ceratopogonidae
40th Ave W.	Coenagrionidae	Insecta	Odonata	Coenagrionidae
40th Ave W.	Dytiscidae	Insecta	Coleoptera	Dytiscidae
40th Ave W.	Empididae	Insecta	Diptera	Empididae
40th Ave W.	Gyraulus	Gastropoda	Basommatophora	Planorbidae
40th Ave W.	Haliplus	Insecta	Coleoptera	Haliplidae
40th Ave W.	Lymnaeidae	Gastropoda	Basommatophora	Lymnaeidae
40th Ave W.	Pseudosuccinea	Gastropoda	Basommatophora	Lymnaeidae
40th Ave W.	Trichocorixa	Insecta	Hemiptera	Corixidae
Reference	Baetidae	Insecta	Ephemeroptera	Baetidae
Reference	Brachycercus	Insecta	Ephemeroptera	Caenidae
Reference	Gyrinus	Insecta	Coleoptera	Gyrinidae
Reference	Helisoma	Gastropoda	Basommatophora	Planorbidae
Reference	Hydroptilidae	Insecta	Trichoptera	Hydroptilidae
Reference	Molanna	Insecta	Trichoptera	Molannidae
Reference	Nectopsyche	Insecta	Trichoptera	Leptoceridae
Reference	Paraponyx	Insecta	Lepidoptera	Crambidae
Reference	Planorbella	Gastropoda	Basommatophora	Planorbidae
Reference	Potamoprygus	Gastropoda	Mesogastropoda	Hydrobiidae
Reference	Serromyia	Insecta	Diptera	Ceratopogonidae
Reference	Sialis	Insecta	Megaloptera	Sialidae
Reference	Somatochlora	Insecta	Odonata	Corduliidae
Reference	Unionidae	Bivalvia	Unionoida	Unionidae
Reference	Viviparidae	Gastropoda	Architaenioglossa	Viviparidae

Invertebrate Metrics

Several metrics indicate a difference in communities associated with each location, and a representative set are provided in Table 2.4. A suite of metrics often helps describe community structure and function more appropriately than a single indicator. Total abundance and taxa richness are two common metrics, and in this survey greater numbers of macroinvertebrates occurred in samples from the 21st Avenue project area. Abundances at both shallow and deep habitats at 21st Avenue were significantly greater compared to either 40th Ave. West or Reference. There was not a significant difference within the 21st Avenue project area when samples were stratified by depth. Mean number of taxa per sample was also different between locations, with 21st and 40th Avenue locations containing significantly fewer taxa compared to Reference. Again, taxa richness in 21st Avenue deep and shallow habitats was not significantly different.

Table 2.4. Benthic macroinvertebrate trait comparisons between sampling locations within the St. Louis River Estuary. Total number and total taxa represent mean values + 1 standard error per sample. Trait characteristics are expressed as a percent of total. Metrics were compared using a one-way ANOVA and are significant at the α= 0.05 level. Metric values with the same letter are not significantly different based on Duncan's Multiple Range Test. Dominance (%) is a proportion of the total numbers represented by a single taxa. ET taxa are those identified as Ephemeroptera or Trichoptera.

	Reference	**40th Ave W**	**21st Shallow**	**21st Deep**
Sample n	n=20	n=20	n=48	n=22
Total Abundance (m^2)	15,921±134^{b}	20,360±4126^{b}	34,857±4579^{a}	44,587±5754^{a}
% Dominance	44±2.6^{c}	49±2.9^{bc}	63±2.3^{a}	57±2.1^{ab}
% Chironomidae	36±3.6^{a}	22±2.8^{b}	9±1.3^{c}	2±0.3^{d}
% Oligochaeta	29±3.1^{b}	39±3.8^{b}	55±3.6^{a}	55±2.6^{a}
% Non-Insects	57±3.6^{d}	75±3.1^{c}	91±1.3^{b}	98±0.4^{a}
Total Taxa	15±0.9^{a}	9±1.1^{b}	9±0.3^{b}	8±0.3^{b}
% Collect-Gather Taxa	40±2.5^{b}	53±4.7^{a}	44±1.3^{a}	37±1.8^{c}
% Grazer-Scraper Taxa	10±1.5^{a}	8±2.2^{ab}	8±1.1^{b}	13±1.6^{a}
% ET Taxa	25±1.3^{a}	14±2.7^{b}	6±1.5^{c}	2±1.3^{c}

The greater abundances but lower taxa richness at the 21st Avenue locations indicates that the assemblages at 21st Avenue may be dominated by a few taxa. This is confirmed by the percent dominance metric, which shows that the 21st Shallow site was significantly more dominated by a single taxon than Reference and 40th Avenue West (Table B4, Figures B1 and B2). Aquatic earthworms (Oligochaeta) comprised 55% of the 21st Shallow and 21st Deep and 40th Avenue West assemblages, which was significantly higher than the percentage of aquatic earthworms at 40th Avenue West (39%) and Reference (29%). All three study locations consisted of significantly greater percentages of non-insects than occurred at Reference,

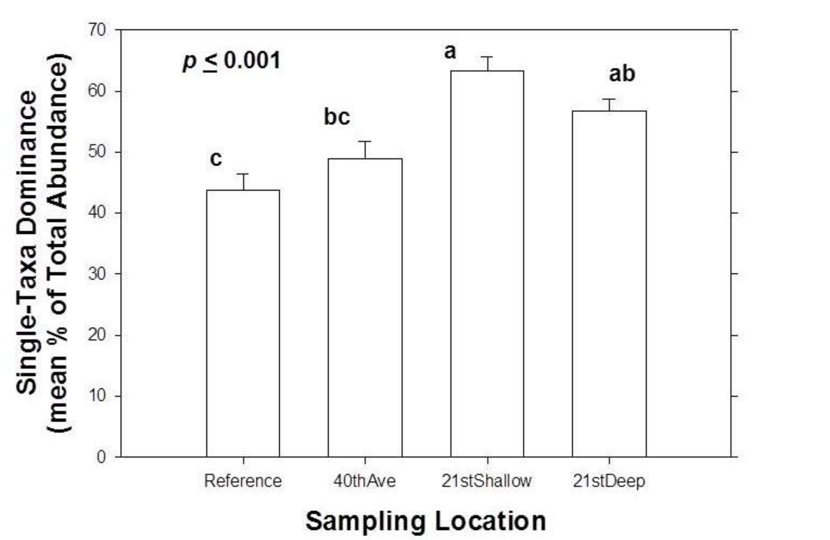


Figure B2. Percent dominance by a single macroinvertebrate taxon at St. Louis River Estuary sampling locations. Values represent mean numbers + 1 standard error. *p* value if from the overall ANOVA. Columns with the same letter are not significantly different (α= 0.05) based on Duncan's Multiple Range Test.

and this percentage was greater than 90% of the total abundance at the 21st Avenue sites (see also Figures B1 and B3). The high percentages of aquatic earthworms and other non-insects suggests habitat conditions that are homogenous and unsuitable to a variety of the taxa observed at Reference, where submergent aquatic vegetation was abundant (Brady *et al*. 2011).

Midge larvae (Chironomidae:Diptera) found at high abundances are often associated with impacted conditions or depositional sediments (Rosenberg and Resh 1993). In this survey, the Reference area contained a large proportion of midge larvae (~ 35% of total), which was significantly greater than the other study locations (Table B4, Figure B1). A large midge population in the Reference Area may be an indication of habitats dominated by fine sediments, rather than anthropogenic disturbance. This supposition is further supported by the higher dominance of aquatic earthworms at the study sites, and the greater occurrence of the more sensitive groups such as mayflies (Ephemeroptera) and caddisflies (Trichoptera) at Reference (Table B4, Figures B1 and B4). In contrast, the 21st Deep location contained the fewest midge (Chironomidae) larvae, mayfly, and caddisfly taxa of the four locations (< 2% of total). EPT taxa results are provided for this comparison; this is a common metric identifying all three taxonomic orders, but it should be noted that Plecoptera were not found at any of the four sampling locations in the estuary. This is consistent with Plecoptera primarily occurring in flowing stream habitats, rather than estuarine depositional zones.

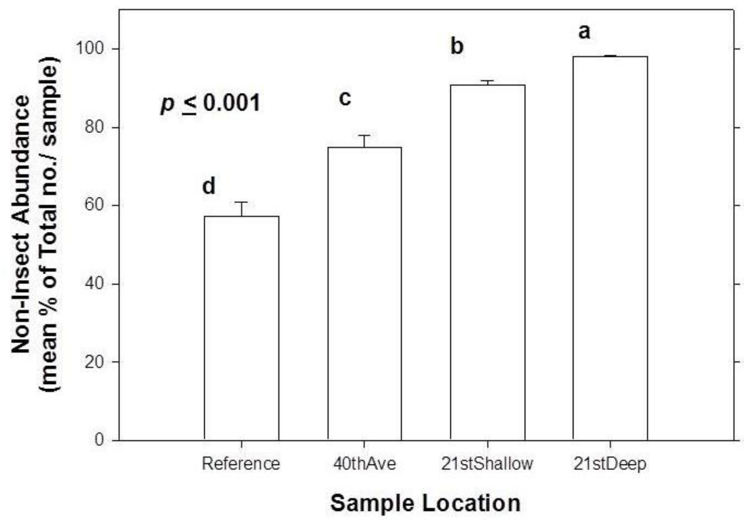


Figure B3. Percent non-insect abundance at St. Louis River Estuary sampling locations. Values represent mean numbers + 1 standard error. *p* value if from the overall ANOVA. Columns with the same letter are not significantly different (α= 0.05) based on Duncan's Multiple Range Test.

Summary and Conclusions

The 21st Avenue West macroinvertebrate assemblage is highly dominated by aquatic earthworms (Oligochaeta) and contains fewer aquatic insects, both in abundance and as representative taxa, than the Reference Area. Lower taxa richness, despite greater sampling effort at 21st Shallow, also indicates an assemblage that is not as good as it could be compared to other areas in the estuary. While part of the cause of this impairment may be due to lack of aquatic vegetation, it is not clear that physical habitat characteristics are the sole reason causing impairment. Ruling out legacy toxins in the substrate as a potential source of the problem may be possible when recent sediment contamination analyses become available (MPCA in progress) and sample points are compared to the results provided here.

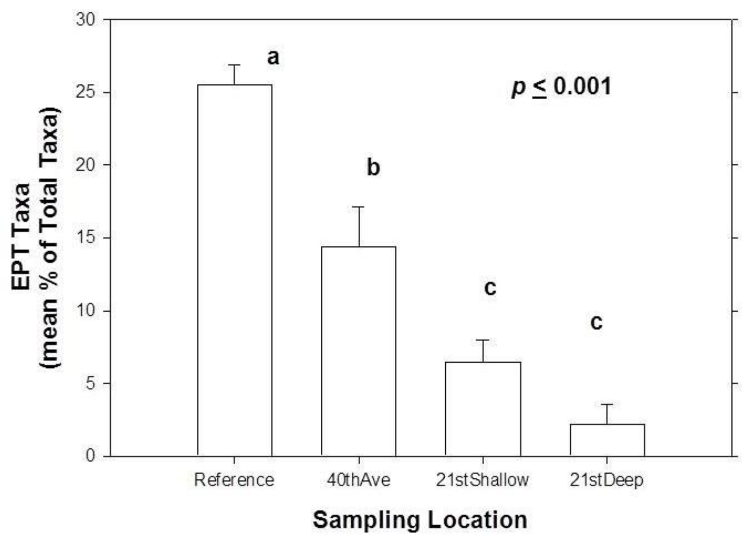


Figure B4. Percent abundance of Ephemeroptera and Trichoptera (no Plecoptera were found) per sample collected at four St. Louis River Estuary sampling locations. Values represent mean numbers + 1 standard error. *p* value if from the overall ANOVA. Columns with the same letter are not significantly different (α= 0.05) based on Duncan's Multiple Range Test.

One favorable observation from this sampling is that the large burrowing mayfly *Hexagenia* was found within the 21st Shallow location (and also found at Reference and 40th Ave. West). (Note also that the family was found within 21st Deep, but could not be identified to genus). However, large shallow areas further into the bay are void of *Hexagenia* even though habitat conditions (e.g., depositional mudflats) would appear to provide suitable refuge (Map 3). This mayfly is particularly sensitive to dissolved oxygen, and its presence indicates that dissolved oxygen is not a limiting factor in areas where it occurs. *Hexagenia* are of particular interest to fisherfolk, who often like to fish the "Hex hatch" when the mayfly emerges to become a winged adult. Scientists and managers are interested in *Hexagenia* because it may also serve as a bioaccumulation link in the estuary food web; it is large-bodied, long-lived, and resides with the sediment, and thus in potentially close proximity to legacy toxins, throughout most of its lifecycle.

Task 3. Avian Community Surveys

Avian surveys began March 1, 2012 and will continue through the breeding season, approximately mid June. We will also conduct weekly surveys from late August to early November 2012 based on a series of observation points throughout the study area. Locations of all bird observations will be identified to specific locations on aerial photo field sheets with accuracies of approximately 25 m in open water and 10 m near or on shore. These data will be transferred to a geographic information system to represent the spatial distribution of species observed within the site.

Task 4. Hydrodynamic Modeling of the 21st Avenue West Complex

Modeling activity thus far has been directed toward characterization of the natural estuarine system under several simple meteorological scenarios (Figure 4.1). The preliminary model output has been compared to observational data which have demonstrated favorable model performance. With confidence in the computational grid and solver, we now press on to further scenario-based modeling and benchmarking of the natural system and will soon begin modifications to the grid to include barrier islands in the vicinity of 21st Ave. West Bay. Most recently, the latest version of modeling software was implemented to take advantage of increased functionality. Selected model runs will continue to be posted to *www.d.umn.edu/~mdjames/modeling/*

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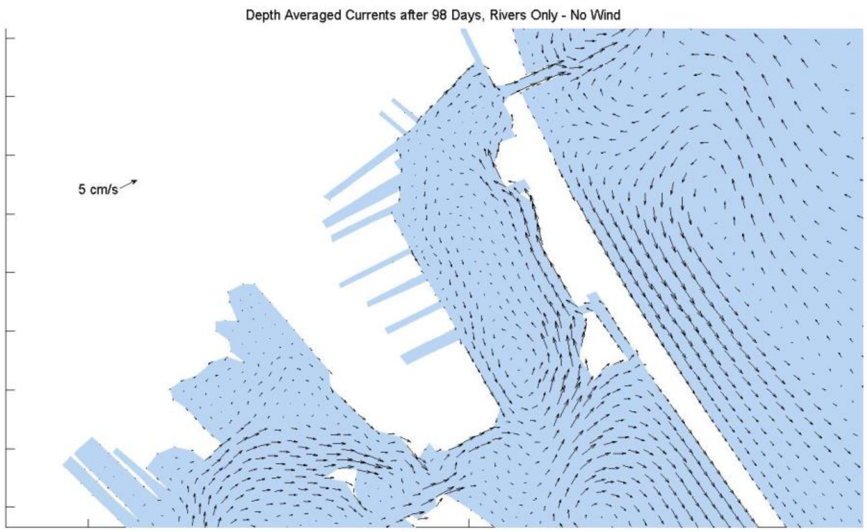

Figure 4. 1 Example of hydrodynamic model output under no wind conditions.

Task 5. Ecological Design

The primary objective for collecting vegetation, macroinvertebrate and avian is to inform the development of an ecological design that will allow the development and assessment of restoration scenarios in the Project Area. The vegetation data collected in the Project and Reference Areas, along with vegetation data collected in other sampling efforts, will be used in the Submerged Aquatic Vegetation (SAV) model to allow the evaluation of restoration scenarios. Relationships between vegetation and the macroinvertebrate and avian communities will provide information on the efficacy of treatments to remediate and restore habitat and biological productivity in the 21st Avenue West site.

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Appendix BA1. Depths and substrate types at benthic sampling locations.

Location	**Site type**	**Depth (m)**	**Secchi Depth (m)**	**Substrate**	**Longitude (DD)**	**Latitude (DD)**
D-01	Shallow	3.1	0.8	silt	-92.117757	46.76067233
D-02	Deep	8.8	0.55	silt/sand/organic	-92.11520042	46.75705623
D-03	Deep	7.4	0.5	silt/organic	-92.11521585	46.75525136
D-04	Deep	8.8	0.57	silt/organic	-92.11260066	46.75523111
D-05	Deep	7.5	0.55	silt	-92.12052525	46.75168426
D-06	Deep	7.5	0.65	silt	-92.11787002	46.75346998
D-07	Deep	7.5	0.6	silt/organic	-92.11003367	46.75341669
D-08	Deep	5.6	0.65	silt/organic	-92.10480276	46.75156889
D-09	Deep	7.5	0.72	silt/organic	-92.10484209	46.74976792
D-10	Deep	5.8	0.69	silt/organic	-92.11534646	46.74805775
D-11	Deep	7.9	0.66	silt/organic	-92.11272664	46.74803189
D-12	Deep	10.1	0.69	silt/organic	-92.11011445	46.74801032
S-01	Shallow	0.7	0.7	silt/detritus/SAV	-92.12034471	46.76249289
S-02	Shallow	1.8	0.61	silt/organic	-92.11772777	46.76247274
S-03	Shallow	0.7	0.57	sand/pebble	-92.12299766	46.76070551
S-04	Shallow	1.5	0.6	silt/zebra mussels	-92.12036739	46.76068869
S-05a	Shallow	2	0.7	silt/muck	-92.12014121	46.75889496
S-06	Shallow	1.3	0.68	silt/organic	-92.12306766	46.75710525
S-07	Shallow	1.7	0.52	organic/silt	-92.12044739	46.75708729
S-08	Shallow	0.7	0.58	silt/sand/wood	-92.12569558	46.75532773
S-10	Shallow	1.5	0.55	organic/silt	-92.12046687	46.75528766
S-11	Shallow	0.5	0.5	sand/silt	-92.12312601	46.75350828
S-12	Shallow	2.9	0.6	silt	-92.12048272	46.75349259
S-13	Shallow	2.6	0.52	silt/organic	-92.11515966	46.75884539
S-14	Shallow	1.6	0.6	silt	-92.11790328	46.75166902
S-15	Shallow	1.7	0.58	silt	-92.11527596	46.75165301
S-16	Shallow	1.6	0.65	silt	-92.11266375	46.75163278
S-17	Shallow	1.6	0.6	silt	-92.11005161	46.75160822
S-18	Shallow	1.8	0.6	silt/organic	-92.11792687	46.74986416
S-19	Shallow	0.9	0.61	sand/clay	-92.11531668	46.74985075
S-20	Shallow	0.6	0.58	sand/silt	-92.11270348	46.74983052
S-21	Shallow	0.5	0.68	sand	-92.11008868	46.74980677
S-22	Shallow	1.7	0.6	silt/organic	-92.12058088	46.74808695
S-23	Shallow	1.9	0.66	silt/organic	-92.11795619	46.74806675
S-24	Shallow	3	0.6	silt/organic/zebra mussels	-92.10739942	46.75338884

Appendix BA2. Taxa lists for each site sampled by NRRI, shown in alignment for easier comparison. Taxa richness for each site is at the bottom of the table.

Ref	21st-Shall	21st-Deep	40th Ave	Taxa	Class	Order	Family
X	X	X	X	Nematoda			
	X	X		Erpobdellidae	Clitellata	Arhynchobdellida	Erpobdellidae
	X	X		Hirudinea	Clitellata	Hirudinea	
X	X	X	X	Oligochaeta	Clitellata	Oligochaeta	
X	X		X	Glossiphoniidae	Clitellata	Rhynchobdellida	Glossiphoniidae
		X		Piscicolidae	Clitellata	Rhynchobdellida	Piscicolidae
X	X	X	X	Polychaeta	Polychaeta		
X	X	X	X	Acari	Arachnida	Acari	
X	X			Caecidotea	Crustacea	Isopoda	Asellidae
X			X	Physella	Gastropoda	Basommatophora	Physidae
			X	Dytiscidae	Insecta	Coleoptera	Dytiscidae
	X			Dubiraphia	Insecta	Coleoptera	Elmidae
X				Gyrinus	Insecta	Coleoptera	Gyrinidae
			X	Haliplus	Insecta	Coleoptera	Haliplidae
			X	Bezzia	Insecta	Diptera	Ceratopogonidae
X	X	X	X	Probezzia	Insecta	Diptera	Ceratopogonidae
X				Serromyia	Insecta	Diptera	Ceratopogonidae
	X	X	X	Chaoborus	Insecta	Diptera	Chaoboridae
X			X	Chironomidae	Insecta	Diptera	Chironomidae
	X	X		Chironominae	Insecta	Diptera	Chironomidae
	X	X		Orthocladiinae	Insecta	Diptera	Chironomidae
	X	X		Tanypodinae	Insecta	Diptera	Chironomidae
			X	Empididae	Insecta	Diptera	Empididae
X				Baetidae	Insecta	Ephemeroptera	Baetidae
X				Brachycercus	Insecta	Ephemeroptera	Caenidae
X	X		X	Caenis	Insecta	Ephemeroptera	Caenidae
		X		Ephemeridae	Insecta	Ephemeroptera	Ephemeridae
X	X		X	Hexagenia	Insecta	Ephemeroptera	Ephemeridae
	X	X		Phylocentropus	Insecta	Hemiptera	Corixidae
			X	Trichocorixa	Insecta	Lepidoptera	
X				Paraponyx	Insecta	Lepidoptera	Pyralidae
			X	Lepidoptera	Insecta	Lepidoptera	
X				Sialis	Insecta	Megaloptera	Sialidae
X	X		X	Coenagrionidae	Insecta	Odonata	Coenagrionidae
X				Somatochlora	Insecta	Odonata	Corduliidae
X			X	Phylocentropus	Insecta	Trichoptera	Dipseudopsidae
X			X	Hydroptila	Insecta	Trichoptera	Hydroptilidae
X				Nectopsyche	Insecta	Trichoptera	Leptoceridae
X	X	X	X	Oecetis	Insecta	Trichoptera	Leptoceridae
X				Molanna	Insecta	Trichoptera	Molannidae
X	X			Polycentropus	Insecta	Trichoptera	Polycentropodidae
X	X		X	Gammarus	Malacostraca	Amphipoda	Gammaridae
X	X		X	Hyalella	Malacostraca	Amphipoda	Hyalellidae
X	X			Hydra	Hydrozoa	Hydroida	Hydridae
	X			Corbicula	Bivalvia	Veneroida	Corbiculidae
X	X	X	X	Dreissena	Bivalvia	Veneroida	Dreissenidae

Appendix BA2. (cont).

Ref	**21st-Shall**	**21st-Deep**	**40th Ave**	**Taxa**	**Class**	**Order**	**Family**
X	X	X	X	Sphaeriidae	Bivalvia	Veneroida	Sphaeriidae
X				Viviparidae	Gastropoda		Viviparidae
	X			Planorbidae	Gastropoda	Basommatophora	Lymnaeidae
X				Planorbella	Gastropoda	Basommatophora	Planorbidae
			X	Pseudosuccinea	Gastropoda	Basommatophora	Planorbidae
X			X	Ferrissia	Gastropoda	Gastropoda	
			X	Gyraulus	Gastropoda	Limnophila	Ancylidae
X				Helisoma	Gastropoda	Limnophila	Planorbidae
	X	X	X	Hydrobiidae	Gastropoda	Mesogastropoda	Hydrobiidae
X				Potamopyrgus	Gastropoda	Mesogastropoda	Hydrobiidae
X	X	X	X	Valvata	Gastropoda	Mesogastropoda	Valvatidae
X				Unionidae	Pelecypoda	Unionoida	Unionidae
X	X	X	X	Turbellaria	Turbellaria		
	X	X	X	Tardigrada			
38	**31**	**21**	**32**		**Taxa Richness**		