A Management Plan for Restoring a Sustainable Population of Northern Pike in the Milwaukee Estuary Area of Concern (AOC)

Will Wawrzyn, WDNR Senior Fisheries Biologist

Introduction

Northern pike (*Esox lucius)* was once an ecologically and commercially important potamodromous fish species in the Great Lakes Basin. Commercial harvest of northern pike in the Great Lakes declined from 1.6 million kg during the early 1900s to less than 0.05 million kg in the late 1960s (Baldwin et al., 1979). Overfishing, destruction of habitat, water pollution, barriers to fish passage, and aquatic invasive species, have been implicated as contributing to the decline of many Great Lake fish stocks, including northern pike, walleye and lake sturgeon (Schneider and Leach, 1979). Spawning and rearing habitat destruction and habitat fragmentation are the primary factors responsible for the long-term decline of northern pike recruitment in the Great Lakes (Carlander et al., 1978). Habitat loss, especially wetland habitats, and the construction of man-made barriers to remaining tributary habitat is especially acute along near-shore and estuary areas located at the confluence of major tributaries where harbors for commerce and cities developed, and where dams were constructed along estuary tributaries for hydropower. Fully developed land uses, economic, social and environmental factors make efforts to restore the estuaries to their once productive prohibitive. Tributary dams and other barriers to fish passage are the most-obvious impairments to creating more sustainable fish populations (Clapp and Horns, 2008). Viable northern pike populations remain in the waters of Green Bay, in large part, because northern pike have access to remaining, albeit reduced near-shore and tributary wetland habitat for spawning and early life stage development.

Northern pike are similar to other depleted populations of native potamodromous species in the Great Lakes. They possess expansive spawning migratory behavior to natal spawning tributaries and habitats, and have limited swimming and leaping ability past natural and man-made obstructions. As such, they are an ideal surrogate for developing management plans for sustainable populations of other ecologically important species between the Great Lakes and their historical riverine habitats.

Background

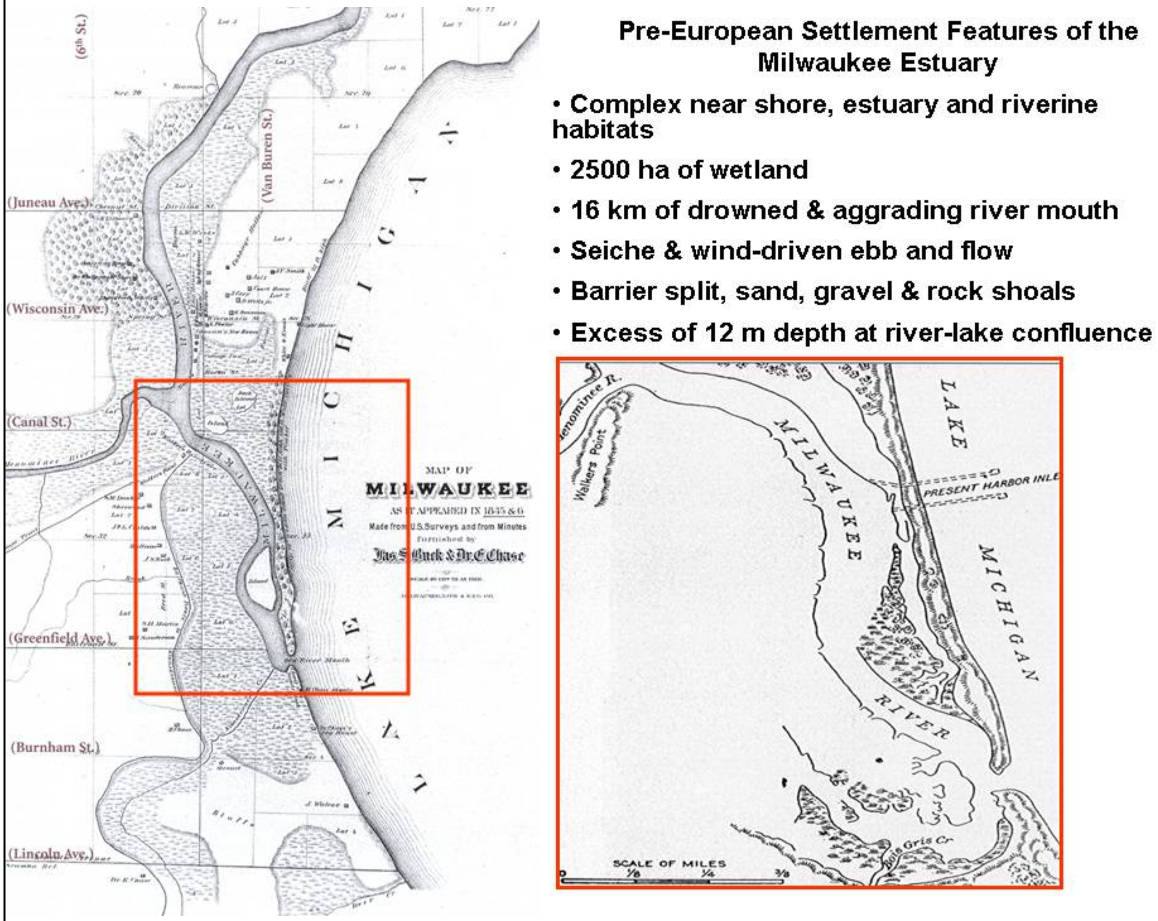
The Milwaukee Estuary

Historical accounts indicate that northern pike and other potamodromous fish species including lake sturgeon, walleye, suckers, muskellunge, trout, whitefish and catfish were once abundant in the Milwaukee Estuary and near shore waters of Lake Michigan (Buck, 1876 and Gregory, 1931). The distribution and abundance of northern pike and other potamodromous species was closely linked with the hydrologic connection between Lake Michigan, wetlands in the Milwaukee Estuary and connecting tributaries. Of the >150 fish species in the Great Lakes Basin, over 90% are dependent on wetlands for part of their life history, and more than 75 species spend their summer months in wetlands (Jude et al., 2005).

The Milwaukee Estuary once totaled over 2,600 ha of deep and shallow water marsh; and access to hundreds of kilometers of rivers, tributary streams and thousands of hectares of wetlands (Figure 1). Although detailed surveys on the bathymetric and vegetative surveys of the Estuary are lacking, we assume that the deep water reaches of the three rivers, the Milwaukee, Menomonee and Kinnickinnic Rivers, and diverse emergent and submergent beds of aquatic vegetation provided for juvenile and adult life-stage requisites, and ultimately self-sustaining fish populations. The complex Estuary habitat also included 16 km of drowned river; dynamic ebb and flow hydrology driven by lake seiche and wind; and a 1.2 km long barrier split located at the Lake Michigan and Estuary confluence that included deep to shallow rock, gravel and sandy shoals, and water depths up to 12 m (Lapham).

Upstream of the hydrologic limits of the estuary over 40,000 ha of wetlands were present, many of them riparian to tributary streams. The principal rivers and tributaries (larger than 3rd order) were dominated by pool and riffle features, moderately steep (> 3 m/km) and formed in coarse alluvial substrates. The middle and lower reaches of the Milwaukee and Menomonee River's included significant reaches of steep pocket water formed over fractured dolomite escarpments. These brief reaches are typically deep eddying pools dominated by large cobble-boulder material (Buck, 1876). Collectively, the basins near-shore waters of Lake Michigan, estuary, and its connected wetlands and riverine habitat provided ample habitat for all for all life-stages of potamodromous and fluvial fish, including phytophilic and simple lithophilic spawners.

Figure 1. Pre-European settlement map and features of the Milwaukee Estuary and near-shore waters of Lake Michigan. Source: S. Buck and Dr. L. Chase Map of Milwaukee 1835-36,
University of Wisconsin – Milwaukee Digital Library.



Pre-European Settlement Features of the Milwaukee Estuary

- Complex near shore, estuary and riverine habitats
- 2500 ha of wetland
- 16 km of drowned & aggrading river mouth
- Seiche & wind-driven ebb and flow
- Barrier split, sand, gravel & rock shoals
- Excess of 12 m depth at river-lake confluence

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The Decline of Fisheries in the Milwaukee Estuary

Beginning in the late-1800s, Milwaukee Estuary wetlands and connecting channels were dredged and filled, and engineered embankments were constructed for developing commercial shipping and urban land uses. In addition, thousands of hectares of riparian wetlands upstream of the estuary and accessible to fish were drained or filled; rivers and tributaries were channelized, in particular Milwaukee and southern Ozaukee Counties. In 1847, the North Avenue Dam was constructed at river kilometer 5 (RK 5) and terminus of the Milwaukee River portion of the estuary and served as a complete barrier to fish passage. Between the late-1800s and 1939, an additional six dams were constructed on the Milwaukee River between the Milwaukee River North Avenue Dam and the Village of Grafton Bridge Street Dam, a distance of 52 km. By the mid-1960's, over 3 km of concrete channel invert were constructed beginning at the estuary terminus of the Kinnickinnic River and 1.3 km of the Menomonee River, creating a barrier to fish passage in those watersheds. By the mid-1960's, less than 1 ha of wetland habitat and less than 1 km of free-flowing riverine habitat were present and accessible to potamodromous fish from the near-shore waters of Lake Michigan and the Milwaukee Estuary. While less imposing than the large river dam structures and channel enclosures and concrete inverts, numerous culverts and bridge structures constructed at smaller tributary road crossings further limit fish throughout the lower Milwaukee River Basin. An inventory completed by Ozaukee County identified approximately 100 man-made complete or effective fish passage barriers among 11smaller tributaries of the Milwaukee River and Lake Michigan in Ozaukee County (Northern Environmental, Inc., 2006).

Modern-day evidence for degraded fish habitat and fish populations in the Milwaukee Estuary was documented by Holey (1984). Using a variety of passive and active fishing gears that included monthly capture replicates for March through October, the fish community was shown to be severely limited in the Milwaukee Estuary. Fish species diversity in the Estuary was greatly reduced with only 23 native species as compared to 60 species elsewhere in the Milwaukee River Basin. Thirteen of the 23 native species were represented by 24 or fewer individuals. Common carp and white sucker dominated the catch and biomass. Omnivores were dominant and top predators as Northern pike, walleye, large and smallmouth bass, flathead and channel catfish were rare to very rare. Insectivores were dominated by lentic sunfishes, most notably pumpkinseed. Wetland-dependent spawning species (phytophilic spawners) and species that spawn on clean rocky substrates without parental care (simple lithophilic spawners) were also rare. Annual WDNR electrofishing surveys since year-2000 of wadable and non-wadable reaches of the Milwaukee estuary, the Milwaukee River and principal tributaries confirm that northern pike relative abundance is low.

More recently, a local creel survey along the lower Milwaukee River and estuary indicated that catch rates for northern pike are uncommon and incidental to fishing for other more common targeted species as salmonids, smallmouth bass and walleye (Petersen and Hirethota, 2008). Creel survey results are consistent with WDNR spring walleye survey observations in the Milwaukee Estuary, and WDNR Wadable Stream and Non-Wadable Stream survey results such that northern pike are uncommon to rare in the Milwaukee Estuary, lower Milwaukee and Menomonee Rivers (WDNR, 2010).

The Milwaukee Estuary Area of Concern (AOC) and Opportunities to Restore Habitat and Self-Sustaining Fish Populations

The Milwaukee Estuary is one of 43 waterbodies designated as a Great Lakes Area of Concern (AOC). Waterbodies are designated AOCs as a result of undergoing severe changes to their chemical, physical, or biological uses and values. In order to be designated an AOC, a waterbody must have one or more of the 14 Beneficial Use Impairments (BUI) assigned it. The Milwaukee Estuary was identified in 1980 as having 11 of the 14 BUIs, including loss of fish and wildlife habitat and, degradation of fish and wildlife populations.

The Milwaukee Estuary AOC Remedial Action Plan (RAP) identified destruction of wetland habitat, dredging, bulkheading of shorelines, fish passage barriers, contaminated sediment, and water quality impairments from point and non-point sources of pollution as contributing to the loss of habitat and degradation of fish and wildlife populations. Loss of fish and wildlife habitat and degraded fish a population are the most common BUIs among the Great Lakes AOCs and is especially acute along the lower reaches of rivers and once productive major estuaries where major cities and ports developed.

The original boundary of the Milwaukee Estuary AOC included the Milwaukee Outer Harbor bounded by the Lake Michigan shoreline and harbor breakwater; and the Inner Harbor that comprised the three river estuary reaches. The boundary of the AOC was expanded to include and additional 47 km of the Milwaukee River upstream to and including a 8 km reach of Cedar Creek, at Cedarburg, Ozaukee County; and an additional 26 km of the Menomonee River upstream to and including a 10 km reach of the Little Menomonee River, at Milwaukee, Milwaukee County. The additional stream reaches added to the AOC were a result of contaminated sediments. However, the loss of wetlands, the construction of dams and other barriers to fish passage along these reaches do contribute to the loss of fish and wildlife habitat and degraded fish populations throughout the original and modified AOC boundaries.

Opportunities for large scale restoration of habitat, fish abundance and diversity within the existing footprint of the Milwaukee Estuary will be especially difficult due to competing economic, social and technical barriers. For example, current land and water-based uses support billions of dollars of fully developed riparian real estate and a viable commercial and recreational harbor.

Complex and connected habitats necessary for many native fish species life requisites and life stages are no longer present. In particular, shallow water spawning through nursery habitats have been dredged and their shorelines hardened. However, some areas of the Outer Harbor have deeper water habitats to support submerged macrophytes. This habitat is suitable for many adult and juvenile fish species. Providing spawning populations of fish access to remaining and restorable habitats along streams and wetlands tributary to the estuary may be a cost-effective, environmentally sound and socially acceptable means of re-creating sustainable fish populations in the Milwaukee Estuary.

Although the information presented in this report directly supports a management plan for restoring sustainable populations of northern pike in the Milwaukee Estuary AOC, the information could also be used in part to create or supplement existing management plans for other fish species in the Milwaukee Estuary AOC (i.e., walleye). Northern pike is well suited as a surrogate for restoring other potamodromous fish species for a variety of reasons: They are a native, relatively long-lived iteroparous species with similar life history requirements (i.e., water quality); they require access to a variety of complex seasonal life stage habitats; they are an important ecological and recreational species; they exhibit strong spawning migratory behavior, and recent studies suggest they possess spawning and natal site fidelity; and compared to other fish species, northern pike adults possess poor swimming and leaping performance past barriers (Schwalme et al., 1985; Peake, 2008a and 2000b) such that designing features to accommodate pike passage around barriers would greatly increase the probability that other fish species with superior swimming and leaping performances, would be able to pass the same barriers.

This report is an initial effort to identify early life stage factors that contribute to northern pike recruitment and ultimately the restoration of spawning populations in the Milwaukee Estuary AOC. Those factors include: the status of northern pike spawning populations; the quality and quantity of wetland functioning spawning and nursery habitat; and the extent of barriers to those wetlands.

Objectives:

1. Identify historical and remaining barriers to adult northern pike migratory movement.
2. Assess the quality and quantity of wetland habitat relative to northern pike spawning and nursery habitat.
3. Complete an assessment of northern pike and other fish community populations in the Milwaukee Estuary AOC, Milwaukee River and its principal tributaries.
4. Complete a preliminary management strategy for restoring sustainable populations of northern pike in the Milwaukee Estuary AOC.

Methods

Study Area

The study area is located along the Milwaukee River (WIBC 15000), Milwaukee River Basin (US Geological Survey Hydrologic Unit Code 04040003). The Milwaukee River headwaters are located in central Fond du Lac County and the river flows south, southeast for 161 km before its confluence with Lake Michigan in Milwaukee County. The basin drains 2,284 km^2 and has a mean annual discharge of 12.7 cms and $Q_{7,10}$ discharge of 0.74 cms at RK 10.3 (1,800 km^2). The principal watersheds include the Milwaukee River East/West Branch (689 km^2), Milwaukee River South Branch (435 km^2), Milwaukee River North Branch (150 km^2), Cedar Creek (334 km^2), Menomonee River (352 km^2) and the Kinnickinnic River (86 km^2). Basin-wide land use is dominated by agricultural (46%); open space as wetland, forest, grassland and open water (43%); and urban (11%). Agricultural and open space land uses are dominant in the in the upper and middle reaches of the watershed, with increasing amounts of urban low-density increasing to urban high-density land uses in the lower reaches of the watershed and estuary in Ozaukee, Waukesha and Milwaukee Counties.

Our study area was limited to streams and wetland resources generally located within the Milwaukee Estuary AOC, including: the Menomonee River and tributaries upstream to the Menomonee River Lepper Dam in the Village of Menomonee Falls in Waukesha County (RK 35); and the Milwaukee River and tributaries upstream to the Milwaukee River Bridge Street Dam in the Village of Grafton, Ozaukee County (RK 52)..

Barrier Inventory and Classification

Recent inventories within the study area by others have identified known or potential man-made barriers to fish movement including weirs and dams, culverts, bridges, concrete channel inverts, and enclosures; and natural barriers as rock escarpments, sediment and debris (SEWRPC, 2009; Northern Environmental, Inc. 2006). These structures generally affect the upstream and downstream movement fish movement by altering the local hydraulic characteristics of a stream including the headwater-tailwater elevation differences, turbulence, velocity, and water depths. In very general terms, the structure may be a *complete* or *partial* barrier to fish movement.

A complete barrier to fish movement prevents all species of fish, regardless of life stage, swimming and leaping performance, from passing the barriers over a full range of hydrological and hydraulic conditions. Complete barriers to fish movement are generally associated with high head structures (i.e., dams or natural rock escarpments) such that even under a full range of estimated and extreme discharge conditions (i.e., drought through 500-year recurrence flood interval) the differences between headwater and tailwater elevations, water depths or velocities are sufficient to prevent *all* fish species from swimming or leaping over or around the barrier.

The extent or effectiveness that a structure is a partial barrier to fish movement depends on its ability to limit all or some species of fish to pass the structure, depending on the species life stage, swimming and leaping abilities, and under certain hydrologic and hydraulic conditions. Partial barriers may impact a specie or species by delaying or preventing spawning migrations, adult and juvenile emigrations.

We proposed using a fish barrier classification system developed by Robison et al., (1999) for assessing barriers along Oregon's Pacific salmon streams, as complete, partial or temporary barriers. The classification expanded on the number of categories to account for the effectiveness of barriers relative to the timing of targeted species spawning and return migrations, average seasonal recurring flows and duration relative to the migrations of targeted species (i.e., native spring migrants versus non-native salmonid fall migrants), and the swimming and leaping performance of targeted species (Table 1).

Table 1: Proposed classification of barriers to fish movement.

Fish Species	**Barrier Classification**	
	All of the Time	Some of the Time
All Species	**Complete Barrier**: A barrier to *all* fish species regardless of species migration period, swimming & leaping performance over the *entire range* of hydraulic conditions.	**Partial Barrier 1**: A barrier to *all* fish species regardless of species swimming & leaping performance under *specific* hydraulic conditions.
Some Species	**Partial barrier 2**: A barrier to *some* fish species possessing limited swimming & leaping performance over the *entire range* of hydraulic conditions.	**Partial Barrier 3**: A barrier to *some* fish species possessing limited swimming & leaping performance under *specific* hydraulic conditions.

We assessed the extent that individual dams are barriers to fish movement by field inspecting existing dams, reviewing WDNR Dam Safety files, the WDNR Dam Safety layers and metadata contained in the WDNR Intranet Surface Water Data Viewer, and interviews with WDNR Dam Safety engineers http://dnrmaps.wisconsin.gov/imf/imf.jsp?site=SurfaceWaterViewer. We compared the leaping ability of various native and managed non-native fish species to the modeled headwater-elevation differences estimated at each weir or dam structure for the 20-year, 50-year, and 100-year recurrence flood interval (equivalent to the 5%, 2% and 1% annual probability of occurrence, respectively).

Dams and weirs were classified complete barriers when the headwater and tailwater elevation differences exceeded 2 m for the estimated 20-year recurrence flood interval (equivalent to 5% annual probability of occurrence) discharge. We chose this criterion because headwater-tailwater elevation differences, accompanying river discharge and flood recurrence intervals are available for all hydraulically significant structures in the study area through the Federal Emergency Management Agency (FEMA) Flood Insurance Studies (FIS), and because the 2 m elevation difference exceeds the reported 1.5 m leaping ability of native northern pike. (Note: Estimated headwater-tailwater elevation differences for the annual and 2-year recurrence flood interval would have been preferred to ascertain annual barrier conditions to spawning fish movements, but those estimates were not available from FEMA). We then compared the individual structures hydrologic and hydraulic characteristics to the published maximum leaping performances of alluvial and potamodromous fish known to be present in the Milwaukee River Basin including the Milwaukee Estuary and Lake Michigan (Meixler et al., 2009; USDA, 2007) (Table 2). We did not distinguish between the different queues or triggers for an individual species leaping behavior (i.e., fright/flight, feeding, spawning migration).

Table 2: Maximum reported leaping ability (ft) for Milwaukee River Basin fluvial and Lake Michigan potamodromous fish species.

Common Name	Reported Leaping Ability (ft)	(m)	Reference
Brown trout	3.6	1.1	Meixler et al., 2009
Chinook salmon	12.0	3.66	Meixler et al., 2009
Coho salmon	7.2	2.2	USDA, 2007
Gizzard shad	1.1	0.34	Meixler et al., 2009
Northern pike	4.9	1.5	Meixler et al., 2009
Shorthead redhorse	1.9	0.57	Meixler et al., 2009
Smallmouth bass	2.0	0.60	Meixler et al., 2009
Rainbow trout	11.2	3.4	USDA, 2007
Walleye	4.0	1.21	Meixler et al.
White sucker	2.2	0.68	Meixler et al.

The inventory of culverts, bridges, concrete channel inverts and grade-control structures as barriers to fish movement for Waukesha and Milwaukee Counties is based on WDNR field staff observations, a reviewing the most recent aerial photographs and the inventory completed by the Southeastern Regional Planning Commission (SEWRPC, 2009).

The inventory of bridges and culverts completed by Northern Environmental, Inc. and Ozaukee County staff includes detailed field surveys, hydrologic and hydraulic modeling to classify each culvert as a complete or partial barrier to fish movement (Northern Environmental, Inc., 2006). Subsequent to their inventory, the Ozaukee County Fish Passage Program has designed and constructed culvert replacements or modification to enable northern pike passage under the 1-year recurrence interval flood discharge.

Wetland Spawning Habitat Classification

We completed a review of northern pike spawning habitat classification systems developed by Inskip (1982; Casselman and Lewis (1996); and Rost and Schuette (1998) and used their work as the foundation for proposing a hybrid classification system for stream and wetland hydrologic and morphological features, and land uses encountered in the study area. Our classification system was selective for wetland habitat adjoining flowing waters and potentially capable of meeting the life requisites for northern pike adult immigration to and emigration from spawning sites; spawning cover types; embryo through free-swimming larvae life stages; and larvae emigration from the spawning grounds.

Species-specific management plans should be based on a review of its life history and habitat requirements for critical life stages to insure that potential physical or biological bottlenecks to northern pike recruitment do not exist or could otherwise be managed. Our proposed habitat classification system also included habitat variables and metrics based on contemporary studies of the northern pike life history when appropriate.

A comparison of the Inskip (1982), Casselman and Lewis (1996), and Rost and Schuettte (1998) habitat suitability models for northern pike is available in Appendix 1, and the results of our review for the northern pike life history is contained in Appendix 2.

Wetland Spawning Habitat Inventory

We completed a coarse, landscape-scale inventory of wetlands adjoining the Milwaukee and Menomonee Rivers and their tributaries using the WDNR GIS wetland layers (scale 1:24000). The original wetland inventory was completed in 1984 and updated in 2005 using aerial photograph imagery. We included wetland parcels that were at least 0.8 ha in area and 10 m in width unless it was contiguous with a larger wetland parcel. Metadata included the unique wetland parcel identification code, wetland code, wetland class and subclass description (vegetation cover type), hydrologic modifier, area and perimeter. The analysis did not attempt to measure the extent of hydrologic connectivity with the stream as that effort was beyond the scope of the assessment.

Northern Pike Young-of-the-Year (YOY) Production

We deployed fish traps design to collect larvae and assess northern pike production at three tributary stations; two stations on Trinity Creek and a single station on Ulao Creek in Ozaukee County during the spring of 2004. We selected Trinity and Ulao Creeks as sample streams because fish distribution surveys since 1975 noted relatively diverse fish assemblages for intermittent streams, including northern pike, and because they are the first watersheds upstream of the Milwaukee Estuary to have existing or restored wetlands suitable for northern pike spawning and nursery habitat (WDNR and USGS GAP Analysis, 2010; WDNR, 1985) (Appendix 3). A third generation landowner near the headwaters of Ulao Creek stated that he and his father observed spawning northern pike on marshes dominated by Reed canary grass and low-intensity grazed pasture when these low areas were flooded each spring (pers. comm. Tim Kaul).

Two traps were located on Trinity Creek. Trap TC1 was located approximately 0.31 km upstream of the Milwaukee River and 20 m downstream of an effective fish passage barrier culvert along Green Bay Rd. (STH 57) in the City of Mequon. Trap TC2 was located 12 m downstream of the restored wetland and stream complex approximately 1 km upstream of the Milwaukee River. A single trap (UC1) was located on Ulao Creek 35 m upstream of CTH Q and 1.3 km downstream of the Ulao Swamp and the Tim Kaul marsh, and 7.9 km upstream of the Ulao Creek confluence with the Milwaukee River Thiensville impoundment (Figure 2 and 3).

Figure 2. Location of northern pike larvae traps in the Trinity Creek (TC) subwatershed.

Figure 3. Location of northern pike larvae trap in the Ulao Creek (UC) subwatershed.

The traps were designed and constructed by Rost and Schuette (1998). The traps were open frame construction of wood lathe measuring 61 cm wide by 36 cm high by 76 cm long. The entire frame is surrounded by 17x14 mesh aluminum window screen. The upstream side and entrance to the trap's collection pot includes a single-funnel screened inlet measuring 46 cm high by 2.5 cm wide that limited fish from escaping the pot. Between two and three traps were fastened together with lathe and braided twine to accommodate sample site stream widths (Figure 4).

Figure 4. Three side-by-side fish larvae trap assembly deployed at Ulao Creek station UC1.
Note incised channel morphology.

Traps were secured to the stream bed using 0.9 m long by 19 mm-diameter steel rebar and/or wood lathe. Where stream widths exceeded the width of the traps, plywood or frame-screened wings were fastened to the traps and extended to the stream bank to prevent fish from escaping around the trap end walls. Three to five rebar posts were set in the stream channel upstream of the traps to collect large floating debris. Debris captured by the rebar and traps was removed during each trap inspection.

Traps were initially inspected 5-days following ice-out and installation, and generally at two to three day intervals thereafter. All fish were removed from the trap using a small dip net.

We obtained hourly instantaneous water temperatures (+/- 0.1^{o}C) for the entire period of trap deployment using an ONSET recording thermistor and ONSET software deployed at Ulao Creek (UC1). The thermistor was attached onto a 0.5 m long rebar driven into the stream bed, submerged and orientated to be in flowing water. We obtained meteorological data from the NOAA National Climatic Center for the City of Port Washington located due northeast of the study area. Warming degree-days were calculated by adding the daily average water temperature over the period of deployment.

Fishery Assessment- Northern Pike and Fish Assemblage

We established two sample *reaches* along the Milwaukee River; one reach located upstream of the T-M Dam (Reach “U”) and the other reach located downstream of the T-M Dam (Reach “D”) (Table 3 and Figures 5-7). We then established four sample *stations*, two sample stations within each reach as stations U1, U2, D1 and D2. Station U1 was located in the headwater of the impoundment where the channel morphology transitions between lentic and lotic features (narrower, higher velocities and sheer stresses, coarser and transient substrates). Station U2 was located midway between the T-M Dam and headwater station characterized as a slack water and fine-sediment depositional reach. Stations U1 and U2 were located 4.4 km apart. Stations D1 and D2 were located downstream of the T-M Dam. Station D1 extended downstream of the T-M Dam tailwater, and station D2 is located in a run/pool river reach approximately 2 km downstream of station D1. Stations D1 and D2 were located 7.2 km apart. Each sample station included two *sub-samples*; a 1.6 km IBI sub-sample where all fish were collected; and a 1.6 km extended fish sub-sample where only top predator fish were sampled, usually northern pike, walleye, largemouth and smallmouth bass, and catfish. All totaled, we electrofished 6.4 km or 20% of the 32.2 km of the Milwaukee River located between the Milwaukee Estuary and T-M Dam; and 6.4 km or 73% of the 8.7 km long T-M impoundment, including the transitioning free-flowing to impoundment headwater segment.

We geolocated (lat/lon DD.deg) upper and lower limits of each sample station and site location, and sample station waypoints and lengths using a Trimble Explorer 3 GPS. We used ArcView GIS and aerial orthophotos to estimate the area (ha) of each sample station and to calculate northern pike density (fish/ha) and biomass (kg/ha).

The fish assemblage was sampled using a boat-mounted, pulsed-DC “mini-boom” electrofishing unit operating from a 4.3 m-long aluminum Jon boat powered by a 20 hp outboard motor. The bow-mounted anode was a single 3.5 m boom with a “Wisconsin Ring” from which 8 cylindrical, 25 mm-long, 14 mm-diameter stainless steel droppers are suspended. All electrofishing was completed during daylight hours, in a downstream direction, and as close to the shoreline as possible where current breaks and the greatest amount of usable fish cover was located. Fish collections dates were made between April 6 and May 6, earlier than the standardized mid-May through late-September IBI sampling protocol. IBI were calculated for each of the four individual sample stations.

Top predator game fish measures included species identification, count, individual length to the nearest 2mm, and weight to the nearest 10g. All other fish were identified to species, counted and either weighed individually (large bodied specimens) or in aggregate (smaller bodied species).

Captured northern pike from each sample station received a unique partial caudal fin clip or punch to identify the specimen's collection station. Sex and condition (as green, ripe or spent) was determined by extrusion of sexual products. Absent sexual products, we determined pike sex the appearance of their external urogenital region according to Casselman (1974).

Table 3. Summary of lower Milwaukee River fish sample reaches, stations, description and location.

Milwaukee R. Station Description	Reach	Station	Distance from River Mouth (km)	Start Lat/Lon	End Lat/Lon
T-M Impoundment Headwater (Transition between lentic and lotic morphology)	U	1	37.7	43.2508900 -87.9420748	43.2704147 -87.9448286
T-M Impoundment	U	2	33.3	43.2397486 -87.9349076	43.2371050 -87.9466737
T-M Dam			31.7		
T-M Dam Tailwater (Mequon Rd. to Dam)	D	1	29.4	43.2304422 -87.9793250	43.2198423 -87.9792726
Range Line Rd to Schroeder Dr. extended	D	2	22.2	43.1863378 -87.9589839	43.17413227 -87.9588603

Figure 5. Aerial view of Milwaukee River fish sample *reaches* upstream (U) and downstream (D) of the Thiensville-Mequon Dam; and sample *stations* (U1 and U2), and *sub-samples* as game or IBI.

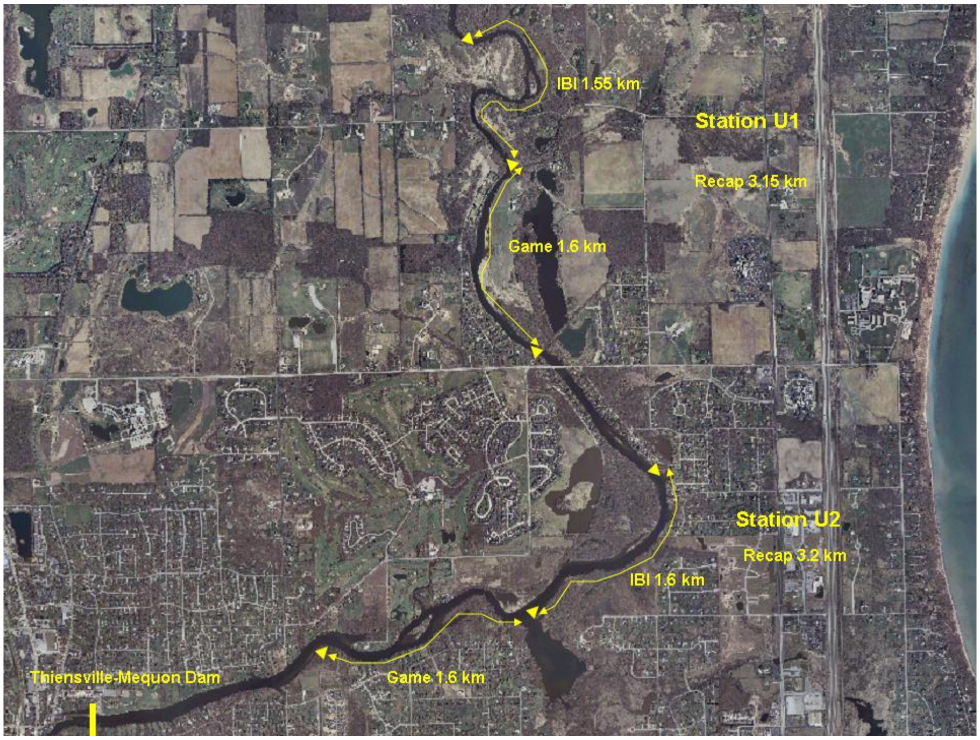


Figure 6. Aerial view of Milwaukee River fish sample *reaches* downstream (D) of the Thiensville-Mequon Dam; and sample *station* (D1), and *sub-samples* as game or IBI.

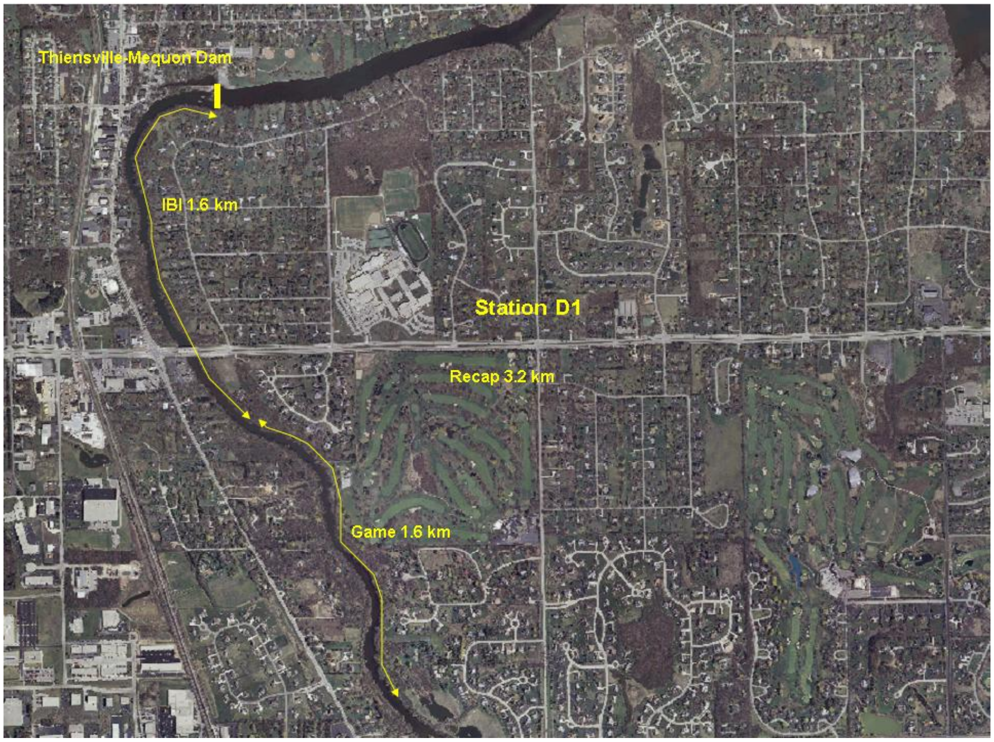
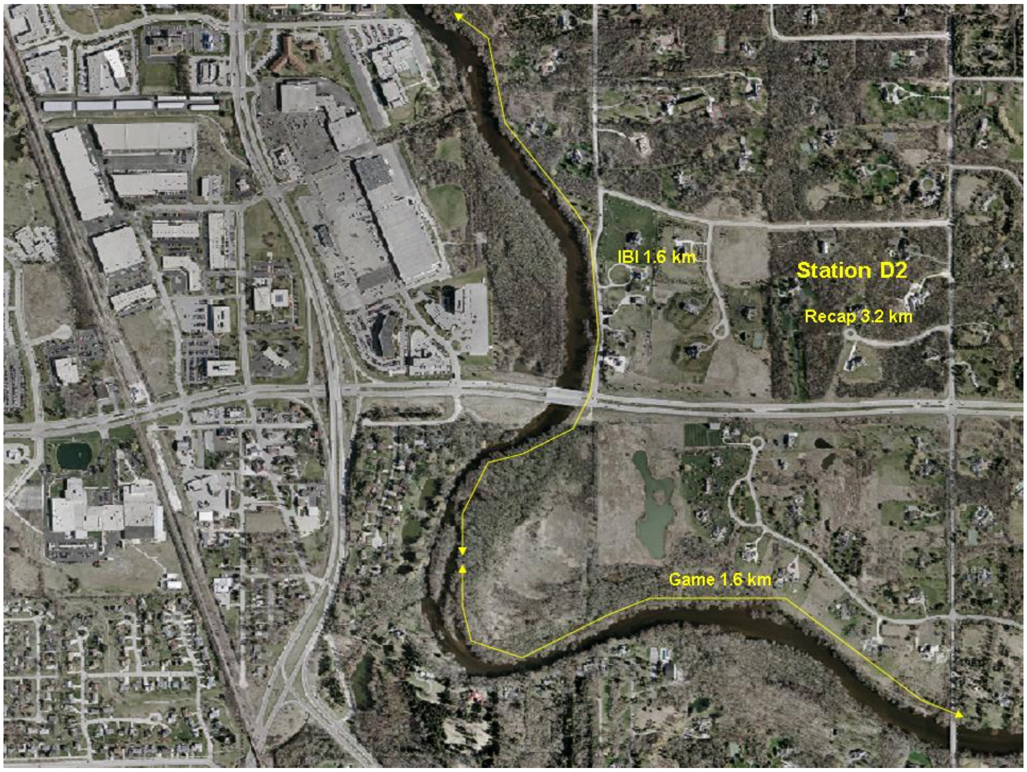


Figure 7. Aerial view of Milwaukee River fish sample *reaches* downstream (D) of the Thiensville-Mequon Dam; and sample *station* (D2), and *sub-samples* as game or IBI.



We generally followed the standardized fish electrofishing protocol for calculating a fish-based Index of Biotic Integrity (IBI) for warm water rivers of Wisconsin that enable simultaneous determination of river health and game fish statistics (Lyons et al., 2001). The warm water rivers IBI includes metrics and scoring criteria, and models calibrated for fish communities located in northern versus southern Wisconsin. We used the southern model that includes 10 metrics: total weight of the catch (excluding tolerant species); the number of native, sucker, intolerant, simple lithophilous spawners or riverine specialist species; percentage of DELT (deformed or diseased as eroded fins, lesions or tumors); and the percentage of the total weight catch that are insectivores or round-bodied suckers. We modified the model to exclude potamodromous salmonids from Lake Michigan that are not present in the Milwaukee River during warmwater periods, and the specified protocol for sampling (mid-May through late-September). We began sampling beginning in early-April with the intentions of capturing concentrated populations of spawning and migrating northern pike.

We estimated the northern pike population (N) for two distinct Milwaukee River populations; upstream of the T-M Dam (stations U1+U2) and downstream of the T-M Dam (stations D1+D2) using a single mark and re-capture event and the Chapman modification of the Petersen equation as described by Ricker (1975). Binomial 95% upper and lower confidence limits and co-efficient of variation for the population estimates were calculated.

We compared northern pike relative abundance (CPUE) from our study to those compiled from the Milwaukee River between the former North Avenue Dam (RK5) and Thiensville Dam (RK_31), and the Milwaukee Estuary. These later data are routinely obtained as part of the WDNR's Baseline Monitoring Program (year 2001-2010). We also compared pike densities (fish/ha) and biomass (kg/ha) from our study to those estimates developed for Wisconsin's statewide waters.

Due to the low numbers of northern pike captured (n<32), we chose not to sacrifice fish for aging purposes. We estimated northern pike length at age by correlating to northern pike mean length at age for Wisconsin waters using bivariate regression analysis with 95% limits and STATVIEW® statistical software.

Results and Discussion

Barrier Assessment

The inventory of man-made fish passage barriers is most complete for the Milwaukee River and tributaries in Ozaukee County; and least known for the major tributaries of the Milwaukee River in Milwaukee County. The least is known about potential barriers along the Menomonee River and its major tributaries in Milwaukee, Waukesha and Washington Counties. The number of barriers to fish movement by type and in descending order is culverts, concrete and enclosed channel inverts, weirs and dams (Table 4). We classified only one Complete Barrier to fish passage in the study area, the Menomonee River Lepper Dam in the Village of Menomonee Falls at RK 23.

Milwaukee River, Milwaukee and Ozaukee Counties

Figure 8 and 9 are maps that identify the approximate location and status of significant fish passage barriers along the Milwaukee River and major tributaries in Milwaukee and Ozaukee Counties.

Estabrook Dam

There are two remaining low-head dams in Milwaukee County that are considered partial barriers to fish passage. The furthest downstream structure is the Estabrook Dam located at RK 10 and is classified as a Partial Barrier 1 to fish passage. Strong-swimming and high-leaping spring running rainbow trout may pass the fixed-crest portion of the spillway under high spring flows. However, the step-like configuration of the spillway, and lack of a sufficiently deep pool and plunging flow below the spillway would even challenge fall-running salmonids. The Estabrook Dam was most recently operated in a fill (late-May) and drawdown (November) mode, and has been drawn down since 2008 under orders by the WDNR to complete a dam stability analysis, and the dam owners decision to repair or replace the dam; and to complete remediation of contaminated sediments behind the fixed crest portion of the spillway. Under the former fill and drawdown operation, the dam was passable by fish during seasonal flowed conditions. Fall-run chinook, coho and fall- and spring-run rainbow trout were the species that took most advantage of the dam’s seasonal flowed operation. Impacts to water quality, fish, other aquatic life and wildlife habitat as a result of seasonal drawdown operations may require the dam to be operated at pool full and run of the river. Under a pooled full run of the river operation, the dam would be a complete barrier to native species fish passage, and fall-running salmonids.

Kletzsch Dam

The Kletzsch Dam in Milwaukee County is located at RK 17.. It is a low-head dam and is submerged for extended periods of time during annual recurring spring flows. It is classified as a Partial Barrier 3 to fish passage. It is not a barrier to salmonids during high spring flows and base fall flows due to the presence of an adequately deep pool and plunging flow. Larger bodied native species with adequate burst-swimming speeds would likely be able to bass the spillway during spring flows when the spillway is submerged or nearly submerged.

Thiensville-Mequon Dam

The T-M Dam in Ozaukee County is located at RK 31 is classified as a Partial Barrier 3 to fish passage. The T-M Dam is considered a low-head hydraulic structure (3.7 m) and is submerged for multiple days on a 2-year to 4-year frequency. A fishway was constructed around the dam in an abandoned millrace in 2010. Funding for the fishway was provided by the NOAA/Ozaukee County Fish passage Program; the USFWS; the Wisconsin Coastal Management Program; and the V. of Thiensville and City of Mequon.

Bridge Street Dam

The Bridge Street Dam located at RK 52. It is classified as a Partial Barrier 2. A recent hydrologic and hydraulic analysis concluded that certain Lake Michigan non-native salmonids, most notably chinook salmon and rainbow trout, possess swimming and leaping abilities to pass the dam during the 20-year and less frequent recurrence river flow conditions. Fish passage by leaping the spillway is enhanced by a deep pool and plunging flow below the spillway. According to the FEMA FIS study, the water elevation difference between the spillway headwater and tailwater during the 20-year recurrence flood interval was estimated at between 1.5 and 1.8 m. Reported leaping abilities of chinook salmon and rainbow trout are 3.7 m and 3.4 m, respectively. Among native species, the highest leaping ability was reported for northern pike and walleye at 1.5 m and 1.2 m, respectively.

Major Tributaries of the Milwaukee River, Milwaukee County

There are five principal tributaries to the Milwaukee River in Milwaukee County including Lincoln Creek, Indian Creek, Southbranch Creek, Beaver Creek and Brown Deer Creek totaling 31 km. These streams are generally low-gradient streams (< 3m/km and < 5% riffle); hydrologic orders ranging from 1st through 2nd, and drainage areas ranging from 4.4 km^2 for Brown Deer Creek to 51.4 km^2 for Lincoln Creek. The watersheds are dominated by urban land uses ranging from Indian Creek (78%) to Southbranch Creek (99%). Total impervious cover is also high, ranging from Indian Creek (27%) to Lincoln Creek (47%).

Beginning in the 1960’s, the MMSD and local communities practiced stream channelization, concrete lining and enclosure as a means of abating flooding as a result of rapid urban development and engineered conveyance systems (curb, gutter and storm sewer) without centralized or site-specific practices to abate storm water quality or quantity pollution impacts. Structures were often included to accommodate potential impacts of invert grade changes and potential for channel head cutting. Concrete or heavy rip rap was included under bridges, bridge piers, and infrastructure crossings to protect them from erosion and failure. Since the late 1990’s, the MMSD has been pursuing a policy to rehabilitate many of these stream and floodplain reaches as part of their continuing flood abatement program. The MMSD also considers concrete invert removal and stream rehabilitation for special and as concrete channels go through attrition. Since 2000, the MMSD has removed 4.2 km of concrete lined stream channel, four grade control structures and three bridges along Lincoln Creek. Additional concrete channel removal, replacement of culvert fish barriers and rehabilitation of the stream channels was completed by the MMSD on Indian Creek and by the Village of Brown Deer on Beaver Creek.

All totaled, there are 31 km of 1st and 2nd orders streams tributary to the Milwaukee R. in Milwaukee County, excluding the Menomonee R. which will be discussed in more detail below. Prior to 2000, 3.5 km or 11% were free of fish passage barriers. Since 2000, the length of fish passage impediment free stream channel in Milwaukee County has increased to 14.2 km, or 45% of the total. Most of these improvements were made along Lincoln Creek.

There is a very limited inventory of other potential fish barriers along these tributaries as perched culverts, grade-control structures, and concrete and heavy rip rap used to protect bridge and other buried infrastructure. These structures, most notably observed around bridges, may still be present along some stream reaches that were enhanced by removal of concrete lined inverts.

Major Tributaries of the Milwaukee River, Ozaukee County

Lac du Cours Creek is a 1st order, intermittent, low-gradient and warmwater tributary to the Milwaukee River. It discharges to free-flowing reach of the river 22 km upstream of the Milwaukee Estuary and 4 km downstream of the T-M Dam. The majority of the subwatershed includes Lac du Cours Lake, a 23 ha man-made lake with a 0.3 m head dam located at the outlet. It is just 0.4 km long, drains 3 km^2 and has a $Q_{7,2}$ of < 0.1 cms and routinely ceases to flow during late-summer and fall months. Deep runs and pools provide refuge to fish during extended drought periods. Land use is a dominated by low-density residential uses and stormwater is conveyed primarily through roadside ditches. A low-head dam at RK 0.4 located in the headwaters is classified as a Partial Barrier 1 and a perched culvert located at the confluence of the Milwaukee River at 0.1 km is classified as a Partial Barrier 3. The culvert was replaced in 2010 and the low-head dam is proposed to be modified in 2011.

Trinity Creek is a 2nd order, intermittent, low-gradient and warmwater tributary to the Milwaukee River. It discharges to a free-flowing reach of the river 22.5 km upstream of the Milwaukee Estuary and 3.5 km downstream of the T-M Dam. It is approximately 4.1 km long, drains 14 km^2 and has a $Q_{7,2}$ of < 0.1 cms and routinely ceases to flow in the summer and early fall months. The entire stream alignment was previously channelized for agricultural uses. Land use is currently a mixture of agriculture, open space, low-density residential and lesser amounts of commercial and light manufacturing. The City of Mequon constructed the 18.2 ha Trinity Creek Wetland Habitat project in the late-1990. Prior to its construction, the entire parcel was in agricultural land use but farming was limited by poor drainage and a high water table. The city acquired the parcel for constructing a multi-purpose facility for attenuating downstream flooding, crating public open park space and wetlands. Two ponds on the site total 3.4 ha and the shoreline includes between 0.33 ha and 0.66 ha of shallow northern pike spawning shelf, the actual shelf dimensions and extent of submergence controlled by weirs and adjustable flashboards. In 2010, the Ozaukee County Fish Passage Program removed a large deposit of railroad ballast RK 1Partial Barrier 1 and dual-elliptical culverts RK 0.3 as Partial Barrier 3 located between the ponds and Milwaukee River were replaced to enable fish movement between the river, Trinity Cr., ponds and wetlands. For the summer of 2011, the program will be lowering the bottom of each weir by approximately .6 m to enable fish movement between Trinity Cr. and spawning habitat along the ponds shorelines. Following these modifications, Trinity Creek will be free of fish passage barriers. The WDNR has proposed an operational and management plan to the City of Mequon that would benefit northern pike production in addition to other ancillary environmental benefits in the Trinity Creek subwatershed. Lowering the weir inverts will allow managers to encourage winter freeze-out for managing common carp and gizzard shad; decrease suspended solids, turbidity and total phosphorus levels presently elevated by the feeding and spawning activity of carp; improve water transparency for macrophyte growth; and expand the amount of shoreline wet-meadow used for northern pike and other phytophilic spawning fish, and perhaps the marsh spawning strain of walleye.

Pigeon Creek is a 3rd order perennial stream that discharges to a free-flowing reach of the Milwaukee River 25 km upstream of the Milwaukee Estuary and 0.35 km downstream of the T-M Dam. It is approximately 13.2 km long and drains 30 km^2 and has a $Q_{7,10}$ of < 0.014 cms. It has a highly dendritic headwater including over 16 km of ephemeral or intermittent tributaries. Land use is dominated by agriculture, open space and increasingly, low- to medium-density residential uses. Approximately 40% of Pigeon Creek has been channelized for agricultural drainage purposes. Along its upper and lower reaches, it is a moderate gradient stream supporting a transitional cool-warmwater fish assemblage. Along its middle reaches, it has a low to moderate gradient, and some areas, a channel substrate of exposed fractured bedrock. This geologic formation includes springs that support a transitional cool-coldwater fish assemblage evidenced by rainbow trout parr collected over multiple year fish samples. Between 2008 and 2010, four partial barriers to fish passage were modified or removed from Pigeon Creek including a concrete invert RK 0.2, dual-perched culverts RK 0.4, railroad ballast RK 3.5 all Partial Barrier 1; and the private WLS low-head dam RK 0.8 Partial Barrier 3.

Ulao Creek is a 3rd order low gradient intermittent tributary that discharges to the Milwaukee River T-M impoundment at RK 39 and 8 km upstream of the T-M Dam. It is approximately 14.2 km long with numerous ephemeral and intermittent tributaries. It drains approximately 35 km^2 and has a $Q_{7,2}$ of < 0.1 cms. Extensive reaches of stream cease to flow during the warmer months. Pools and deep runs provide fish refuge during low-flow and drought. Over 90% of the stream was historically channelized for agricultural purposes. Current land use is predominately agriculture although portions of the middle watershed adjoining Interstate I-43 in the Village of Grafton are being developed in urban commercial land uses. Landowners in the headwaters gave accounts of northern pike spawning runs in the 1950-1970s with observed runs waning since then (pers. corr. Tim Kaul). Partial man-made barriers to fish passage include multiple perched culverts RK 4.6 and two discharge measuring flume at RK 4.2 and RK 7 all classified as Partial Barrier 1. These barriers were removed or modified by the Ozaukee County Fish Passage Program in 2010 and the stream is considered to be fish barrier free.

Figure 8. Status of significant fish passage barriers along the Milwaukee River and major tributaries in Milwaukee County; and Menomonee River in Milwaukee and Waukesha Counties.

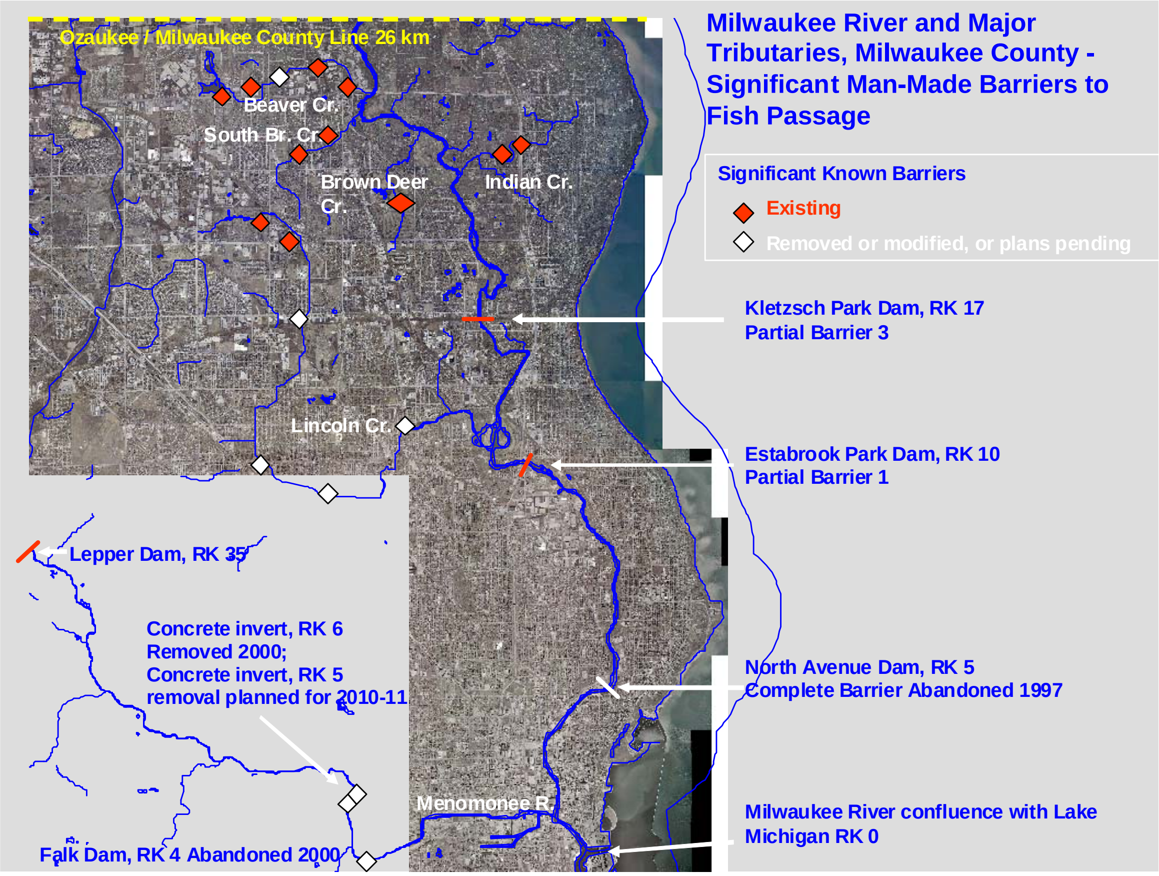
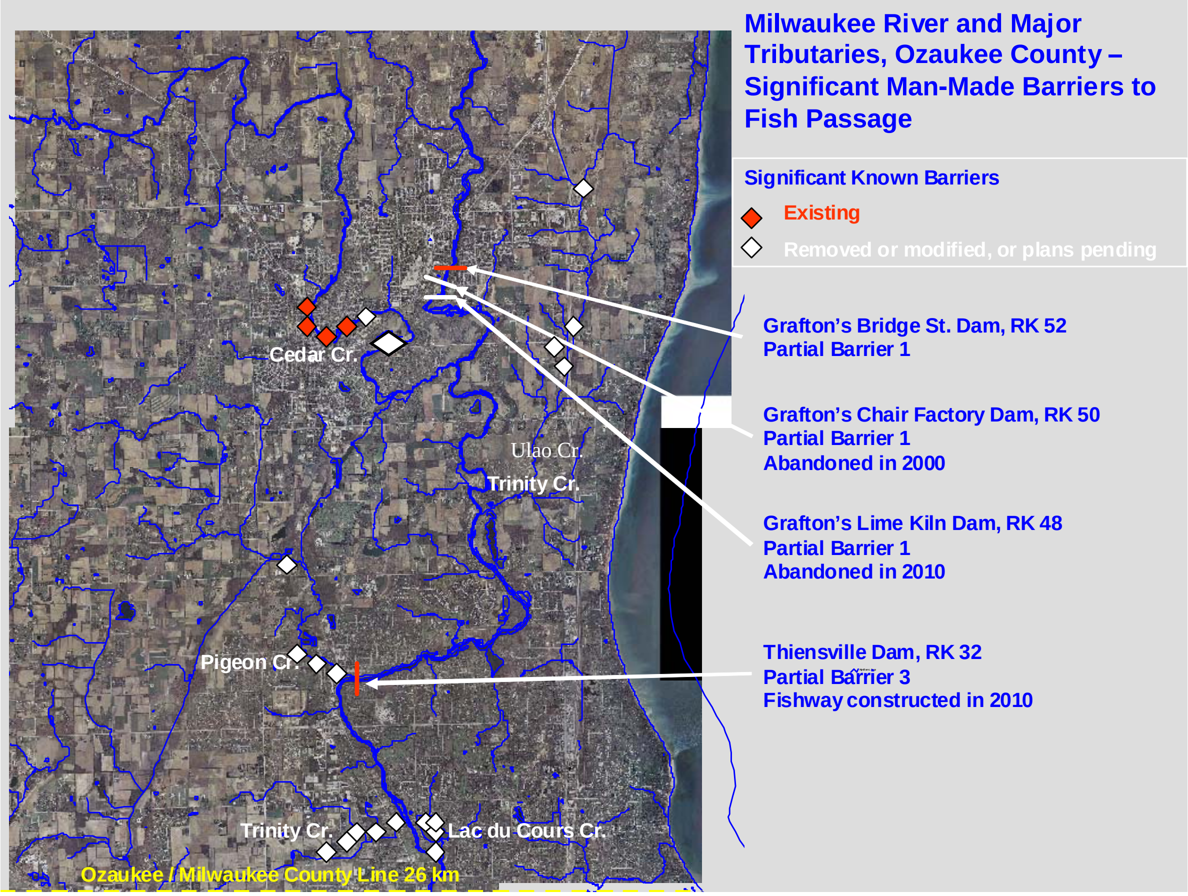


Figure 9. Status of significant fish passage barriers along the Milwaukee River and major tributaries in Ozaukee County downstream of Village of Grafton Bridge Street Dam.



Menomonee River, Milwaukee and Waukesha Counties

The Menomonee River discharges to the Milwaukee River estuary at RK 1.7. It is a 4th order stream, moderate gradient stream draining 353 km^2 draining portions of Milwaukee, eastern Waukesha, and southern Washington and Ozaukee Counties. It is one of the largest urbanized watersheds in the state especially in the middle and lower reaches of the watershed. Urban land uses make up approximately 65% of the watershed and most of the stormwater is conveyed by engineered stormsewer systems. As a result water quality is limited and excessive hydraulic loads contribute to bed and bank erosion and scouring of fish and aquatic life habitat. Significant barriers to fish passage along the Menomonee River are located on Figure 8. They include the Falk Dam RK 4 Partial Barrier 3 abandoned in 2000; a grade-control structure and 0.6 km long concrete lined invert located between RK 5 and 6 as Partial Barrier 2 of which a 0.3 km reach and grade-control structure were removed in 2000 and an additional 0.3 km is planned to be removed in 2010-2011; and the Village of Menomonee Falls Lepper Dam RK 35 to remain as a Complete Barrier to fish passage.

Aside from the obvious barriers described above, there is no detailed or screening level inventory of potential barriers to fish passage along the Menomonee River or its tributaries in the project area. However, the SEWRPC (2009) did recently complete a cursory inventory of known and potential barriers to fish passage in the Menomonee River watershed recognizing that most potential barriers will require individual and more detailed field surveys to ascertain them as non-barriers, partial or complete barriers. Following their review, SEWRPC identified approximately 300 potential barriers, the majority of them located within our study reach downstream of the Village of Menomonee Fall Menomonee River Lepper Dam at RK 35 (Appendix 4). The most common known or potential man-made fish passage barriers included bridge and culvert crossings, railroad crossings, concrete-lined channel inverts, channel enclosures, grade control structures, and encased infrastructure crossings. Potential natural barriers to fish passage include beaver dams, debris jams, and sediment deposits.

Major Tributaries of the Menomonee River, Milwaukee, Waukesha and Ozaukee Counties

The principal tributaries to the Menomonee River in include Honey Creek (RK 10), Underwood Creek (RK 13) and its tributary the South Branch Underwood Creek, the Little Menomonee River (RK 20), Butler Creek (RK 23), Lily Creek (RK 31), and Nor-X-Way Creek (RK 33). These watersheds are highly urbanized with engineered storm sewer systems, and numerous road crossings. All of these streams have been channelized initially to accommodate agriculture land use drainage, and later for urban development and flood control. A summary of some of the WDNR verified and obvious barriers to fish passage along the Menomonee River and its major tributaries is shown is summarized in Table 4.

Approximately 13 km or 16% of these stream lengths have been placed in a concrete invert and 15 km or 18% have been enclosed resulting in an extensive network of Complete Barriers to fish passage, and very poor habitat. The Little Menomonee River has the longest open channel length of any tributary in the Menomonee River watershed, and although channelized, has a broad and often natural functioning floodplain and wetlands. The Little Menomonee River is a Superfund Site as a result of sediment contaminated by creosote-based carcinogenic polynuclear aromatic hydrocarbons (CPAHs). The contaminated sediments have been remediated and a portion of the channel has been enhanced with meandering morphological features and hydrologically connected floodplain resulting in 1.1 km of additional stream length and annually flooded wetlands.

The impacts of barriers to fish movement, especially in developed watersheds with many partial and complete barriers, can not be over stated. Many fish species migrate to satisfy habitat requisites for foraging, protection, rearing, and spawning. In freshwater systems, migrations may range from several meters to many kilometers on a daily or seasonal basis. Migrating or moving fish are vulnerable to injury and mortality if normal movement patterns are blocked or impeded by constructed barriers. They are also more susceptible to injury and predation as they try to negotiate manmade barriers. If fish passage is impeded during spawning migrations, impacts on population can be severe and include failed or reduced year classes, decreased egg size and fecundity, injury or mortality (NRCS, 2007).

Table 4: Major stream and major man-made fish barrier identified by WDNR in the Milwaukee River, Menomonee River watersheds in Milwaukee, Ozaukee and Waukesha Counties.

Stream	WIBC	Stream Total Length (km)	Barrier Free Pre-2000 (km) (%)	Barrier Free Post-2000 (km) (%)	Remaining man-Made Barriers and Classification (from Table 1)	Comments
Milwaukee R. Watershed						
Milwaukee R.	15000	52	52 (100)	52 (100)	Estabrook Dam RK 10 Partial Barrier 1 Kletzsch Dam RK 17 Partial Barrier 3 Bridge St Dam RK 52 Partial Barrier 1	North Avenue Dam RK 5 Complete Barrier abandoned 1997 Chair Factory Dam RK 50 Partial Barrier 1 abandoned in 2002 Lime Kiln Dam RK 48 Partial Barrier 1 abandoned in 2010 T-M Dam RK 31 fishway constructed in 2010 Permit to construct fishway through Bridge St. Dam denied by WDNR due to potential spread of Viral Hemorrhagic Septicemia (VHS) upstream
Lincoln Cr.	19400	14.5	2.1 (14)	12.8 (88)	Complete Barrier	Culvert with grade control structure; concrete invert 4 km of concrete invert and no less than four grade control structures as Complete Barriers removed by MMSD since 2000
Indian Cr.	19600	4.2	0.6 (14)	0.6 (14)	Complete Barrier	Perched culvert; concrete invert
Southbranch Cr.	24000	3.8	0.3 (8)	0.3 (8)	Complete Barrier	Concrete invert; perched culverts; bridges
Brown Deer Cr.	19700	3.4	0.3 (11)	0.3 (11)	Unknown	Multiple culverts; on-line ponds and weirs; concrete invert; enclosure
Beaver Cr.	20000	5.1	0.2 (4)	0.2 (4)	Complete Barrier	Enclosure; low-head dams; concrete inverts
Milwaukee Co. Tributary Subtotal		**31**	**3.5 (11)**	**14.2 (45)**		
Lac du Cours Cr.	20200	0.5	0 (0)	0.5 (100)	None	Culverts (2) RK 0.1 and 0.2 km Partial Barrier 3 and dam RK 0.4 Partial Barrier 1
Trinity Cr.	20400	4.1	0.3 (7)	4.1 (100)	None	Dual-culverts 0.3 km Partial Barrier 1, railroad ballast RK 1 Partial Barrier 3, culvert (2) Partial Barriers 1 removed or modified in 2010; weirs (2) RK 1.1 and RK 1.4 Partial Barriers 1 to be modified in 2011
Pigeon Cr.	20500	13.2	0.5 (4)	13.2 (100)	None	Concrete invert RK 0.2, dual-perched culverts RK 0.4, and railroad ballast RK 3.5 as Partial Barrier 1; and WLS Dam RK 0.8 Partial Barrier 3 all removed between 2008 and 2010.
Ulao Cr.	24000	14.2	4.5 (31)	14.2 (100)	None	Flume RK 4.4, multiple-perched culverts at RK 4.6, stone ford and improperly sized and placed rip rap as Partial Barrier 1 removed or modified in 2010.
Ozaukee Co. Tributary Subtotal		**32**	**5.3 (17)**	**32 (100)**		
Menomonee R. Watershed *						
Menomonee R.	16000	23	4 (17)	3.7 (16)	Concrete Invert RK 5 Partial Barrier 2 Lepper Dam RK 35 Complete Barrier	Falk Dam RK 4 Partial Barrier 3 abandoned in 2000 Menomonee R. 0.3 km concrete invert and grade control structure RK 6 Partial Barrier 2 removed in 2000. Additional 0.3 km concrete invert to be removed in 2011-12.
Honey Cr.	16300	16	1.4	1.4	Complete Barrier	1.7 km concrete invert and 13 km enclosed channel
Underwood Cr.	16700	16	0 (0)	0 (0)	Complete Barrier	4 km concrete invert and two grade-control structures. MMSD concrete removal project partially constructed in 2010 with remainder under design.
S.Br. Underwood Cr.	16800	9	0 (0)	0 (0)	Complete Barrier	5.5 km concrete invert and 2 km of enclosed channel.

L. Menomonee R.	17600	14	14 (100)	14 (100)	Unknown	Inventory of potential barriers lacking upstream of the Milwaukee – Ozaukee County line.
Stream	WIBC	Stream Total Length (km)	Barrier Free Pre-2000 (km) (%)	Barrier Free Post-2000 (km) (%)	Remaining man-Made Barriers and Classification (from Table 1)	Comments
L. Menomonee Cr.	17900	6	1.3	1.3	Unknown	Perched and hydraulic barrier culvert at Granville Rd. Inventory incomplete upstream of Granville Rd.
Nor-X-Way Channel	18450	8	0.4	0.4	Complete Barrier	1.6 km long concrete invert. Barrier inventory incomplete upstream of concrete invert.
Lily Cr.	18400	8			Unknown	Culvert barrier inventory incomplete
Butler Cr.	18000	5			Unknown	Culvert barrier inventory incomplete
Tributary Subtotal						
Tributary Total						

* A comprehensive inventory of potential fish passage barriers has been completed by SEWRPC (2009) (Appendix 4).

Wetland Spawning Habitat Classification

We proposed a system for classifying northern pike wetland spawning habitat relying extensively on the reviews and research by Roth and Schuette (1998), Casselman and Lewis (1996), and Inskip (1982) (Table 5). We also referenced the observations and conclusions of other authors whose works documented a narrower focus on northern pike habitat requisites. As stated earlier, the proposed classification was selective for wetland habitat contiguous with flowing waters. These are the dominant habitat type encountered in the study area and potentially available to spawning populations of northern pike.

We adopted the structure and six of the eight physical habitat variables proposed by Casselman and Lewis (1996), and added another variable. The six habitat variables included vegetation type, vegetation density, water depth, water fluctuation, connectivity with the stream, and substrate type. We excluded the habitat variable rate of warming, and water exchange from the Casselman and Lewis model (Appendix 1). We felt that that the rate of warming based on sun exposure was not as limiting to the wetlands encountered in our study area where continuous mixing of the cooler stream flow with the wetland is limited to the initial inundating flow and stage. Similarly, we excluded the habitat variable water exchange as the wetlands present in our study area are not exposed to dramatic mixing events by the wind, wave action or overbank stream flows. This variable may be more relevant for large river systems with broad active floodplains and anastomosing or braiding channels; or wind swept lake shorelines.

Within our study area, watershed development has altered the natural seasonal peak flows and their duration. In addition, developed watersheds have significant lengths of headwater and low-order streams that have undergone hydrologic modifications, the most common being draining or filling of wetlands, and stream channelization. These conditions combine to reduce the vertical extent and duration of stream flows to supply water to the wetland. As a result of these modifications and impacts to connectivity between streams and wetland habitats, we proposed a habitat variable for *hydrologic connectivity*. The habitat description describes some of the stream's morphologic features relative to its floodprone dimensions, and allows one to approximate the vertical extent and frequency of overbank and wetland filling stream flows (Rosgen, 1996). Absent this information, it is difficult to estimate the connectivity between the stream and wetland that would enable pike to migrate and emigrate to and from spawning habitat, and provide adequate water depths and water level duration for spawning and development.

Similar to Casselman and Lewis, the proposed classification structure includes an assigned numerical *weight* for each habitat variable, and numerical *rank* for each habitat description. We expanded Casselman and Lewis two habitat descriptions and ranks ("Best highest rank 9; Poorest lowest rank 1") for each habitat variable to include more specific habitat descriptions and ranks for each habitat variable. The increase in habitat descriptions ranged from three (water level fluctuation and duration; hydrologic connectivity; connectivity to stream) to 12 (vegetation type).

Habitat descriptions were modified to include the original qualitative and quantitative descriptions included by Casselman and Lewis, in addition to the variables and ranks developed by Inskip (1982) and Roth and Schuette (1998), in addition to the conclusions and habitat criteria from other reviews and publications.

Use of the proposed classification system does require some degree of field assessment. Ideally, the field assessments would be conducted during the spring when streams and wetlands are flowed, and summer low flow periods to evaluate stream morphological features. All field data should be collected with a sub-meter survey grade GPS enabled computer. Access and use of GIS would provide some economy for selecting field assessment sites over a range of anticipated site features.

Table 5: Proposed wetland spawning habitat classification for northern pike and other phytophilic spawning fish species.

Habitat Variable	**Habitat Metric and Description**	**Weight (2-9)**	**Rank (1-9)**	**References ***
Vegetation Cover type	Moderately dense hummocks (2-4 per m^2) of native grass & sedge	9	9	2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13
	Native grasses	9	7	1, 6, 8, 9, 11, 12
	Un-mowed hay	9	6	6
	Canary-reed grass	9	5	12, 15
	Coarse leaf litter	9	5	12
	Submerged macrophytes	9	3	6, 9, 11, 14
	Emergent macrophytes	9	2	
	Cattail	9	2	3, 12, 13
	Mowed hay	9	2	6, 12
	Grazed pasture	9	2	12
	Floating macrophytes	9	2	
	Turf grass	9	1	
Vegetation Density	>80% of substrate covered by coarse, loosely compacted, and thick layer of vegetation. Plant material occupies >80% of water column. Coarse plants material with large amount of basal coverage. Abundant cover for egg and larvae. Not tightly compacted allowing for water circulation.	8	9	9, 11, 12
	50-80% of substrate covered by coarse, loosely compacted, and thick layer of vegetation. Plant material occupies 50-80% of water column. Coarse plants material with large amount of basal coverage. Abundant cover for egg and larvae. Not tightly compacted allowing for water circulation.	8	7	9, 11, 12
	25-50% of substrate covered by coarse, loosely compacted, and thick layer of vegetation. Plant material occupies <50% of water column.	8	5	9, 11, 12
	5-25% of substrate covered by coarse, loosely compacted, and thin layer of vegetation. Plant material occupies <25% of water column.	8	3	9, 11, 12
	0-5% of substrate covered by coarse, loosely compacted, and thin layer of vegetation. Plant material occupies <5% of water column.	8	1	9, 11, 12
Water Average Depth	0.2-0.4 m	9	9	6, 9, 11
	0.4-0.7 m	9	7	6, 9, 11
	0.7-1.5 m	9	5	14
	>1.5 m	9	3	14
	<0.2 m	9	2	
Water Fluctuation and Duration	Gradually increasing prior to adult migration to spawning site, and stable until larvae emigrate from spawning grounds ~ 6-8 weeks.	7	9	2, 5, 9, 11
	Steady water level prior to adult migration to spawning site, and gradually decreasing until larvae emigrate from spawning grounds ~ 6-8 weeks.	7	5	2,5, 9, 11
	Fluctuating or abrupt drop in water level prior to adult migration to spawning site; or abrupt drop prior to larvae emigrating from spawning grounds ~ 6-8 weeks.	7	1	2, 5, 9, 11

Habitat Variable	Habitat Metric and Description	Weight (2-9)	Rank (1-9)	References *
Hydrologic Connectivity	Very broad and active floodplain. Ratio of flood-prone width to bankfull width >10 and only slightly entrenched. Bankfull width to depth ratio >20 and banks stable. Top of bank and bankfull elevation are nearly equal. Floodplain spawning cover inundated on an annual recurring basis.	7	9	11, 12
	Broad and active floodplain. Ratio of flood-prone width to bankfull width 3-10 and only slightly entrenched. Bankfull width to depth ratio 12-20 and banks stable. Top of bank and bankfull elevation are easily distinguished apart. Floodplain spawning cover inundated on an annual recurring basis.	7	5	11, 12
	Narrow and confined floodplain or terrace. Ratio of flood-prone width to bankfull width <3 and highly entrenched. Bankfull width to depth ratio <12 and evidence of bank instability. Floodplain spawning vegetation inundation infrequent, less than on an annual recurring basis.	7	1	11, 12
Connectivity to Stream	Floodplain vegetation with well defined channels connected to stream; hummocks or rivulets provide unobstructed ingress and egress for spawning adults and larvae.	4	9	11
	Floodplain vegetation with some defined channels connected to stream; hummocks or rivulets uncommon and some obstructed ingress and egress for spawning adults and larvae.	4	5	11
	No defined and frequent channels connected to stream; hummocks or rivulets absent ingress and egress by spawning adults and larvae is generally obstructed.	4	1	11
Substrate Type	>80% of substrate and water column obscured; dominated by grass/sedge; abundant cover for egg and larvae; well oxygenated	3	9	9,11, 12
	50-80% of substrate and water column obscured; dominated by grass/sedge; abundant cover for egg and larvae; well oxygenated	3	7	9,11, 12
	25-50% of substrate and water column obscured; dominated by leaf or other coarse organic matter; moderate cover for egg and larvae; mixed with oxygenated and decomposing material	3	3	9,11, 12
	<25% of substrate and water column obscured by thinly scattered vegetation or debris; little to no cover for eggs and larvae; decomposing or anoxic	3	1	9,11, 12

* References
[1] Carbine, 1942
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[3] Franklin and Smith, 1963
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[5] Hassler, 1970
[6] McCarraher and Thomas, 1972
[7] Priegel and Krohn, 1975
[8] Fago, 1977
[9] Inskip, 1982
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[11] Casselman and Lewis, 1996
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[13] Farrell, 2001
[14] Farrel et al., 1996
[15] Morrow et al., 1997

Wetland Spawning Habitat Inventory

Within the study area, we inventoried 1809 ha of riparian wetlands having vegetative cover types potentially suitable for northern pike spawning habitat. The Milwaukee River and Menomonee River watersheds contained 1,000ha (55%) and 809 ha (45%) of the wetlands, respectively. Forested and mixed forested, emergent wet meadow and forested, scrub/shrub are the dominant wetland cover types in the Milwaukee River and Menomonee River watersheds totaling 78% and 74%, respectively. Emergent wet meadow and mixed emergent wet meadow, scrub/shrub contribute 20% and 25% of the wetland cover type in the Milwaukee River and Menomonee River watersheds, respectively. The earliest land surveys from 1835-1836 indicated that the dominant European pre-settlement upland vegetation of the study area and basin was largely beech/maple forest, and the lowland floodplain wetlands were a combination of hardwood and conifer swamp forest (SEWRPC 1997). Lowland hardwood forests included black and green ash, American elm, willow, red and silver maple. Less common conifer swamps included white cedar and tamarack (Table 6).

Although the dominant vegetative cover type inventoried in our study area may not be considered optimum for northern pike spawning habitat, Rost and Schuette (1998) observed most spawning pike to utilize forested and mixed forested wetland cover types along tributaries to Green Bay, Lake Michigan. The pre-settlement vegetative cover type in their studied watershed was cedar and tamarack swamp. They reported that over 3,000 pike larvae were captured from 17 of 61 larvae trap sites. While the highest rate of production of pike larvae was observed from restored emergent wet meadow wetlands and grass-lined intermittent ditches, significant production of pike larvae occurred in subwatersheds dominated by forested, and mixed forested wetlands present in our study area. Rost stated that accessibility, substrate density and hydrology (water depth and duration) were more crucial to pike production than vegetation cover type (Rost, per. corr.).

In the Milwaukee River watershed, most of the inventoried wetlands are currently considered accessible by resident, estuary and Lake Michigan fish stocks. In the longer-term, accessibility to wetland spawning habitat will depend on Milwaukee County's decision to abandon the Estabrook Park Dam at RK 10 or in the event they decide to repair and maintain the dam, provide the infrastructure to enable fish passage. Similarly, while the Kletzsch Park Dam at RK 17 is not considered at most a partial barrier to fish passage, a more detailed assessment should be completed to identify the seasonality of such a barrier and the potentially impacted fish species. Similarly, fish resident to Lake Michigan and the Milwaukee Estuary would have access to wetlands in the Menomonee River watershed following the planned removal of the Menomonee River concrete lined channel at RK 5. However, a complete inventory is needed to identify potential barriers to fish passage along the Menomonee River, and especially its major tributaries. When completed, a plan should be completed that identifies and prioritizes barriers in need of modification or removal based on the proposed spawning habitat classification system.

The wetland inventory confirms that the ability to create self-sustain populations of northern pike and other phytophilic spawning fish stocks for the Milwaukee Estuary, rivers and tributaries is entirely dependent on removing or modifying remaining barriers to fish movement and access to spawning habitat, and enabling the return of adults and emigrating juveniles to reach feeding habitat in the estuary and Lake Michigan. Potentially suitable wetland spawning habitat is located well upstream of the Milwaukee Estuary. Suitable quality and quantity of wetland pike spawning habitat is not encountered along the Milwaukee River until Lac du Cours and Trinity Creeks until RK 27, and especially RK 30in the Trinity Creek-Pigeon Creek subwatersheds in Ozaukee County, and along the Menomonee River at RK 19 in the Little Menomonee River subwatershed.

Table 6. Summary of riparian wetlands by watershed and vegetation cover type (hectares and percent).

Watershed	Emergent/wet meadow	Emergent/wet meadow, Open Water	Forested	Forested, Emergent/wet meadow	Forested, Scrub/shrub	Scrub/shrub	Scrub/shrub, Emergent/wet meadow	Total (ha)	Percent of Total Wetlands by Watershed (%)
Milwaukee R. Watershed cover types (ha)	**113**		**466**	**213**	**96**	**22**	**89**	**1000**	**55**
%	11		47	21	10	2	9		
Menomonee R. Watershed cover types (ha)	**136**	**8**	**352**	**181**	**67**		**64**	**809**	**45**
%	17	1	44	22	8		8		
Total Study Area cover types (ha)	**249**	**8**	**818**	**394**	**163**	**22**	**153**	**1809**	**100**
%	14	0	45	22	9	1	8		

Previous field observations suggest many of the study areas wetlands may not possess suitable hydrologic connectivity and hydroperiod for northern pike reproduction. Due to channelization and the highly developed and impervious nature of some subwatersheds, the extent of stream channel entrenchment relative to their floodplains has increased significantly. Stream channel forming and floodplain filling discharge events occur during all but winter seasons, and the duration of these frequent floodplain filling events are brief relative to the minimum 30-day hydroperiod necessary for pike spawning and development. This condition may be more common in the Menomonee River watershed where channelization and excessive hydraulic loads have increased channel width and depth, but channel entrenchment is common along some of the Milwaukee Rivers major rural tributaries as a result of channelization (Figure 10). Depending on the location and time of original and maintenance channelization, land use changes, and sediment and discharge characteristics the impacts of channelization may become less over time and opportunities to correct the impacts may exist.

Figure 10. Example of stream reaches hydrologically connected and disconnected from riparian floodplain wetlands in the Ulao Cr. subwatershed.

Ulao Cr. Slightly entrenched channel hydrologically connected with floodplain. Bankfull width:depth ratio >20. Mixed forest, emergent wet meadow.

Ulao Cr. Highly entrenched channel hydrologically disconnected from floodplain. Bankfull width:depth Ratio <12. Emergent wet meadow, Reed canary grass dominant.

Milwaukee River Watershed

We identified 1000 ha of riparian wetlands in the Milwaukee River watershed in our study area that met our definition of riparian wetlands potentially suitable and accessible for northern pike reproduction. The greatest concentrations of wetlands are located along tributary streams. Approximately 695 ha or 70% of the wetlands were located tributary subwatersheds while 305 ha or 30% were riparian to the Milwaukee River (Table 7).

Table 7. Summary of riparian wetlands for the Milwaukee River watershed by subwatershed and vegetation cover type (hectares and percent).

Milwaukee River Watershed	Emergent/wet meadow	Emergent/wet meadow, Open Water	Flats/ unvegetated wet soil	Forested	Forested, Emergent/wet meadow	Forested, Scrub/shrub	Scrub/shrub	Scrub/shrub, Emergent/wet meadow	Total (ha)	Percent of Total Wetlands Milwaukee Watershed
Lincoln Cr (ha)									0	
%										0
Beaver Cr (ha)									0	
%										0
Southbranch Cr. (ha)				1					1	
%				100						0
Lac du Cours Cr. (ha)				6					6	
%				100						1
Brown Deer Cr. (ha)				6					6	
%				100						1
Indian Cr. (ha)				6					6	
%				100						1
Trinity Cr. (ha)	16		1	25			2	8	53	
%	31		2	48			4	14		5
Ulao Cr. (ha)	25			67	129	37	1	20	280	
%	9		0	24	46	13	0	7		28
Pigeon Cr. (ha)	53			206	31	6	11	38	344	
%	15		0	60	9	2	3	11		34
Tributaries (ha)	**94**		**1**	**316**	**160**	**43**	**14**	**66**	**695**	
%	14		0	46	23	6	2	10		**62**
Milwaukee R (ha)	**19**			**150**	**53**	**53**	**8**	**23**	**305**	
%	6		0	49	17	17	3	7		**31**
Total cover type (ha)	**113**		**1**	**466**	**213**	**96**	**22**	**89**	**1000**	
% Total	11		0	47	21	10	2	9		

Comments:

62% of all wetlands in the Milwaukee River Watershed are located in Pigeon Creek and Ulao Creek subwatersheds

93% of all wetlands in the Milwaukee River Watershed are located in Pigeon Creek, Ulao Creek and Milwaukee River subwatersheds

78% of all wetlands in the Milwaukee River Watershed are forested (47%), mixture of forested, emergent/wet meadow (21%) or forested, scrub/shrub (10%)

The five tributary subwatersheds in Milwaukee County drain a total of 8,000 ha and contain only 19 ha or just 3% of the mapped riparian wetlands. Lincoln Creek and Beaver Creek subwatersheds in Milwaukee County did not include any mapped wetlands capable of providing suitable northern pike spawning habitat, while Brown Deer and Indian Creek contained just 6 ha of wetland each. Previous field observations suggest these wetlands and streams may not possess suitable hydrology and hydroperiod for northern pike reproduction, and are located upstream of partial or complete fish passage barriers. The MMSD constructed a 12 ha flood control detention and wetland facility along Lincoln Creek on the WDNR's Havenwood Park facility. While not a "mapped" wetland on the WDNR wetland inventory, the detention facility may provide wetland quality suitable for northern pike spawning. A passively operated weir functions to store water during a predetermined recurring flood event and without details on the hydrology of the site, would appear to be drained relatively quickly following each design flood event. As such the facility may not be capable of providing the needed 30-day hydroperiod for northern pike reproduction. A more detailed analysis would be required to determine if the existing or modified facility could be suitable spawning habitat.

The quantity of wetlands distributed among the nine tributary subwatersheds is skewed toward tributaries in Ozaukee County. The quantity of wetlands was independent of watershed drainage area and was driven by the extent of urban land uses. Four Ozaukee County tributaries with a total drainage area of 8,200 ha contained 682 ha or 97% of the riparian wetland parcels. Inversely, Pigeon Creek and Ulao Creek subwatersheds contained 345 ha (34%) and 280 ha (28%) of the total riparian wetlands in the Milwaukee River watershed project area. The majority of wetlands in the Pigeon Creek subwatershed are located along ephemeral and intermittent tributaries to Pigeon Creek.

Following completion of the Ozaukee County Fish Passage programs construction project to modify or replace barriers to fish passage, fluvial and adfluvial fishes will have free movement between the Milwaukee River, its principal tributaries and habitats. Ultimate fish population connectivity between Lake Michigan and Milwaukee Estuary fish stocks with viable habitats along the Milwaukee River and its tributaries will be dependent on ensuring fish passage at the Estabrook Park and Kletzsch Park Dams in Milwaukee County.

Wetlands along the Milwaukee River between the estuary and Bridge St. Dam at Grafton totaled 305 ha, or 31% of the total riparian wetlands. Within specific reaches of the Milwaukee River, the 32 km reach between the Milwaukee Estuary and T-M Dam totaled 70 ha (23%) while the 21 km reach between the T-M Dam and Bridge St. Dam totaled 438 ha, or 84% of the Milwaukee River riparian wetlands. All totaled, Milwaukee River, Pigeon Creek and Ulao Creek subwatersheds accounted for 929 ha, or 92% of the wetlands in the Milwaukee River watershed study area. With the addition of Trinity Creeks 53 ha of wetlands, these four watersheds contained 98% of the study area wetlands. Watershed-wide, we estimated similar wetland quantities when the Milwaukee River watershed was divided into two reaches, between the estuary and T-M Dam (485 ha or 48%); and between the T-M Dam and Bridge St. Dam at Grafton (516 ha or 52%). Within the Milwaukee Estuary and T-M Dam reach, Pigeon Creek contained 344 ha, or 71% of the total.

Within the Milwaukee River watershed, the dominant wetland vegetation cover type classes where forested 466 ha (47%) and mixed forested, emergent wet meadow 213 ha (21%). Together they accounted for 679 ha (68 %) of the cover type class. Among river reaches and tributary subwatersheds, forested wetland cover type dominated ranging from 48% to 60%. The exception was the Ulao Creek subwatershed where mixed forested, emergent wet meadow dominated at 46%. The majority of wetlands in the Ulao Creek subwatershed are located in the headwaters of the Ulao Swamp 152 ha (54%) where the pre-settlement vegetation was dominated by a closed canopy of mixed hardwood and cedar/tamarack conifers, and lesser amounts of shrub-carr and wet-meadow. Channelization and land use changed increased flooding in the central and southern portion of the swamp causing hardwood tree mortality whereby the current vegetative cover type is dominated by forested, emergent wet meadow and forested, shrub-carr. Absent these hydrologic impacts the “swamp”, like the remainder of the Ulao Creek subwatershed would be dominated by forested vegetation (Harpner and Reinartz, 2005).

Menomonee River Watershed

We identified 809 ha of riparian wetlands in the Menomonee River watershed in our study area that met our definition of riparian wetlands potentially suitable and accessible for northern pike reproduction. The greatest concentrations of wetlands are located along tributary streams. Approximately 588 ha or 73% of the wetlands were located along tributary subwatersheds while 305 ha or 27% were riparian to the Milwaukee River. There are no mapped wetlands located in the Menomnee River reach of the Milwaukee Estuary (Table 8).

The quantity of wetlands distributed among the seven tributary subwatersheds and the Menomonee River is skewed toward three of the seven tributaries in Milwaukee and Waukesha Counties. Three tributary subwatersheds, Underwood Creek, the Little Menomonee River and Lily Creek contained 466 ha or 58% of the riparian wetland parcels. However, all 165 ha of riparian wetlands in the Underwood Creek subwatershed are currently inaccessible by fish due to an impassable concrete invert and grade control structures upstream of its confluence with the Menomonee River. Excluding Underwood Creek wetlands, tributary subwatersheds contributed 52% of the Menomonee River watershed wetlands. Honey Creek did not contain any riparian wetlands; and Butler Creek, Little Menomonee Creek and the Nor X Way Channel each contributed 5% of the watersheds total wetland area.

Within the Menomonee River watershed, the dominant wetland vegetation cover type classes where forested 327 ha (40%) and mixed forested, emergent wet meadow 181 ha (22%). Together they accounted for 508 ha (62%) of the cover type class. Among river reaches and tributary subwatersheds, forested and mixed forest, emergent wet meadow cover types ranged from 36% in the Butler Creek subwatershed to 65% in the Lily Creek subwatershed. Emergent wet meadow is the dominant cover type in the Butler Creek (46%) and Nor X Way Channel (24%) subwatersheds.

The estimated 218 ha of wetland cover type for the Little Menomonee River was revised from the original wetland inventory to reflect the recent conversion of approximately 25 ha of forest wetland cover type to emergent wet meadow. The change in wetland cover type was necessitated by extensive clearing and grubbing of woody plants to provide construction access for the removal of creosote contaminated sediment and floodplain soils along the Little Menomonee River in 2005. Post-remediated stream reaches were re-meandered to a higher bed elevation and floodplain elevations were lowered creating a stable and non-incised channel plan form and hydrologically connected floodplain wetlands. The Little Menomonee River contains the largest tract of contiguous emergent wet meadow cover type in the Menomonee River watershed capable of meeting the hydroperiod requirements of northern pike for spawning and development.

There are a significant number of restorable wetlands present in the study area. Kline (et al., 2006) identified restorable wetlands in Ozaukee County based on a variety of landscape-scale features. In addition, wetlands that do not currently have the optimum hydrologic connectivity for fish and wildlife uses could be enhanced. An inventory of potentially restorable or enhanceable wetlands in the study area was beyond the scope of our study.

Table 8. . Summary of riparian wetlands for the Menomonee River watershed by subwatershed and vegetation cover type (hectares and percent).

Menomonee River Watershed	Emergent/wet meadow	Emergent/wet meadow, Open Water	Flats / unvegetated wet soil	Forested	Forested, Emergent/wet meadow	Forested, Scrub/shrub	Scrub/shrub	Scrub/shrub, Emergent/wet meadow	Total (ha)	Percent of Total Wetlands Menomonee Watershed
Honey Cr									0	
%										0
Butler Cr	18			2	12			7	40	
%	46		0	5	31			18		5
L. Menomonee Cr	5			14	3			19	41	
%	11		0	35	7			47		5
Nor X Way	10	8		9	7			7	41	
%	24	20	0	22	17			18		5
Lily Cr	18			46	14	7		7	92	
%	20		0	49	15	7		8		11
Underwood Cr	57			83	19			7	165	
%	34		0	50	11			4		20
L. Menomonee R	51			51	82	25		2	208	
%	25		0	25	39	12		1		26
Tributaries	**159**	**8**		**205**	**137**	**31**		**50**	**588**	
%	27	1	0	35	23	5		8		**73**
Menomonee R	**4**			**123**	**44**	**36**		**15**	**221**	
%	2		0	55	20	16		7		**27**
Total covertype (ha)	**163**	**8**	**0**	**327**	**181**	**67**		**64**	**811**	
% Total	20	1	0	40	22	8		8		

Comments:
58% of all wetlands in the Menomonee River Watershed are located in L. Menomonee River, Underwood Creek and Lily Creek subwatersheds
74% of all wetlands in the Menomonee River Watershed are located in Menomonee River, L. Menomonee River and Underwood Creek subwatersheds
74% of all wetlands in the Menomonee River Watershed are forested (47%), mixture of forested, emergent/wet meadow (21%) or forested, scrub/shrub (10%)
Estimated covertype for Little Menomonee River is based on assumptions of post-sediment remediation wetland restoration planting.

Northern Pike YOY Production

Fish larval traps were deployed in the Ulao Creek subwatershed at Ulao Creek Station UC1 and the Trinity Creek subwatershed at Trinity Creek Stations TC1 and TC2 for 30-days (April 6 and May 5, 2004) and over 331 water degree-days. Although the traps were planned to be deployed for a minimum of 90-days (30-days per trap), we estimated that the traps fished effectively for only 54 days, ranging from 14 days at Trinity Creek TC1 to 20 days at Trinity Creek TC2 and Ulao Creek UC1 (Table 9). Filamentous algae, *Cladophora spp*., was a common problem clogging traps at all stations beginning right after deployment and especially during and following high flow events. Between April 17 and April 27, 7 cm of rain fell at Port Washington, WI located 3 km northeast of the Ulao Cr. and Trinity Cr. watersheds. According to a local observer in Mequon, 5 cm fell over a 4-hour period on April 25 and the Ulao Creek and Trinity Creek subwatersheds and were not recorded at the Port Washington observer. These precipitation amounts caused the traps to be inundated, and in the case of Ulao Cr. UC1 the traps were dislodged and demolished. All traps were removed on April 21 and re-deployed on April 27 at Trinity Creek TC2 and, Ulao Creek UC1 and there were not enough serviceable traps to re-deploy at TC1. Streams remained above or near bank full conditions until they were removed on May 5.

No northern pike larvae were captured. Two white sucker larvae, a 20 mm specimen from UC1 and a 10 mm from TC1 were captured on April 15 providing only limited evidence that the deployment period coincided with the initial emigration of white sucker. Geen (et al., 1966) and Corbet and Powles (1986) observed white sucker to migrate 7-14-days after hatching, and Franklin and Smith (1963) reported pike to begin emigrating from spawning grounds 16 to 24-days after hatching. These observations suggest we might not have expected to see northern pike larvae for 9 to 20-days, a period that would have occurred during the heavy rain and high flow period. Rost and Schuette (1998) operated pike larval traps in the Pensaukee River watershed in northeast Wisconsin from mid-April through mid-August 1996. Their report did not include daily logs of fish captures, but it presumed that at least some of these traps continued to effectively capture some pike larvae over the 120 day monitoring period.

Of the remaining 9 white sucker captured among all stations, 2 were spent males captured at Station TC1 on April 20 five days after capturing the sucker larvae. One northern pike, a 360 mm spent male and presumed emigrating back to the Milwaukee River was captured at Trinity Creek TC1 on April 19.

When the traps were fishing during more normal seasonal conditions, they were effective at capturing small bodied fish. If northern pike had been present in the watershed at the time the traps were fishing, the traps would have been effective at capturing them. A total of 1,208 fish were captured averaging 19.1 fish per trap day. Trinity Creek UC1 and Ulao Creek UC1 averaged 23.4 and 30.8 fish per trap day or approximately 3 to 7 times the number of fish at Trinity Creek TC2. Age 0+ centrarchids were captured at Trinity Creek Stations TC1 and TC2 likely owing to the ponds upstream. Trinity Creek stations also captured spotfin shiner and sand shiner, species that typically inhabit larger riverine systems and are common to the Milwaukee River.

Table 9. Summary of larvae trap fishing effort by subwatershed and station.

Subwatershed and Stations	Number Fish Captured	Trap Days Fished	Fish per Trap Day
Trinity Creek TC2	63	20	3.2
Trinity Creek TC1	328	14	23.4
Ulao Creek UC1	616	20	30.8
All Stations	**1008**	**54**	**Average 19.1**

Sixteen fish species were collected from the three combined sites. Five species accounted for 92.1% of the total catch: fathead minnow (59.8%); bluntnose minnow (12.1%); spotfin shiner (8.6%); central mudminnow and common shiner (5.8%) each. Bluegill, white sucker, green sunfish and sand shiner contributed between 1-2% of the total three station catch. Brook stickleback, central stoneroller, blackstripe topminnow, rock bass, northern pike (adult), Johnny darter and black crappie each contributed <1% of the total catch (Table 10).

Table 10. Summary of fish species numbers and percent of total catch captured by larvae fish traps for all stations.

Species	Number All Stations	Percent All Stations
Black crappie	1	0.1
Johnny darter	1	0.1
Northern pike	1	0.1
Rock bass	1	0.1
Blackstripe topminnow	2	0.2
Central stoneroller	6	0.6
Brook stickleback	7	0.7
White sucker	11	1.0
Sand shiner	13	1.3
Green sunfish	17	1.7
Bluegill	21	2.1
Common shiner	58	5.8
Central mudminnow	58	5.8
Spotfin shiner	87	8.6
Bluntnose minnow	122	12.1
Fathead minnow	602	59.8
Total Catch	**1008**	**100.0**
Total Species	**16**	

Species richness was greatest from the Trinity Creek subwatershed at 14 compared to the Ulao Creek subwatershed at 8. Trinity Creek TC1 and TC2 included 13 and 10 species, respectively. Ulao Creek UC1 included 8. The greater diversity of fish in the Trinity Creek watershed may be a result of the two trap sites being located a considerable distance closer to the Milwaukee River. Trinity Creek TC1 and TC2 are located 0.3 km and 1 km from the Milwaukee River, whereas Ulao Creek UC1is located 7.9 km from the stream’s confluence with the Milwaukee River. Trinity Creek discharges to a free-flowing reach of the Milwaukee River that has more diverse riverine habitat and more diverse fish assemblage. Ulao Creek discharges to the Milwaukee River T-M impoundment which has more limited riverine habitat and less diverse fish assemblage.

Trinity Creek TC1 included four unique fish species (central mudminnow, northern pike, rock bass and blackstripe topminnow) absent from Trinity Creek TC2. Trinity Creek TC2 included a single specimen of black crappie not captured from Trinity Creek TC1. Ulao Creek UC1 included two fish species (johnny darter and central stoneroller) absent from Trinity Creek collections (Table 11).

Ulao Creek UC1 accounted for the greatest number of captured fish among all three sites at 61%. The number of fish captured at Ulao Creek UC1 was skewed toward fathead minnows accounting for 87% of the catch at Ulao Creek UC1, and 53% of the total fish catch among all three sample sites. Central mudminnow totaled 9.3% of the catch at UC1 and combined with the fathead minnow catch, comprised 96.6% of the total catch at Ulao Creek UC1.

Table 11. Relative abundance of fish captured, by species, at larvae trap stations at Trinity Creek (TC1 and TC2) and Ulao Creek (UC1).

Trinity Cr. TC1	**Species**	**Count/Species**	**Percent of Total**
Trinity Cr. TC1 only	Central mudminnow	1	0.3
Trinity Cr. TC1 only	Northern pike	1	0.3
Trinity Cr. TC1 only	Rock bass	1	0.3
Trinity Cr. TC1 only	Blackstripe topminnow	2	0.6
Trinity Cr. TC1	Central stoneroller	1	0.3
Trinity Cr. TC1	Green sunfish	2	0.6
Trinity Cr. TC1	White sucker	5	1.5
Trinity Cr. TC1	Sand shiner	10	3.0
Trinity Cr. TC1	Bluegill	19	5.8
Trinity Cr. TC1	Fathead minnow	50	15.2
Trinity Cr. TC1	Common shiner	51	15.5
Trinity Cr. TC1	Spotfin shiner	66	20.1
Trinity Cr. TC1	Bluntnose minnow	119	36.3
Trinity Cr. TC1	**Total / Species**	**334 / 13 species**	**100.0**
Trinity Cr. TC2	**Species**	**Count/Species**	**Percent of Total**
Trinity Cr. TC2 only	Black crappie	1	1.6
Trinity Cr. TC2	Bluegill	1	1.6
Trinity Cr. TC2	Central stoneroller	1	1.6
Trinity Cr. TC2	White sucker	1	1.6
Trinity Cr. TC2	Bluntnose minnow	3	4.8
Trinity Cr. TC2	Common shiner	3	4.8
Trinity Cr. TC2	Sand shiner	3	4.8
Trinity Cr. TC2	Fathead minnow	14	22.2
Trinity Cr. TC2	Green sunfish	15	23.8
Trinity Cr. TC2	Spotfin shiner	21	33.3
Trinity Cr. TC2	**Total / Species**	**63 / 10 species**	**100.0**
Trinity Cr. TC1 and TC2	**Species**	**Count/Species**	**Percent of Total**
Trinity Cr. TC1 only	Central mudminnow	1	0.3
Trinity Cr. TC1 only	Northern pike	1	0.3
Trinity Cr. TC1 only	Rock bass	1	0.3
Trinity Cr. TC2 only	Black crappie	1	1.6
Trinity Cr. TC1 only	Blackstripe topminnow	2	0.6
Trinity Cr. TC1 + TC2	Central stoneroller	2	0.5
Trinity Cr. TC1 + TC2	White sucker	6	1.5
Trinity Cr. TC1 + TC2	Sand shiner	13	3.3
Trinity Cr. TC1 + TC2	Green sunfish	17	4.3
Trinity Cr. TC1 + TC2	Bluegill	20	5.1
Trinity Cr. TC1 + TC2	Common shiner	54	13.8
Trinity Cr. TC1 + TC2	Fathead minnow	64	16.4
Trinity Cr. TC1 + TC2	Spotfin shiner	87	22.3
Trinity Cr. TC1 + TC2	Bluntnose minnow	122	31.2
Trinity Cr. TC1 + TC2	**Total / Species**	**385 / 14 species**	**100.0**

Ulao Cr. UC1	**Species**	**Count/Species**	**Percent of Total**
Ulao Cr. UC1	Bluegill	1	0.2
Ulao Cr. UC1	Johnny darter	1	0.2
Ulao Cr. UC1	Central stoneroller	4	0.6
Ulao Cr. UC1	Common shiner	4	0.6
Ulao Cr. UC1	White sucker	4	0.6
Ulao Cr. UC1	Brook stickleback	7	1.1
Ulao Cr. UC1	Central mudminnow	57	9.3
Ulao Cr. UC1	Fathead minnow	538	87.3
Ulao Cr. UC1	**Total / Species**	**616 / 8 species**	100.0

Central mudminnow and fathead minnow are relatively tolerant of lower dissolved oxygen levels. Dissolved oxygen levels are extreme during summer months along the upper through middle reaches of Ulao Creek. Previous continuous logging of certain diel water quality parameters suggests that summer conditions may not be very conducive to a diverse fish assemblage. In some locals of Ulao Creek, daylight dissolved oxygen concentrations were supersaturated during daylight hours and fell to levels ranging as low as 0.3 mg/l and 1.5 mg/l (Appendix 5). Low dissolved oxygen levels in these reaches may be associated with intermittent flow, warmwater temperatures, and based on extreme variations between observed daytime and evening hour dissolved oxygen concentrations, the respiration by aquatic plants. Filamentous algae, *Cladophora spp*., were abundant at all stations during our study and may persist through the summer months.

In order to reduce monitoring costs and maintain a higher degree of sampling efficiency, more dependence on local volunteers would be needed. Our results suggest that a single trap site located further downstream in the smaller of the two watersheds was relatively effective at accounting for >90% of the watersheds potential species richness and >75% of the watershed catch. Limiting trap sites to a single site in smaller watersheds may reduce trap operating costs. A trap design and installation compatible with site-specific channel dimensions and anticipated seasonal stream discharges would improve trapping efficiency and reduce clogging by algae and other debris.

Fishery Assessment- Northern Pike and Fish Assemblage

All totaled, 12 km of the 51 km or 23% of the lower Milwaukee River upstream of the Milwaukee Estuary were sampled during this assessment. Fish assemblage sample efforts were similar among all stations ranging from 76 min. at station D2 to 83 min. at station U2. Pike mark-recapture efforts were also similar among all stations ranging from 86 min. at station U1 to 109 min. at station D2.

Sample stations were electrofished between April 6, 2005 and May 6, 2005. Stations U1 and U2 upstream of the T-M Dam were sampled 14 to 30 days, respectively after Stations D1 and D2 located downstream of the T-M Dam due to equipment scheduling conflict or equipment malfunction. Instantaneous water temperatures during the April electrofishing surveys downstream of the T-M Dam were 12^{o}C and 13^{o}C at Stations D1 and D2, respectively. These temperatures were 3-4.8^{o}C cooler than water temperatures obtained from sample Stations U1 and U2 upstream of the T-M Dam.

River discharges ranged from 5.4-29.2 cms. Discharges at the stations downstream of the T-M Dam were 2.5-5 times greater than the stations located upstream of the T-M Dam between sample dates. River discharges did not appear to affect electrofishing efficiencies within and between sample stations.

Malfunctioning of the outboard motor made downstream operation and control of the boat impossible in the fast flowing waters at Station U1 during the IBI fish assemblage run. Protocol for non-wadable electrofishing is in a downstream direction but the outboard would not operate between idle and mid-RPM making boat control difficult. When working in an upstream direction, the current swept fish below the boat and the dipper was unable to collect fish due to the heavy drag on the net. While he observed abundant fish numbers, most notably redhorse, he estimated fishing efficiency at < 95%. We concluded that aside from the mechanical problems experienced during the Station U1 event, electrofishing with the Wisconsin “miniboom” was effective and provided an accurate sample for species richness and relative abundance during seasonally high flow periods. Fishing with the miniboom during seasonal low- or base-flow conditions would not have been possible along free-flowing reaches of the river.

We estimated that 75% of the fish sampled at sample Station D1 located downstream of the T-M Dam were obtained within 75 m of the tailwater area. The large concentration of fish below the dam, in particular redhorse, was a result of the dam preventing upstream movement of fish and the forced aggregation of fish below the barrier.

Northern Pike Population Characteristics

Overall, pike populations in the study area are low with a total of just 23 northern pike captured from our study area (Table 12). Pike CPUE for the 12.75 km of river was 1.8 pike/km and 1.9 pike/hr. Seventeen of the 23 pike were captured downstream of the T-M Dam at station D1 and D2. Pike CPUE was lowest at the impounded station U2 (0 captures) and highest in the dam spillway Station D1 at 3.1 pike/km and 3.2 pike/hr. Based on higher water temperatures exhibited at the time Stations D1 and D2 were fished, we surmised that pike would have already emigrated from spawning sites to their summer preferred habitat including the lacustrine-like habitat in the T-M impoundment. However, no pike were captured from the T-M impoundment.

Pike CPUE are higher in our study area when compared to capture rates compiled for the lower Milwaukee River and Milwaukee Estuary baseline sample period between 2001 and 2010. Pike/km and pike/hr from our study area were 2-times more abundant than free-flowing reaches along the lower Milwaukee River, and 10 to 22-times more abundant than reaches in the Milwaukee Estuary. The more abundant pike population in our study area is due in part to the congregation fish below the T-M Dam. It may also involve a natural seasonal pulse whereby lake and estuary populations ascend streams to access wetlands for the purpose of spawning and development.

Their seasonal movements and overlapping life-stage preferences for both riverine-lacustrine habitats may explain, in part, the low numbers of pike captured during the summer baseline sample events along the lower free-flowing reaches of the Milwaukee River.

The low numbers of post-spawn pike adult and juveniles from summer Inner Harbor estuary baseline collections is due in large part to the lack of preferred summer-winter habitat, and avoidance of poor water quality. Post-spawned adults and juveniles emigrate from their spawning grounds and river habitats, and when available, return to preferred lacustrine habitat of cooler and deeper water, with abundant aquatic vegetation for cover and foraging. These habitat features, along with abundant forage, are present in the northern and southern ends of the Outer Harbor area of the Milwaukee Estuary but are lacking in the Inner Harbor. While water depths are adequate in the Inner Harbor area of the estuary, aquatic vegetation is absent. Heated cooling water from a power plant located on the Menomonee River portion of estuary maintains large areas of the Inner Harbors summer water temperatures in excess of 32^{o}C, with maximum summer water temperatures measured as high as 37^{o}C. Pike and their forage avoid these extreme summer water temperatures. Based on creel surveys and anecdotal evidence, pike and their primary forage gizzard shad return to the Inner Harbor in late-fall through winter when extreme water temperatures are moderated but still remain atypical of natural seasonal conditions. There are no passive or active fishing or tracking data to conclude that river and Inner Harbor estuary pike populations concentrate in the Outer Harbor during summer warm water periods.

Table 12. Northern pike relative abundance (pike/km and pike/hr) by station, reach and among all stations versus relative abundance along the lower Milwaukee River and Milwaukee Estuary Baseline Monitoring sites.

Reach/Station		**Number**	**Kilometers**	**Pike/km**	**Hours**	**Pike/hr**
U1		6	3.15	1.9	2.8	2.1
U2		0	3.2	0	3.1	0
Reach U		6	6.35	0.9	5.9	1
D1		10	3.2	3.1	3.1	3.2
D2		7	3.2	2.2	3.1	2.3
Reach D		17	6.4	2.7	6.1	2.8
All Stations		23	12.75	1.8	12	1.9
Baseline Sites		**Number**	**Kilometers**	**Pike/km**	**Hours**	**Pike/hr**
Milwaukee Estuary Non-Wadable Baseline Monitoring 2001-2010 N=21	Totals	3	35.9	0.1	19.05	0.2
	Mean	0	1.71	1.3	0.91	1.4
	Min	0	1.55	0	0.63	0
	Max	2	3.22	3.7	1.93	4.4
Milwaukee R Wadable & Non-Wadable Baseline Monitoring 2003-2010 N=13		**Number**	**Kilometers**	**Pike/km**	**Hours**	**Pike/hr**
	Totals	16	17.32	0.9	17.27	0.9
	Mean	1	1.33	1	1.33	1
	Min	0	0.8	0	0.57	0
	Max	2	1.79	2.5	2.68	2.1

Compared to statewide measures, northern pike populations in the lower Milwaukee River are well below expectations (WDNR, 2010) (Table 13). Statewide average for pike densities is 18 fish/ha and range between 1.7-121 fish/ha. Pike density estimates for the Milwaukee River study area are 0.1 fish/ha and 0.7 fish/ha upstream and downstream of the T-M Dam, respectively, or 26 to 180 times lower than the average pike densities from statewide waters. Similarly, the statewide average pike biomass is 10.3 kg/ha and range between <1.1-66.1 kg/ha. Pike biomass estimates for the lower Milwaukee River upstream and downstream of the T-M Dam were 0.004 and 1.2 kg/ha, respectively. The highest biomass of pike from our study area is 9 times lower than the average pike biomass from state-wide waters. Pike density and biomass differences between river and estuary baseline surveys versus statewide levels are even more extreme.

Table 13. Northern pike density and biomass estimates for Wisconsin waters (n=2,874) compared to the lower Milwaukee River.

Wisconsin Statewide Waters (WDNR, 2010)	Density (fish/ha)	Biomass (kg/ha)	Density (fish/ac)	Biomass (lb/ac)
Average	18.0	10.3	7.3	9.2
Minimum	1.7	<1.1	0.7	<1
Maximum	121.1	66.1	49	59
Lower Milwaukee River				
Reach U Upstream of T-M Dam (N=8)	0.1	0.004	0.004	0.004
Reach D Downstream of T-M Dam (N=29)	0.7	1.2	0.30	1.1

Sex ratios for sexed pike were approximately 11 male to 8 female and 4 unknown. Sexing of pike was not certain as reproductive fluids were not always present from samples obtained in early May upstream of the T-M Dam. Inspection of the urogenital area for purposes of determining pike sex absent reproductive fluids was not always obvious for males but was more certain for females. Station U1 was sampled 14 and 30 days after stations located downstream of the T-M Dam. All pike collected downstream of the T-M Dam during April were spent. Assuming male reach sexual maturity at year 2 and females at year 3 and the mean of the average length at age of northern pike in Wisconsin is age 2 at age 360 mm and age 3 at 442 mm then 19 of the 23 pike captured were sexually mature.

Unique marks provided all captured northern pike at each station, their release and subsequent recapture did not show any movement of pike between stations. However, drawing conclusions about the lack of pike movement may be premature since the recapture survey was completed just 24 hours later at each station.

All northern pike, regardless of age and maturity, were used in population estimates for each river reach (Table 14). The pike population estimate for the Milwaukee River upstream of the T-M Dam was 8 for $R=1$, 95% lower (LCI) and upper confidence (UCI) interval for the estimate $N=8$ is $3 \leq N \leq 17$. The northern pike population estimate for the Milwaukee River upstream of the T-M Dam was 29 for $R=3$, 95% LCI and UCI for the estimate $N=29$ is $15 \leq N \leq 71$. Not unexpectedly, population estimates assuming a common population of northern pike was 41 for $R=4$, 95% LCI and UCI for the estimate $22 \leq N \leq 96$.

Table 14. Petersen (Chapman modification) single capture event method to estimate northern pike populations along the lower Milwaukee River for stations upstream and downstream of the T-M Dam.

Reach (Stations)	Initial No. Marked M	Final No. Examined for Marks C	No. of Recaptures R	R/C	Population Estimate N	Lower CI (LCI)	Upper CI (UCI)
U (U1+U2)	2	5	1	0.20	8	3	17
D (D1+D2)	11	9	3	0.33	29	15	71
Combined	13	14	4	0.29	41	22	96

The mean length of northern was 559mm (s = 141mm) (Figure 11 and Table 15). Mean length for female pike was only slightly greater than male by 54mm. Mean length of northern pike at station U1 was 160-196mm less than those observed for stations D1 and D2, respectively (Table 15 and 16).

Figure 11. Length frequency (mm) for northern pike for all stations independent of sex.

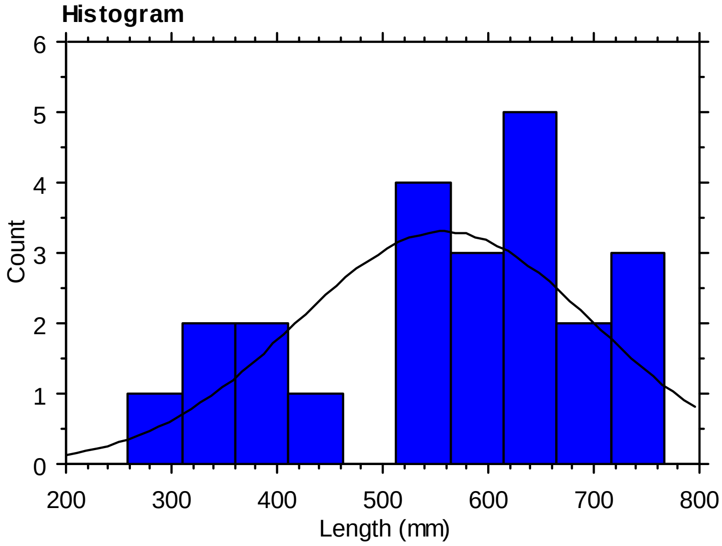


Table 15. Descriptive statistics for northern pike lengths (mm) by sex and for all stations.

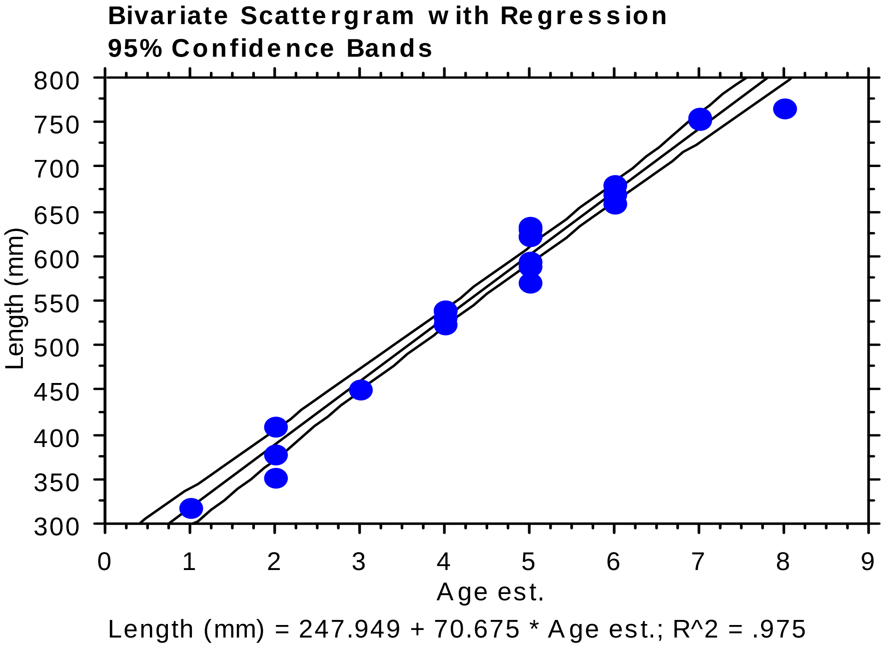
	All Sex (mm)	Female (mm)	Male (mm)
Mean	559	639	585
Std. Dev.	141	87	102
Count	23	8	11
Minimum	259	539	410
Maximum	767	757	767
Coef. Var.	0.253	0.136	0.174

Table 16. Descriptive statistics for northern pike lengths (mm) by station.

	Length (mm)	Station U1 Length (mm)	Station U2 Length (mm)	Station D1 Length (mm)	Station D2 Length (mm)
Mean	559	430		590	625
Std. Dev.	141	127		131	103
Std. Error	29	52		41	39
Count	23	6	0	10	7
Minimum	259	318		259	524
Maximum	767	671		767	757
Coef. Var.	0.253	0.295		0.222	0.165

Northern pike within the sampled population is estimated to range from 1-8-years of age (Figure 12).

Figure 12. Length at age and growth estimates for northern pike independent of sex.



Fish Assemblage

We collected a total of 22 native species and two non-native species the rainbow trout and common carp; 507 individuals totaling 398.9 kg of biomass, including common carp and rainbow trout. Five species comprised 65% of the total number of individuals and included golden redhorse (28%), smallmouth bass (11%) and white sucker (9%), common carp (9%) and greater redhorse (8%). Three species comprised 67% of the total biomass included golden redhorse (29%), common carp (24%) and greater redhorse (15%). Five top predator species comprised 17% of the total biomass including northern pike (7%), smallmouth bass (6%), channel catfish (2%), walleye (2%) and largemouth bass (<1%) (Table 17).

Table 17. Summary statistics for species, number of individual species and biomass (kg) of individual species for all stations.

Native Count	Species	Count	Count (%)	Weight (kg)	Weight (%)
1	Black bullhead	1	0.2	0.3	0.1
1	Black crappie	4	0.8	0.5	0.1
1	Bluegill	13	2.6	1.5	0.4
1	Bluntnose minnow	4	0.8	0.0	0.0
1	Channel catfish (TP)	6	1.2	7.4	1.9
	Common carp	46	9.1	97.0	24.3
1	Common shiner	28	5.5	0.2	0.1
1	Golden redhorse	143	28.2	116.5	29.2
1	Greater redhorse	41	8.1	57.4	14.4
1	Green sunfish	12	2.4	1.2	0.3
1	Horneyhead chub	6	1.2	0.1	0.0
1	Largemouth bass (TP)	4	0.8	1.2	0.3
1	Logperch	2	0.4	0.0	0.0
1	Northern pike (TP)	23	4.5	29.5	7.4
1	Pumpkinseed	2	0.4	0.1	0.0
	Rainbow trout	4	0.8	10.6	2.7
1	Rock bass	38	7.5	4.7	1.2
1	Shorthead redhorse	24	4.7	11.7	2.9
1	Smallmouth bass (TP)	51	10.1	22.4	5.6
1	Spotfin shiner	6	1.2	0.0	0.0
1	Walleye (TP)	3	0.6	6.7	1.7
1	White sucker	46	9.1	29.9	7.5
20	**Totals**	**507**	**100.00**	**398.9**	**100.0**
	(TP) = Top Predator			67.2	16.8

Stations D1 and D2 downstream of the T-M Dam included 17 native species and Stations U1 and U2 upstream of the dam included 13 native species. Stations D1 and D2 downstream of the dam included seven species that were absent from Stations U1 and U2 located upstream of the T-M Dam. They included black bullhead, bluegill, common shiner, horneyhead chub, logperch, spotfin shiner and white sucker. Stations U1 and U2 included three species that were absent from Stations D1 and D2 including channel catfish, largemouth bass and pumpkinseed. Channel catfish were unique to Station U1. A single walleye each was captured at Stations D1, U2, and U1. The walleye at Station D1 weighed 4.7 kg and was unmarked. Similarly, the walleye captured at Station U1 was also unmarked whereas the walleye collected from impounded Station U2 included a left pectoral fin clip that was unique to it being stocked in the Milwaukee Estuary. The fish may have passed beyond the dam when it was submerged during a high flow period, but may have been relocated by fishers after it was caught below the dam. This is a popular practice, especially by younger fishers.

Four species of sucker were captured including the state listed Threatened greater redhorse (WDNR 2006 and 2007), golden and Shorthead redhorse, and white sucker. Silver redhorse are present in the lower Milwaukee River watershed but were not captured from any of the station samples.

We collected a total of three intolerant species among all stations. They included rock bass, smallmouth bass and greater redhorse. All three species were present at Stations D1 and D2 downstream of the T-M Dam. Upstream of the T-M Dam, intolerant rock bass and smallmouth bass were present at Station U1 while intolerant greater redhorse and smallmouth bass were present at impounded Station U2. It is noteworthy that only one of the 36 smallmouth bass collected between Stations U1 and U2 was collected from impounded Station U2.

We collected only three riverine species among all four stations. They included the horneyhead chub, spotfin shiner and golden redhorse. All stations were well below the optimum number of riverine species (>6), with all stations including 1-2 riverine species each. Based on a review of current and historical fish distribution records, the Milwaukee River Basin contains approximately 12 riverine species, including recently stocked lake sturgeon, but excluding flathead catfish and freshwater drum captured in the Milwaukee Estuary. Riverine species known to be present in our studied reaches based on collections since 1999 include gizzard shad, largescale stoneroller, rosyface shiner, sand shiner, emerald shiner, blacknose dace, creek chub, silver redhorse, stonecat, fantail darter, and blacksided darter. Higher sample flow and water depth conditions, and sampling outside the June 15-September 15 window for non-wadable streams may partly account for the absence of more of these species from our samples. While sample stations were low in the number of riverine species, specialized riverine species comprised 22% to 49% of the number of fish captured at stations U2, D1 and D2, with golden redhorse being the dominant riverine species in terms of numbers and biomass.

IBI results for Station U1 indicated “poor” (15 points) environmental quality. We felt that the “poor” results for Station U1 did not accurately represent the observed environmental quality of the station but were instead more reflective of the equipment malfunction and resulting poor fishing effectiveness. The rivers current and drag on the dippers net made it especially difficult to capture the large bodied suckers (Catostomidae) that dominated the station. The presence or absence of suckers reflect on a number of key metrics and scores, specifically the weight per unit effort (WPUE), number of species, and the proportion by weight of sucker, riverine, simple lithophilous spawners, insectivores and round suckers. Therefore, we limit the discussion about the fish assemblage results for Station U1.

IBI values and ratings for the remaining stations ranged from “good” (65 points) at Station U2 located in the T-M impoundment and Station D2 located at the lower limits of the free-flowing study area; to “excellent” (85 points) at Station D1 located downstream of the T-M Dam (Table 18) (Appendix 6).

According to Lyons (2001) variations in IBI values of 5-15 points are considered normal and not statistically different, and variations of 20 points are marginally significant. Temporal and spatial variations of 25 points or more represent a significant change in the fish assemblage. Between station differences were marginally significant at 20 points difference between Stations U2 (65 pts.) and D2 (65 pts.) versus Station U1 (85 pts.). The marginal differences in IBI may suggest that environmental factors impacting the fish assemblage may be influenced more by local sources/features than watershed-wide conditions. Environmental quality along the T-M impoundment Station U2 is typical of many impounded rivers in developed watersheds. Water quality is limited by turbidity and algae blooms and there are extensive and deep deposits of fine textured sediments. Cover is limited to woody debris and lesser amounts of submerged rip rap. Macrophytes are scarce and may be limited by turbidity and the benthic feeding behavior of an abundant common carp population. Approximately 50% of the shoreline is developed with minimal or no vegetative buffer. Station D2 is located in the lowest reach of our study area. It is a low gradient reach of river consisting exclusively as deep run, and there are long stretches with accumulated fine sediment. Woody debris provides most of the cover for fish. Of all the stations sampled, it is most impacted by urban non-point sources of pollution. Sewers discharge storm water from the high density commercial development along SH 100 and the direct discharge from the fully developed Beaver Creek subwatershed. Station U1 has the most diverse stream features compared to Stations U2 and D2. The stream channel has a steeper slope and greater shear forces promote scouring of fine textured sediment. Substrates are coarse cobble and gravel and features include pool/riffle and run.

The value of the IBI for evaluating river ecosystem conditions and trends is made possible by the inclusion of individual fish species richness, abundance, composition, indicator species, reproductive function, and relative health. Individual IBI metrics, and not just the "final" IBI score and rating, should be used to interpret environmental problems and differences between sites. Stations D2, D1 and U2 scored optimum or "good" metrics for weight per unit effort (WPUE), % fish captured as riverine taxa, % fish captured as simple lithophilic spawners, % of total biomass catch as insectivores, and % of total biomass catch as round suckers. Station D1 also scored "good" for the number of intolerant taxa and % of fish captured with DELTs (deformities, eroded fins, lesions and tumors), while Station D2 and U1 scored "fair" or "poor" for the same metrics. Among the stations that scored optimum for individual metrics, Station D2 and D1 had more than twice the WPUE than Station U2. Differences in WPUE were a result of the greater biomass (and numbers) of golden redhorse, greater redhorse and northern pike captured at Station D2 and D1. Station D1 scored "fair" for the number of native species with 14, while Stations D2 and U2 scored "poor" with nine native species.

Although non-native and tolerant species are not included in the IBI, the non-native and tolerant common carp were very abundant in the T-M impoundment Station U2. The shear numbers and size prevented the dipper from obtaining even larger and more representative biomass sample of the carp. Even after excluding anymore carp from capture, common carp from Station U2 sample comprised 56% of the biomass compared to 22% at Station D2 and 11% at Stations D1. The large number and biomass of carp in the T-M impoundment relative to the free-flowing stations is not unexpected. Carp prefer warm, eutrophic and sluggish waters such as the T-M impoundment. They are suited for feeding in fine substrate, and can tolerate high levels of turbidity and depressed oxygen concentrations for all life stage, including eggs, and prefer low gradient and velocity (Edwards and Twomey, 1982).

Golden redhorse were the dominant fish biomass at Stations D2 and D1 comprising 39% and 26%, respectively. Golden redhorse comprised 30% of the fish biomass at impounded Station U2 and were second to common carp at 56% of the total biomass. Golden redhorse were relatively rare throughout impounded Station U2 with exception of a small area located in the "narrows", a short, deep and narrower, and moderately scoured area with coarse sand and gravel substrate.

The fish assemblage results suggest that the number and biomass of forage for top predator fish is not limiting to the maintenance of a self sustaining population of northern pike and other top predator (i.e., walleye and smallmouth bass) recreational fishery.

Table 18. Index of Biotic Integrity (IBI) metrics, scores and ratings by station.

Station	Caught (n)	Weight (g)	IBI Score	IBI Rating	WPUE excluding tolerant sp. & salmonids	No. Native Species (n)	Sucker Species (n)	Intolerant Species (n)	Riverine Species (n)	% DELT (n)	% Riverine (n)	% Lithophils (n)	% Insectivore (wt)	% Round suckers (wt)
U1	73	24.68			22.28	10	2	2	1	1.37	1.40	4.17	2.19	1.34
U1			15		5	0	0	5	0	5	0	0	0	0
U1				V. POOR	fair	poor	poor	fair	poor	fair	poor	poor	poor	poor
U2	96	92.88			41.08	9	3	2	1	2.08	48.96	62.39	41.63	41.55
U2			65		10	0	5	5	0	5	10	10	10	10
U2				GOOD	good	poor	fair	fair	poor	fair	good	good	good	good
D1	206	153.75			104.11	14	4	3	2	0.00	22.33	66.00	46.72	58.72
D1			85		10	5	10	10	0	10	10	10	10	10
D1			EXCELLENT		good	fair	fair	good	poor	good	good	good	good	good
D2	132	127.57			92.63	12	4	3	2	3.8	46.20	65.90	60.94	60.74
D2			65		10	5	5	5	0	0	10	10	10	10
D2				GOOD	good	fair	fair	fair	poor	poor	good	good	good	good
			0	Poor	0-9.9	0-11	0-2	0-1	0-4	>3	0-10	0-25	0-20	0-10
			5	Fair	10-25	12-15	3-4	2	5-6	3-0.5	11-20	26-40	21-39	11-25
			10	Good	>25	>15	>4	>2	>6	<0.5	>20	>40	>39	>25

Score	**Ratings**
80 -100	**Excellent**
60 - 75	**Good**
40 - 55	**Fair**
20 - 35	**Poor**
0 - 15	**Very poor**

Milwaukee R. Station I.D. and Description

U1	T-M Impoundment Headwater (Transition between impoundment and free-flowing river)
U2	T-M Impoundment
D1	T-M Dam Tailwater (Mequon Rd. to Dam)
D2	Range Line Rd to Schroeder Dr. extended

Recommendations

Unless otherwise stated, the following recommendations are not proposed to be undertaken by any particular management group or individuals.

Fish Passage Barriers

Selective barrier removal or modifications to enable fish to reach historical spawning habitats is a viable management practice for restoring or otherwise enhancing Great Lakes fish populations on a regional and local scale (Francis et al., 1979; Kelso and Minns, 1995). Bouvier (et al., 2009) studied the influences that wetland connectivity have on local and regional fish assemblage in the lower Great Lakes and concluded that increases in the rate of connectivity had a positive affect on fish assemblage species richness and piscivore richness. A watershed approach to reconnecting northern pike wetland spawning habitat beyond the fully developed Milwaukee Estuary AOC may provide the only viable means for creating a more sustainable and abundant population of northern pike. The watershed approach is a viable model for restoring or enhancing other phytophilic and lithophilic spawning fishes in the Milwaukee Estuary AOC including walleye and lake sturgeon, two species currently being managed with active restoration plans. Despite removal of major impediments to fish passage in the Milwaukee AOC since 1997, hundreds of potential complete or partial barriers to fish passage remain, especially along major tributaries of the Milwaukee River, and the Menomonee River and its major tributaries (SEWRPC, 2009).

1. Complete a screening level inventory of potential for the Menomonee River and its major tributaries in Milwaukee, Waukesha, Washington and Ozaukee Counties (SEWRPC, 2009), and the major tributaries of the Milwaukee River in Milwaukee County using standardized protocols (Great Lakes Connectivity Workgroup. 2011).
2. Complete a hydrologic and hydraulic assessment of the Estabrook Park and Kletzsch Park Dams as partial barriers. Specifically, determine the tailwater versus surface water elevation differences between the fixed crest and control spillway for a full range of flood events including the annual and 2-year recurrence interval to ascertain these structures impacts on fish passage.
3. Identify a full array of structural management alternatives for the Milwaukee County owned Estabrook and Kletzsch Dams that will enable year-around and unrestricted fish passage.

Wetlands

Prior to European settlement, the Milwaukee Estuary AOC once contained a diverse and abundant fish assemblage complimented by the complex and diverse habitats formed at the confluence with Lake Michigan, over 2500 ha of estuary wetlands, and unimpeded access to watershed-wide riverine and wetland habitats. Wetlands are no longer present in the Milwaukee Estuary, and absent access to suitable wetland spawning habitat, northern pike abundance would remain below expectations. Our landscape-scale inventory for the AOC revealed over 1,800 ha of riparian wetlands along the Milwaukee and Menomonee Rivers and their major tributaries. However, while the quantity of remaining wetlands appears adequate for pike spawning habitat, the quality of wetlands can not be determined at this scale. Similarly, there is little quantifiable information regarding the hydrologic connectivity, depth and duration (hydroperiod) between the subject streams and wetlands necessary for adult and juvenile access, spawning and development. Traditional hydrologic analyses have emphasized estimating extreme conditions such as low-flow and flood frequencies. Restoring the biological function of streams and their floodplains requires extending these analyses to recurring seasons, duration and timing (Fischenich and McKay, 2011).

1. Using existing landscape-scale inventory of wetlands in this study and those recently completed by Kline (et al., 2006), classify wetlands according to the proposed wetland classification system for northern pike spawning.
2. Complete detailed reach-scale topographic surveys, and subwatershed-scale hydraulic and hydrologic (H&H) analyses for major tributary stream channels and their active floodplains. To the greatest extent possible, the H&H analyses should include daily and monthly (March through May) mean flows and surface water elevations for the 90 percent annual probability of occurrence (approximately the annual or 1-yr recurrence interval).
3. Following 1 and 2 above develop a tiered approach for completing the next level of inventory that can be used for prioritizing stream reaches and wetland parcels for restoration or enhancements, stocking efforts for northern pike, and monitoring.
4. Identify potential water-based parcels and explore the feasibility of re-creating coastal wetlands in the Outer and Inner Harbor of the Milwaukee Estuary including but not limited to the upper-most reaches of the Burnham and Menomonee Canals (Menomonee River); Menomonee River immediately upstream of the 6th St. Bridge; Grand Trunk Yards (Kinnickinnic River); and upstream-most reaches of the Milwaukee River estuary and between the former North Avenue Dam (RM 3.2) and Pleasant St. (RM 2.3).
5. Efforts and priorities to restore or enhance wetlands for northern pike spawning and nursery habitat should not be made independent of potential benefit and impacts to multiple wetland uses and values.

Northern Pike Management

Once considered abundant, northern pike populations in the Milwaukee Estuary and connecting rivers are well below expectations compared to state-wide waters. A strategy to rehabilitate a spawning and ultimately a self-sustaining population of northern pike in the Milwaukee Estuary AOC should only use Lake Michigan genetic populations. Northern pike should be stocked at various early life stages (embryo, larvae and juvenile) with the goal of establishing local stocks that exhibit spawning- and natal-site fidelity. At a minimum, stocking sites should be located at a subwatershed (i.e., tributary) scale. Based on our landscape-scale inventory of spawning habitat, fish accessibility, and subwatersheds with prior documented northern pike production, we propose stocking of pike larvae in the following subwatersheds:

1. Menomonee River Watershed, Little Menomonee River Subwatershed – Located in the Menomonee River watershed, it includes the largest contiguous tract of emergent wet meadow or mixed emergent wet meadow cover type in the study area. Monitoring their subsequent survivability, return migrations and potential spawning success may provide transfer information for other urban streams in the Great Lakes Basin.
2. Milwaukee River Watershed, Pigeon Creek Subwatershed – Has the largest concentration of riparian wetlands among all tributaries in the study area. Removal of two partial barriers has enabled access to the majority of these riparian wetlands.
3. Milwaukee River Watershed, Ulao Creek Subwatershed – Located upstream of the T-M Dam fishway, pike returning to this “imprinted” watershed would provide additional evidence regarding the effectiveness of the fishway. In addition, the T-M impoundment has few top predators. Northern pike recruitment to the T-M impoundment would provide a top-predator to partially control the abundant common carp population.
4. Milwaukee River Watershed, Trinity Creek (spawning ponds) Subwatershed – Three options:
    - Field transfer of “green” adults from the Milwaukee River and Milwaukee Estuary to spawn on Trinity ponds spawning shelves,
    - Gametes obtained from Milwaukee Estuary pike stock fertilized and placed onto spawning shelves, or

    - Stocking with pike larvae. Use of this facility for pike production would be dependent on planned alterations to the pond inlet/outlets and changes to pond management described earlier in the report.
5. These populations should be marked to enable biologists to track their movements beginning with their emigration from their natal (stocked) sites; their juvenile and adult habitat through return spawning migrations.

Ultimately, selection of smaller-scale site-specific larvae stocking locations in these subwatersheds should account for the sites quality and quantity of spawning and nursery habitat; the extent of barrier-free access for adults and juveniles; the sites hydroperiod; and the quality, extent and proximity to juvenile-adult habitat.

Casselman and Lewis (1996) and Minns (et al., 1995) concluded that pike survival to juvenile stage was highly dependent on the proximity between spawning and vegetated deep water habitat. The tributary stocking sites recommended above are located a minimum of 32 km upstream of the Milwaukee Estuary and more optimum juvenile and adult habitat. In order to increase the survivability and recruitment of northern pike, stocking should also include sites in the Milwaukee Estuary. We conservatively estimated 200 ha of suitable juvenile-adult habitat (based on optimum depth and macrophyte coverage) present in the Milwaukee Estuary's 624 ha Outer Harbor, including the South Shore harbor to the south.

WDNR guidelines for northern pike "rehabilitation" projects recommend stocking larvae at a rate of 1,000/acre (405/ha) of available habitat and a maximum of 200,000 per water; followed by fingerling in the fall if assessments show poor larvae survival. Fingerling may be stocked again the following year, if desired. Small fingerlings 3.5-5.5 inches long (89-140 mm) may be stocked at a rate of no more than 5/acre (2/ha) and a maximum of 5,000 per water; and large fingerlings >7 inches long (>178 mm) at a rate of no more than 2/acre (1/ha) and a maximum of 5,000 per water. Stocking adults (field transfer) to reproduce is also acceptable.

In addition, several other projects would enhance the chances for successful northern pike rehabilitation in the Milwaukee Estaury AOC:

1. Provide technical assistance to the City of Mequon and Ozaukee County Fish Passage Program in modifying the inlet/outlet to the Trinity Creek wetland area; developing a comprehensive management plan for the facility that enhances northern pike spawning habitat and pike production; reduces or eliminates common carp and other undesirable fishes through managed winter-kill; reduces turbidity and phosphorus loadings from bioturbation, increases light penetration and aquatic plant diversity and abundance, and overall water quality.
2. Work with the MMSD to determine if the 12 ha flood control detention pond and wetland along the upper reaches of Lincoln Creeks could provide suitable northern pike spawning and nursery habitat. If feasible, include this waterbody in the northern pike rehabilitation plan above.
3. Complete a comprehensive assessment of adult northern pike spawning populations in the Milwaukee Estuary to include mark/recapture and tracking surveys to assess their seasonal movements within the estuary and along connecting rivers and their major tributaries.

Milwaukee Estuary AOC Habitat Assessment

In the absence of access to suitable spawning habitat, protecting and restoring juvenile and adult habitat is critical to the creation of sustainable northern pike populations in the Great Lakes ecosystem. Casselman and Lewis, 1996, and Minns (et al., 1996) concluded that spawning habitat was less critical but more easily manipulated for optimizing pike recruitment than juvenile and adult habitat, especially in environments with low anthropogenic impacts. Juvenile and adult pike need unrestricted and contiguous access to preferred juvenile and adult habitat, most importantly moderately dense (40%-90%) submergent and emergent native aquatic plant beds and suitable water depths (Casselman and Lewis, 1996).

Although shallow and deep water habitat in the Milwaukee Estuary has been highly modified, portions of the Milwaukee Estuary, in particular the Outer Harbor possess more complex habitat than the Inner Harbor. The Outer Harbor's northern-half and extreme-southern end have more variable depths and submerged macrophyte beds. Local units of government and private entities are managing rooted aquatic plants through cutting/harvesting and chemical treatments, in order to operate and maintain marinas and connecting channels for recreational navigation without an appreciation of the impacts on pike and other fish populations.

The Milwaukee Estuary Inner Harbor is fully developed with steel and wooden bulkheads at various stages of structural integrity. Most of the river channel and connecting canals were dredged for commercial navigation. Approximately 3.3 km of the 5 km of the upper Milwaukee River portion of the estuary has been "de-certified" for commercial navigation and maintenance dredging and shoaling rates are increasing. These changes in river use may provide opportunities for small-scale habitat restoration projects that benefit fish, other aquatic life and wildlife, and enhanced water and land-based recreational uses.

There has never been a comprehensive inventory of the physical, chemical and biological habitat attributes in the Milwaukee Estuary AOC, and connecting waterways. Completing such an inventory would provide the basis for identifying realistic goals and plans for restoration or enhancement of fish, aquatic life and wildlife populations in the AOC.

Complete a detailed GIS based inventory of the physical, chemical and biological features of the Milwaukee Estuary Inner and Outer Harbor areas. Multiple state and federal agencies, academic institutions and utilities currently monitor various media in the Milwaukee Estuary. The results should be used to develop a comprehensive plan, developed by stakeholders, to prioritize protection of existing critical habitats, and potential habitat restoration projects.

Non-Wadable Baseline Monitoring

There are long reaches of the lower Milwaukee River whose fish assemblages can not be adequately assessed using wadable electrofishing methods because of excessive water depths. By conservative estimates, approximately 29 km of the 52 km, or 55% of the lower Milwaukee between its confluence with Lake Michigan and the Bridge St. Dam in Grafton can not be effectively sampled using wadable electrofishing gear. Approximately 17 km or 33% of this reach is impounded.

The results of this study suggest that Non-Wadable Baseline Monitoring protocol can be effective for assessing the environmental quality and fish assemblages in medium-sized rivers that include similar lengths of wadable and non-wadable reaches. The use of Non-Wadable protocol to estimate river IBI and resulting environmental quality outside the summer base-flow sample period used to calibrate and verify the IBI model does require a footnote when reporting the results. When our results are compared to fish sample results obtained from nearby and comparable river reaches following summer base-flow Wadable Baseline protocol and towed electrofishing gear, Wadable Baseline sample results included a greater diversity of fish species, most notably among small-bodied and benthic species (i.e., cyprinids and percids). On the upside, sampling fish populations under spring high-flow conditions using mini-boom electrofishing gear and Non-Wadable protocol is an effective means of fishing for large-bodied potamodromous species that exhibit spawning migrations and concentrations, and the ability to examine fish populations too deep and inaccessible using towed electrofishing gear.

Water-based resource managers recognize that the value and accuracy of reporting IBI results and trends can be compromised when following a less than an adequate sample frequency. As with many biological-based environmental indices, metrics, final scores and ratings, and temporal trends can be masked by natural and anthropogenic variations. Lyons (et al, 2001) noted that IBI temporal variations in high-quality reaches were relatively low at 5-9 points or 5-10% of actual IBI scores; however, temporal variations were significantly higher in degraded reaches at 28-30 points or 70-110% of actual scores. To account for these variations, Lyons recommends multiple samples over several years in order to detect significant spatial and temporal differences in river ecosystem condition, especially from more degraded river reaches.

Given the limited fishery information for the lower Milwaukee Estuary AOC due to wadable sample constraints; the demonstrated effectiveness of this studies use of Non-Wadable Baseline Monitoring protocol in sampling and assessing fish assemblages, including game and non-game species; and assessing environmental quality in the Milwaukee Estuary AOC, the following recommendations are made for future monitoring fish assemblages in the Milwaukee Estuary AOC:

1. Continue to monitor the four Non-Wadable Baseline sites in the Milwaukee Estuary AOC on an annual basis.
2. Repeat the spring mini-boom electrofishing survey for the Milwaukee River and T-M Impoundment from this assessment on a bi-annual basis, for a total of four survey sites to gage the pre- and post-effectiveness of the above management recommendations, as appropriate.
3. Expand the number of bi-annual spring mini-boom surveys for the Milwaukee Estuary AOC to include free-flowing reaches upstream and downstream of the Estabrook Park and Kletzsch Park impoundments, and the impoundments for a total of six survey sites.

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Appendix 1. Northern pike spawning and nursery habitat variables included by Inskip (1982), Casselman and Lewis (1996), and Roth and Schuette (1998) rating systems.

Inskip (1982) (Riverine Model)	Casselman and Lewis (1996) (**RW** = Relative Weight)	Rost and Schuette (1998)
SPAWNING HABITAT	***SPAWNING HABITAT***	***SPAWNING HABITAT***
Vegetation – Type & Density (V_1) **Class A** Vegetation obscures >80% of substrate; dense plant material throughout 15 cm of water column; vegetation not tightly compacted allowing for water circulation; abundant cover for egg and fry (i.e., flooded grass and sedges). **Class B** Same as A above and 60-80% of substrate obscured by vegetation. **Class C** Vegetation obscures most of substrate but plant material does not occupy most of water column; may include compacted vegetation, branches, woody plants and leave from deciduous trees. **Class D** Thinly scattered vegetation or debris only; little or no cover for eggs and fry.	**Vegetation - Type & Density** **Type RW 9** **Best 9** – Hummocks of grasses and sedges **Poorest 1** – Cattails, bog laurel, Potamogeton spp., floating aquatic plants **Density RW 8** **Best 9** – Moderately dense, 2-4 hummocks per m^2 **Poorest 1** – Sparser or denser	**Vegetation - Type & Density** **<u>Stream Channel</u>** **Class I** >80% of substrate obscured by grass/ sedge. **Class II** 50-80% of substrate obscured by grass/ sedge. **Class III** 25-50% of substrate obscured by grass/ sedge. **Class IV** 0-25% of substrate obscured by grass/ sedge. **Class IV-T** 0-5% of substrate obscured by grass/ sedge. **Class V-T** 0-25% of substrate obscured by grass/ sedge. **<u>Riparian</u>** **Class VI** Other wetlands contiguous with tributary stream with appropriate water levels. **Class VII** Flooded uplands including mowed or un-mowed hay fields and flooded woodlands.
Water level – Drop in water level during embryo - fry stages (V_2) Embryo and early fry stage Non-linear curve: Suitability 1.0 @ 0 m drop in water level Suitability 0.2 @ 0.5 m drop in water level Suitability 0 @ ≥1 m drop in water level Fry stage (after yolk sac absorbed) Non-linear curve: Suitability 1.0 @ 0 m drop in water level Suitability 0.7 @ 0.5 m drop in water level Suitability 0 @ ≥1 m drop in water level	**Water level - Depth & fluctuation** **Depth RW 9** **Best 9** – 0.1-0.7 m, avg. 0.2-0.4 m (high water associated with strong year classes) **Poorest 1** – Deeper or shallower **Fluctuation RW 7** **Best 9** – Gradually increasing prior to spawning; stable until fry start to move from spawning grounds, ~6-8 weeks, then gradually decreasing **Poorest 1** – Fluctuating or not increasing prior to spawning; decreasing abruptly immediately after spawning.	**Water level – Depth** **<u>Stream Channel</u>** **Classes I, II, III** Mean water depth <0.3 m (n=5) **Classes IV, IV-T** Water depth <1.5 m (n=5) **ClassV-T** Water depth sometimes ≥1.5 m (n=5) Perennial stream with discharge >0.3 m^3/s used primarily for fish migration and emigration. **<u>Riparian</u>** **Class VI** Perennial or long-term standing water ("pooled"). **Class VII** Ephemeral flooded upland areas in agricultural or natural land uses.
Average length of frost-free season (V_6) (surrogate measure for air temperature) Gaussian function or bell curve: Suitability 0.0 @ 0-20 days Suitability 1.0 @ 120-170 days Suitability 0.0 @ > 220 days	**Exposure of the site** (surrogate measure for air temperature) **RW 6** **Best 9** – Sheltered, warming rapidly in early	

	spring; receiving direct sunlight from south or west **Poorest 1 –** Warming very slowly in early spring; exposed to north or east	
	Connecting waterway **RW 4** **Best 9** - Rivulets that permit easy movement of spawners into sheltered spawning areas of marsh and allow fry to move out with receding water **Poorest 1 –** Few or no deeper connecting channels for drainage access, or very deep channels congregating predators	**Connecting waterway** **Stream Channel** **Classes I, II, III** Wetted area within stream banks gently sloping. **Class IV-T** Banks steep and stream substrate flat. **Class V-T** Banks steep.
	Substrate type **RW 3** **Best 9** - Well-oxygenated vegetative detritus; good rooting medium for inundated grasses and sedges **Poorest 1 –** Decomposing organic debris or any type of relatively infertile organic or inorganic substrate	**Substrate type** **Stream Channel** **Classes I, II** Very coarse detritus suitable of holding eggs and/or off the substrate in oxygenated water. **Class III** Fine inorganic or fine particulate detritus not suitable of holding eggs and/or alevin off the substrate in oxygenated water. **Class IV** Rubble, gravel or sand, or fine particulate organic matter not suitable of holding eggs and/or alevin off the substrate in oxygenated water. **Class IV-T** Rubble, gravel or sand or fine particulate detritus not suitable of holding eggs and/or alevin off the substrate in oxygenated water. **Class V-T** Rubble, gravel or sand or fine particulate organic matter not suitable of holding eggs and/or alevin off the substrate in oxygenated water. **Riparian** **Class VI** n.a. **Class VII** n.a.
	Water exchange **RW 2** **Best 9 –** Moderate; during high water some exposure to wind and wave action **Poorest 1 –** Little or no wind exposure or water movement, or extreme water movement or wave action	
Least suitable pH in spawning habitat during embryo – fry (V_5) Gaussian function or bell curve: Suitability 0.0 @ 0-4.5 su pH Suitability 1.0 @ 6-9 su pH Suitability 0.0 @ > 10 su pH		

NURSERY, JUVENILE AND ADULT HABITAT	*NURSERY, JUVENILE AND ADULT HABITAT*	*NURSERY, JUVENILE AND ADULT HABITAT*
Percent of midsummer area with aquatic vegetation or remains of terrestrial vegetation (V_3) Max. depth <3 m and ice covered >2 months Gaussian function or bell curve: Suitability 0.1 @ 0 % Suitability 1.0 @ 25% - 75% Suitability 0.5 @ 100% Max. depth >3 m and ice covered $\leq$2 months Gaussian function or bell curve: Suitability 0.1 @ 0 % Suitability 1.0 @ 25% - 75% Suitability 0.2 @ 100%	**Proximity to spawning habitat** **RW 9** **Best 9** – Contiguous **Poorest 1 –** More distant or separated from the spawning ground by various obstructions or restrictions, docks, etc.	
	Vegetation **RW 8** **Best 9** – Dense submergent and emergent aquatic plants (>40-90% coverage) **Poorest 1** – Sparser or denser	
	Extent of habitat **RW 6** **Best 9** – Extensive; >10x size of adjacent spawning habitat. **Poorest 1** – Limited; equal size to adjacent spawning habitat.	
Percent riverine pools and backwaters with sluggish flows (< 5cm/sec) during midsummer (V_8) Linear curve: Suitability 0.0 @ 0% Suitability 1.0 @ 100%		
Stream gradient (V_9) Non-linear curve: Suitability 1.0 @ 0-0.75 m/km Suitability 0.9 @ 1 m/km Suitability 0.5 @ 2 m/km Suitability 0.3 @ 3 m/km Suitability 0.1 @ 5 m/km		
Log (base 10) of total dissolved solids (TDS) concentrations of surface waters 1-2 m deep during midsummer (V_4) (surrogate measure for productivity) Exclude from riverine habitats unless TDS > 800 mg/l Gaussian function or bell curve: Suitability 0.0 @ 0-4 mg/l TDS		

Suitability 1.0 @ 80-800 mg/l TDS Suitability 0.0 @ > 2,800 mg/l TDS **Maximum weekly average summer water temperature of surface water 1-2 m deep** (V_7) Gaussian function or bell curve (riverine): Suitability 0.0 @ 0-6 ^oC Suitability 1.0 @ 20-25 ^oC Suitability 0.0 @ > 32 ^oC		

Appendix 2. Literature Review for the Northern Pike Life History

For purposes of this discussion, we chose to modify Inskip's (1982) description of the four life stages of northern pike to include a fifth life stage as yolk-sac larvae:

1. Spawning - Includes spawning and embryo stages.
2. Yolk-sac larvae - Hatching through absorption of egg sac.
3. Larvae – Free-swimming post-yolk sac larvae to size that assumes adult proportions ~ 60 mm.
4. Juvenile – From ~ 60 mm to onset of gonad development.
5. Adult – From sexual maturity until death.

Following is a brief summary of their reproductive habitat requirements.

Spawning Movement Behavior

Early studies suggested that juvenile through adult northern pike were a relatively sedentary species making limited and short excursions from their natal habitat. Masters et al., (2004) synthesized the results and conclusions of seven early studies of northern pike spatial behavior (published 1977 through 2001) in lake ecosystems. These studies concluded that pike movement behaviors were highly variable within and between populations as some individuals stayed within compact areas while others moved between two and three preferred areas, or move freely throughout the lakes.

Franklin and Smith (1963) reported that northern pike begin to migrate to Minnesota lake spawning sites shortly after ice-out when water temperatures ranged from 1.1-4.4°C, and peaked between 2.2-2.8°C. Initial entry to shallow spawning areas was dependent on their being suitable water clearance between the ice and the bottom. Peak migration times were between 2100and 0400 in 1956, and 2000 and 2100-hrs in 1957.

Carbine (1942) observed northern pike to undergo extensive spawning migrations from a large Michigan lake to spawning habitat in tributary ditches and streams. Spring migrating pike migrated between 2 km and 76 km, with one fish reported to move 16 km in 22 hours. Approximately 95% of the migrants entered spawning ditches from the lake between 2100 and 0300-hours.

Priegel and Krohn (1975) reported the entire spawning immigration period to shallow (mean depth 0.6 m) Gilbert Lake, Washington County, WI between March 21 and March 27 over a surface water temperature range of 0.6-13.9°C, with peak immigration occurring over a water temperatures range of 3.4-10.6°C over a period of 15-days, with the majority of fish moving during a 2-4-day period; that males entered and exited the spawning marsh faster than females; and that the average size of males increased as the spawning migration progressed to peak, and then decreased after the peak. The size of the female northern pike did not show a similar trend relative to the intensity of the spawning migration.

Northern pike recruitment to Green Bay and Lake Michigan is dependent on adult fish being able to migrate unencumbered along rivers and smaller tributaries to suitable wetland spawning habitat, far removed from their adult habitat. Using biotelemetry, Rost and Schuette (1998) observed northern pike migrations from Green Bay, Lake Michigan upstream along the Pensaukee River to be steady with water temperatures holding between 8-10°C; while fluctuating migrations occurred when water temperatures fluctuated between 4-10°C, then to 6°C and back to 10°C. Two of the 21 surviving telemetry implants were tracked 24 km upstream of Green Bay to spawning wetlands. While no implanted fish were tracked beyond 24 km, emigrating young-of-year northern pike were collected from fish larval traps up to 53 km upstream of the bay from small perennial and intermittent streams, roadside ditches and wetland fringes suggesting that northern pike may have migrated well beyond the 24 km limit of tracking fish.

Reproductive Fidelity

More recent studies in riverine or lake-river systems using more sophisticated biotelemetry technology concluded that while adult northern pike may exhibit a sedentary existence during most of the year, they do exhibit extended spawning migrations. Additional studies have concluded that northern pike, like some other iteroparous fish, possess reproductive fidelity.

Reproductive fidelity can lead to isolation between populations and ultimately to genetic differentiation and can occur even among populations that share the same body of water. There are two types of reproductive fidelity: *Spawning-site fidelity* occurs when a large number of individuals in a population return to the same spawning site in subsequent seasons, regardless of where they were born. Spawning-site fidelity is not enough to maintain population differentiation since fish must initially spawn at the site of their birth and ultimately return to the same spawning site to prevent cross-mating and genetic homogenization of populations. *Natal-site fidelity* occurs when a large number of individuals in a population return to spawn very near the same spawning site of their birth. Natal-site fidelity tends to result in reproductive isolation and reduced gene flow between spawning populations. Populations from the same waterbody that exhibit reproductive fidelity may overlap habitats during non-reproductive periods (Miller et al., 2001).

Clark (1990) tagged 2,659 northern pike over an eight year period along the southwestern shoreline of Lake Erie. Of these, 698 were recaptured over a one to seven year period, and 16 were recaptured four to six times. Except for few strays, most of the pike were limited in movement to the area along the shore where they were tagged. The large number of net returns during the month of March but scarce during the remainder of the year on the spawning grounds at East harbor where they were originally captured or recaptured a homing trend and spawning-site fidelity.

Karas and Lehtonen (1993) studied the movement of 23 tagged and relocated northern pike in the Baltic Sea region of Finland and Sweden to assess their homing behavior towards their initial capture and spawning site. As much as 80-95% of the tagged pike relocated within 10 km of their spawning and capture site exhibited strong homing behavior back to their initial spawning sites even if several other potential spawning sites were encountered. Homing behavior did not occur at relocation distances >60 km. Fish recaptured outside the spawning season were dispersed throughout the study area and showed no homing behavior.

Rosell and MacOscar (2002) netted and tagged 508 pike from Lower Lough Erne in Northern Ireland between 1994 and 1997 during the pre-spawn months of March and April. By August 2000, 89 fish were recaptured, and 10 of 27 pike recaptured and released a second time, were then captured a third time. Distances from tagging to recapture sites ranged from 0 to 16 km and averaged 10 km, dispersing widely after spawning and tended to return to the same spawning sites year after year. The lake has a surface area of 109 km^2 with extensive spawning wetlands on each end of the lake. Despite evidence of fish traversing the lake during summer months, all recaptured fish returned to their spawning sites located at the lakes opposite shorelines. Eighteen of the 36 fish recaptured during their spawning period were found within 500 m and 5 fish were recorded at the same site of their previous years spawning site. These results suggest individuals within the same population exhibit spawning-site fidelity.

Masters et al., (2004) studied the movement of nine mature female and six mature male radio-tagged northern pike along the Frome River, a medium sized (mean width 14 m) chalk stream in the UK. They were testing the hypothesis that pike populations included static and mobile individuals. The study described the long-term spatial behavior of a riverine pike population by tracking their seasonally identified “home” range location, and by “interval” tracking the fish throughout the year including the spawning period. The primary study reach was 2,000 m in length and included tributary drainage ditches and an approximate 800 m long millrace. A weir located at the upper limits of the study reach is a barrier to fish movement and no barriers to fish movement exist downstream of the study reach. Fish were captured and tagged along the entire study reach between May 2000 and November 2001, and all tagged fish were released at their capture site. Results showed high variation in spatial behavior between individuals and did not fit the model of static or mobile individuals. Many of the pike displayed a high degree of site fidelity straying a few hundred meters of river throughout their tracked time. The population utilized side channels during high flow periods but avoided the side channel during summer low-flow and high water temperature periods. Females made longer excursions than males and excursions to spawning sites. Maximum excursions were observed by females during spawning periods and between the main and side channels during high flow events.

Ovidio and Philippart (2005) used six radio tagged northern pike to study their annual movement and reproductive migrations along a 30 km reach of the Ourthe River in Belgium. Individual fish were tracked between 145days and 349 days, and a mean of 303 days. Winter pre-spawning movements were restricted and spaced 40 to 500 m and rarely exceeded 300 m. Spawning migrations began when mean water temperatures were between 6.7^{o}C and 8.7^{o}C and discharges ranging from 52 m^3/s and 199 m^3/s. Spawning migrations to spawning sites ranged from 0.75 km and 15.7 km, arriving at their eventual spawning sites 4 to 13 days from commencing to spawn. Weirs may have prevented spawning migrations and tracking beyond the studies limits reinforcing the need to restore free movement of fish in rivers. Spawning occurred at temperatures ranging from 2.9^{o}C and 10.0^{o}C, mean 6.97^{o}C, and all fish spawned at different sites along the main river or tributary. Spawning sites were shallow (10-60 cm), calm water and over submerged vegetation or flooded terrestrial vegetation. Pike remained at their spawning site for 5 to 25 days as mean water temperatures ranged from 2.9-10.0^{o}C, and emigrated to their previous pre-spawning winter habitat and returned to more sedentary behaviors and limited movement. During their spawning migrations, pike were repeatedly tracked at suitable spawning areas before migrating further upstream to their final spawning, and one fish tracked for more than one year returned to the same spawning site used the previous year site suggesting spawning site fidelity.

Koed et al., (2006) captured and radio-tagged five mature male and female northern pike in August 1998 and tracked their movement along a brackish Denmark river. Pike displayed a sedentary existence during most of the year preferring cool tidal water habitat. Movement of females increased significantly between mid-March and mid-May followed by females migrating to other localities for spawning, migrating upriver between 1.3-37 km and averaged 10.3 km. Male fish spawning migrations were not as extensive, ranging from 0-10.3 km and averaged 2.3 km. Females were observed to migrate past areas having suitable spawning habitat suggesting females may possess a homing and spawning natal-site fidelity, more so than males whose spawning migrations did not always extend beyond the range of movement exhibited the remainder of the year. By late June, all females had returned to their initial tidal tagging area.

Vehanen et al., (2006) used telemetry to study a Finnish riverine population of northern pike, the magnitude and patterns of their individual movement behavior, and classification as either sedentary or mobile. Forty northern pike (23 males and 17 females) were captured during the May 2002 spawning season, tagged and returned to their capture site. Fish were followed between May 2002 and July 2003. The tracking reach was 9 km long and was bounded at its upstream limits by a large dam that acted as a complete barrier to fish passage. The lower limit of the study reach was a narrow strait located at the confluence of the river and large lake (928 m^2). The river has a mean discharge 53.6 m^3/s, a channel width ranging from 300-1000 m, and a maximum depth 20 m. A permanent tracking station was located at the river and lake confluence to detect movements between the river and lake. Fish were tracked at 24 hour intervals from a small boat during open water periods or over the ice during ice covered periods. All fish were geolocated on maps and GPS. Fish that remained in the river were classified as "sedentary" and fish the move between the river and lake were classified as "mobile". The results indicated that all pike exhibited homing behavior returning to the same river spawning area the following year. Within the spawning population, 16 remained in the river year around after spawning while the 24 pike classified as mobile moved to the lake after spawning where they remained through the winter. Pike moved short distances during the summer month and there was no significant differences observed between sedentary and mobile pike, and females moved more than males (mean 397 ± sd 623 versus mean 246 ± sd 658 m). A significant difference in the length of summer movements was detected between the summer of 2002 and 2003. Pike moved shorter distances during warmer summer water temperatures (20^oC) in 2002 compared to cooler water temperatures (15^oC) in 2003.

Burkholder and Bernard (1994) studied the movement of northern pike in a large river-lake-marsh complex in the Alaskan interior. Radio-tagged adults displayed extensive seasonal spawning and fall migrations in excess of 100 km. Summer populations spent considerable time in deep and shallow marsh habitats but migrated to river habitats in the fall to avoid low dissolved oxygen levels during ice covered periods.

The specific physiological queues (i.e., olfactory) and genetic mechanisms for pike "homing" and reproductive fidelity has not, based on a review of the literature, been identified.

Genetic Variation Within and Among Populations

Senanan and Kapuscinski (2000) used microsatellite loci techniques developed for pike by Miller and Kapuscinski (1996) to determine the within-population genetic variation within North Central United States populations from Wisconsin, Minnesota, Michigan, Hudson Bay, Mississippi and Great Lakes Basins; and secondly compared these results from Alaska, Quebec, Siberia and Finland out groups to determine if modern day pike populations were derived from the same or different refugia. Genetic distance agreed on the relationship among populations at the continental level, with Siberian populations more related to North American populations than Finnish populations. Genetic distance agreed on the relationship among populations in Finland but not among populations in North America. There was a strong difference among the three sampled Finnish populations, with the two brackish water populations being more closely related to each other than either one of them to the freshwater sample indicating population genetic structure can develop in this species. Four of five genetic measures differentiated the Alaskan and Young Lake (Great Lakes drainage) populations from others. It was not clear as to why the Young Lake population was so different from other geographical surrounding samples, but the lake contains the normal form and color variant known as "silver pike" and these two phenotypic forms may be genetically different than surrounding populations. The reason for the limited genetic differences and relationship among other populations in the North Central United States is not clear. The authors offered four possible hypotheses. First, pike populations have only recently converged. Second, microsatellite markers may not be polymorphic enough to differentiate among populations. Third, pike may have very low levels of genetic variation throughout its genome. Fourth, lack of genetic variation from pike populations could be a result of human stock transfers. Others have suggested that three refugia contributed to post-glaciation fish redistribution and that the northern pike populations from North Central United States were derived from a single Mississippian refugium. Similarities between the single Alaskan sample and North Central North American sample populations would require more extensive sampling of Alaskan and Canadian populations to ascertain these populations with the Mississippian refugium or the unglaciated portion of the Yukon that formed the Beringium refugium.

Miller et al., (2001) completed a physical tagging study to test the hypothesis that individual pike from two lake spawning sites exhibited spawning-site fidelity. They collected and marked 1,900 northern pike using a variety of physical tags over a 4 year period at two of the three principal spawning tributaries in a 10,400 ha Minnesota Lake during the spring spawning run. The two spawning sites were located 14.8 km apart. In the first year, 23% were recaptured from their original spawning site one to three times over the 4 year period. Of those re-captured, only 1.3% and 4.8% were recaptured from the other spawning site. Tag returns from anglers showed year around wide dispersal and overlap between the two tributary spawning populations. Following the conclusion that the pike population exhibited strong spawning-site fidelity, the study was expanded to test the hypothesis that that the fish also exhibited natal-spawning site fidelity resulting in genetic differentiation of the two spawning populations. Using more detailed single-locus microsatellite marker techniques, genetic analysis completed on the 1983 and 1985 spawning populations indicated low levels of gene flow between the two spawning site populations. Reproductive isolation would occur if most individuals initially spawn at the site of their birth and then return during subsequent spawning migrations (natal-site fidelity), and could not occur if fish selected their first spawning site randomly even if they kept returning to the initial spawning site.

Miller and Senanan (2003) completed a review of northern pike genetics research and its implications for management. Their synthesis of the research concluded that pike have shown low within-population genetic variation as detected by less robust genetic testing procedures, including allozymes, mitochondrial DNA and randomly amplified polymorphic DNA. More exact tests for genetic variation using microsatellite DNA loci techniques did indicate more within-population variation, but much lower than other species, in particular species (i.e., yellow perch and walleye) that shared similar glacial refugium and post-glacial distribution history. Low pike genetic variation within-populations may be caused by low effective population size and bottlenecks in their early distribution, or both. Populations lose within-population genetic variation through genetic drift at a rate inversely related to effective population size. As a top predator, pike populations are generally lower than their forage and other competing predators. Northern pike spawn and develop at the winter-spring cusp and experience a greater number of extreme meteorological and hydrological events, and other biotic and abiotic factors that limit recruitment, and ultimately smaller effective populations. The low pike genetic variation within-populations compared to other species might suggest that the population resulted from a smaller initial refugia population or lost genetic variation at a faster rate than other species since the last glaciation.

The WDNR has taken the conservative recommendations from geneticists to manage northern pike by genetic management units to ensure the species local adaptive fitness and evolutionary traits. Wisconsin's proposed five northern pike genetic management units (WDNR, 2010); including the Great Lakes Unit that includes the Milwaukee River Basin.

Spawning

Northern pike males may be sexually mature after year 1 and always in year 2, while females may mature in year 2 and always in year 3 (Becker, 1983). Northern pike congregate in spawning areas a few days before spawning actually occurs and actual spawning occurs during daylight hours at temperatures ranging from between 4.4-17.2^{o}C (Franklin and Smith, 1963; Forney 1968; Scott and Crossman, 1979; Anderson, 1993; Karås & Hudd 1993; Gillet and Dubois 1995; Casselman and Lewis, 1996; Nilsson 2006). Under stable environmental conditions (i.e., temperature and water level) northern pike spawning is short in duration. Peaking spawning occurs when water temperatures are steady and warmed to 8-12^{o}C over a period of 2-5 days (Morrow et al. 1997; Casselman and Lewis, 1996). Priegel and Krohn (1975) reported peak spawning over a 2-day period when surface waters reached 10-17.8°C in Gilbert Lake, Washington County, WI. Franklin and Smith (1963) observed spawning to occur between 1400 and 1800 hours when surface water temperatures were 11.1-17.2°C. Fabricus and Gustafson (1958) observed that the combination of increasing length of day, the visual stimulus of suitable vegetation and rising water temperature are the primary stimulus for initiating spawning. Farrell et al. (1996) reported egg deposition peaking at water temperatures ranging from 7-12°C and 10-days after commencing; and spawning was suspended with a sudden drop in water temperature and resume once adequate water temperatures are reached. Spawning may also be suspended or delayed by anthropogenic barriers that "interrupt" passage to spawning grounds including channelization, excessive aquatic plant growth (eutrophication), sedimentation (Rost and Schuette, 1998), and road culverts (Paoli, per. corr.). Repeated suspension and resumption of spawning attempts may result in cessation of spawning and re-adsorption of gametes (cited by Inskip, 1982).

Spawning Site Characteristics

While the type of vegetation does not appear to be absolutely critical, ideal spawning substrate for promoting successful year classes is dense, short or matted, living or dead vegetative cover as sedges and grasses, free of fine silts and anoxic substrates. Northern pike have been reported to spawn at depths ranging from 10 cm to 100 cm, but prefer to spawn in slack water areas free of wave action or slow moving water less than 60 cm deep water capable of warming earlier than surrounding areas (cited by Raat, 1988 and cited by Inskip, 1982; Fago, 1977; Casselman and Lewis, 1996; Rost and Schuette, 1998; Priegel and Krohn, 1975; Farrell, 2001).

A comparison with pike eggs' density on plots of winter wheat and adjacent natural vegetation in New York showed egg deposit variation between undisturbed natural vegetation and seeded plots of winter wheat. Natural vegetation consisting of sedges, *Carex* spp., grasses, *Spartina* spp. and water plantain,

Alisma spp. appeared as attractive as winter wheat as a substrate for egg deposition (Forney, 1968). Schryer (Cited from by McCarraher and Thomas, 1972) observed pike spawning preferences among a variety of inundated vegetative cover types in a newly impounded reservoir in Kansas. Among the different types of vegetation that included alfalfa, milo, numerous species of annual weeds, and native buffalo grass and blue grama, only buffalo and blue grama grasses contained pike eggs indicating a preference for plants with a large amount of basal coverage.

Franklin and Smith (1963) observed the highest egg densities in mats of sterile culms of *Eleocharis* spp., and concluded that pike overall preferences for spawning substrate were loosely arranged grasses, sedges or rushes.

Kennedy (1965) showed that spawning occurred in Irish lakes over bottom habitat consisting of broken clumps of *Phragmites* spp. and on *Agrostis stolonifera, funcus bulbosus, Mentha* spp., *Hippuris* spp., and *Fontinalis* spp.

Bluejoint grass, *Calamagrostis caruulensis*, was listed by Carbine (1942) as the dominant plant and preferred pike spawning substrate in the drainage ditches flowing into Houghton Lake, MI.

McCarraher and Thomas (1972) observed that flooded native meadow grasses and matted mowed hay had similar deposited egg densities at 51-100 eggs per 30 cm^2, followed by *Elodea* spp. and *Utricularia* spp. At 31-51 eggs per 30 cm^2, and *Potamogeton* spp. and *Chara* spp. at 26-30 cm^2. Mud-dead vegetation, *Najas flexilis*, sand-scirpus, sand-detritus, *Scirpus-Phragmites*, and *Myriophyllum-Ceratophyllum* were low at 0-10 eggs per $30cm^2$.

Great Lakes populations spawn in sheltered near shore and tributary flooded wetlands where water is heated more rapidly (Farrell, 2001), with earliest spawning occurring in warmer and shallower backwater areas extending to deeper water (< 1 m).

Pike will also spawn on other substrates such as mowed hay and flooded hay bales (McCarraher and Thomas 1972), flooded plots of winter wheat (Forney 1968), scattered vegetative debris such as coarsely shredded dead *Typha* spp. and over deciduous leaves from previous fall leaf off. Rost and Schuette (1998) radio tracked northern pike that migrated from the waters of Green Bay, Lake Michigan to spawn. Adult spawning pike used a variety of natural and disturbed wetland habitats including wet meadow, broad-leaved deciduous wetland forests covered with coarse leaf litter and woody debris, Reed-canary grass (*Phalaris arundinace*a) lined ephemeral and perennial agricultural and roadside drainage ditches, wet meadow mitigation wetlands, and marshes dominated by *Typha* spp. Using young-of-the-year (YOY) traps, the authors collected YOY from each type of spawning habitat, with greater production from the restored wet meadow wetland and roadside ditches.

Many wetlands have been converted from higher ecological value wet meadow cover types to *Typha* spp. as a result of sedimentation and hydrologic alterations. *Typha* spp. has been shown to be much less preferred and often avoided by spawning pike (Farrell, 2001; Rost and Schuette, 1998; Franklin and Smith, 1963).

Adult Emigration from Spawning Sites

Carbine (1942) reported that the peak emigration by post-spawned northern pike from the wetland spawning habitat back to Houghton Lake, MI occurred between April 25 and May 7, or 11-21 days, following their peak spawning migration of April 14 and April 17. Franklin and Smith (1963) reported that approximately 60 percent of post-spawn adult pike left their spawning sloughs and returned to the lake proper after approximately 40-days in 1957 and 1958. Priegel and Krohn (1975) reported adult post-spawning emigration from spawning marshes back to Big Cedar Lake peaked 3-4 days after spawning.

Egg and Larval Development

Pike embryo and larvae development is highly dependent on moderate and stabile or slightly rising water temperatures. Based in a review of the current literature, Franklin and Smith (1963) noted that the pike embryo period is generally reported to be between 10-days and 21-days and is highly dependent on water temperature (Franklin and Smith, 1963). Becker (1983) stated that 210-270 degree-days above 0^{o}C are required for hatching. A controlled temperature study by Swift (1965) concluded the average length of incubation is approximately 26-days at 6^{o}C; 17-days at 8^{o}C; 12-days at 10^{o}C; 9-days at 12^{o}C, 6-days at 14^{o}C, and 5-days at 16 to 20^{o}C. Reduced survival of embryo and larvae is associated with rapidly rising water temperatures; and mortality of eggs is highest at incubating temperatures greater than 16^{o}C. On the lower temperature extremes, Hassler (1970) reported that most developing eggs die when temperatures fall too suddenly below 10^{o}C or remain near 5^{o}C for prolonged periods of time. Lillelund (1966) reported optimum embryo hatching success for incubating temperatures between 9 and 15^{o}C. Under controlled laboratory bioassay conditions, Hokanson et al., (1973) concluded that the constant optimum temperature range for northern pike egg incubation was 6.4 to 17.7^{o}C.

Some water circulation is beneficial to egg development in order to maintain dissolved oxygen levels and remove metabolic wastes. Dissolved oxygen levels of at least 4.5 mg/l and a flow rate of 30 ml/min optimizes embryo development, and oxygen tensions <33% of saturation were inadequate for proper development (Siefert et al., 1973). Sedimentation from excessive wave action and stormwater spates is deleterious to embryo development. Hassler (1970) reported northern pike early embryonic mortalities approaching 100 percent in Lakes Oahe and Sharp Lakes in South Dakota with sudden drops in water temperature below 10°C or prolonged temperatures near 5°C. Silt deposition rates of 1 mm per day in spawning sites as a result of wave action or tributary sources was associated with 97 percent mortality of early embryonic northern pike.

At hatching, pike do not possess a functioning mouth and remain very close to the spawning grounds. At this stage, they average 7 to 9 mm in length and are very active for up to 24-hours after which they attach to vegetation via a secreted mucous-like substance produced from specialized epithelial cells on their heads. The ability to attach themselves to suitable substrate is critical for their early survival as it prevents the yolk -sac larvae from sinking into anoxic substrate often associated with decomposing wetland vegetation and organic-rich backwater areas. While attached, they remain relatively inactive until their yolk-sac is absorbed for several days (Cited in Inskip, 1982). Becker (1983) stated that the absorption of the yolk-sac takes between 4 and 15 days depending on water temperature. Franklin and Smith (1963) reported that the yolk-sac larvae stage lasted 10-days before actively feeding, and only 12.6 percent began to actively feed after reaching between 10 mm and 12 m long. They also report from previous studies that the yolk-sac larvae stage to last between 4-days and 6-days and a maximum of 15-days before actively feeding.

Between 18 and 24-days after hatching the yolk-sac is absorbed, and the larvae is approximately 20 mm in length and free-swimming feeding on zooplankton and macroinvertebrates (Becker, 1983). Small fish become the principal diet at 40 to 50 mm in length (Morrow et al., 1997).

Juvenile Emigration from Spawning Sites

Hunt and Carbine (1951) and Franklin and Smith (1963) observed that light intensity was the main queue causing juvenile migration from spawning and rearing sites. On sunny days, emigration would start as early as sunrise and traps were relatively empty during evening hours. On cloudy days, peak migration did not occur until after the sun appeared. Marrow (1997) reported that larval pike emigration from artificial spawning wetlands began soon after hatching with larval as small as 14 mm in total length, and that emigrating pike were larger than pike that remained in wetlands, indicating that emigration is triggered by an ontogenetic change. Larval northern pike have been observed emigrating from spawning sites at sizes ranging from 17 mm to 20 mm (Hunt and Carbine 1951; Forney 1968). Franklin and Smith (1963) reported that pike larvae emigration from spawning sloughs back to George Lake, MN began between 16-days and 24-days after hatching and at an average length of 20 mm.

Hydroperiod

More than the availability of suitable spawning substrate and vegetative cover, northern pike YOY recruitment is highly dependent on the hydrologic characteristics and condition of the watershed and spawning site. High and stable water levels are critical during the pike's reproductive and developmental hydroperiod, beginning with adult migration and access to suitable spawning habitat, egg deposition and development, larval through juvenile development, feeding, and free-swimming emigration by juveniles. The critical hydroperiod for northern pike is dependent on water temperature, generally extending on the order of 30-days to 50-days and a median of 36-days (Hunt and Carbine, 1951; Franklin and Smith, 1963; Hassler,1970; Priegel and Krohn, 1975; Inskip,1982; Becker, 1983; Minns et al., 1996; Morrow et al, 1997. Casselman and Lewis (1996) proposed an optimum hydroperiod of 6 to 8 weeks with water levels gradually increasing prior to spawning, stable until larvae start to emigrate from spawning grounds, and then gradually decreasing. Johnson (1957) studied northern pike recruitment and water levels in marshes adjoining a reservoir in Minnesota for seven years. He concluded that high water levels during spawning and small declines in levels during egg incubation produced the greatest pike year classes.

Hassler (1970) reported optimum northern pike year classes over a six year period from Lakes Oahe and Sharp Lakes in South Dakota was associated with stable to gently rising water levels and temperature, extent and access by spawning adults to flooded vegetation, and calm weather during spawning and egg development periods.

A high and stable water level increases access to ephemeral spawning habitat, and reduces the potential for predation and cannibalism (Casselman and Lewis, 1996). Inversely, fluctuating water levels during the growing season can inhibit the growth and access to suitable vegetative cover for spawning, egg deposition and development, and nursery habitats (Inskip, 1982).
Maintaining a suitable hydroperiod for optimum northern pike recruitment can be especially challenging in developed watersheds. Riparian wetlands dependent on stream overbank flooding for their water budget can be especially sensitive to a watersheds altered hydrology. Developed watersheds have greater runoff rates and more abrupt peaking hydrographs. Similarly, developed watersheds have a greater amount of channelized and entrenched streams. Both types of alterations reduce the frequency and duration of overbank flows and as a result, can negatively impact the hydroperiod required by northern pike reproduction and development.

Northern Pike Larvae Nursery Habitat

Nursery habitat requirements for larvae pike are less understood than other life stage habitat requirements and are a result of the difficulty in sampling techniques and the solitary behavior exhibited by larvae pike (Casselman and Lewis, 1996). As a result, the importance of the quality and extent of larvae pike nursery habitat may be presumed to be less limiting than other life stage requisites. Larvae pike grow rapidly and increase in feeding activity. These conditions may make them more vulnerable to predation and as such, they require larger habitat areas and extensive cover, especially aquatic vegetation, and increased water depths.

Casselman and Lewis (1996) proposed a general guideline for habitat frequented by larvae pike is approximately 10 cm deep for every 10 mm of body length or for every week after peak spawning, until such time they reach 150 mm in length. Anderson (1993) developed suitability indices for water depth, vegetative type and density (ranging from 20 percent to 50 percent) for young pike and concluded that intermediate densities of vegetative cover were optimum and that larvae pike preferred a combination of submerged and emergent vegetation. Randall (et al., 1996) observed optimum pike larvae and adult numbers from areas that contained between 31 percent and 70 percent vegetation based on electrofishing surveys conducted in the lower Great Lakes.

Holland and Huston (1984) studied larvae pike number from backwater areas of the upper Mississippi River and observed pike larvae numbers from submergent vegetative cover types to be three times greater than areas with emergent vegetative types, and 10 times greater than from areas with no vegetation. Young pike left vegetated areas in the summer months when dissolved oxygen levels fell and flow within the beds decreased.

Mortality and Recruitment

According to Franklin and Smith (1963), the mortality of pike eggs and young pike ranged from 99.6% and 99.9% over a three year period. Rost and Gaumnitz (2004) reported that even under more ideal environmental conditions, significant year class recruitment occurs on the average of once every four to five years reinforcing management efforts to eliminate man-made factors that impact critical life stages. The most frequent cited anthropogenic factors that impact northern pike recruitment include barriers that prevent or delay adult and juvenile immigration and emigration, modifications or destruction of wetland spawning habitat, channelization, shoreline development and other hydrological modifications, non-native vegetation, sedimentation and turbidity, and eutrophication (Hassler, 1970; cited in Inskip, 1982; Becker, 1983; Casselman and Lewis, 1996; Rost and Schuette, 1998; Miller and Senanan, 2003; Jude et al., 2005; cited in Nilsson, 2006).

Water Quality

Northern pike are classified as a coolwater species over most of its (Casselman, 1978). Lyons et al., (2009) used modeled stream water temperatures and fish assemblages from wadable streams in Wisconsin and Michigan to map coolwater streams and their fish assemblages. Their results indicated that coolwater streams were variable and lacked clear diagnostic species, generally intermediate in species richness and overlapped the composition of fishes associated with coldwater and warmwater streams. The best fit was associated with a four group analysis (cold, cold-transition, warm-transition and warmwater) compared to a three group analysis (as cold, cool or warmater). Their results indicate that the appropriate thermal classification for northern pike was for a warmwater stream and fish assemblage. Their study also classified fish thermal classification according to literature that reported on a species laboratory preferred and critical threshold temperatures. Based on their review, the preferred temperature and critical thermal maxima was 19.0-24.0^{o}C, and 30.8-33.3^{o}C, respectively. Sustained water temperatures of 32^{o}C coincided with pike die off in a Missouri reservoir as high water temperatures increased stress and lowered fish resistance to disease. Dead fish were infected by bacteria, fungi and protozoans. Extensive mortality was observed from an Iowa marsh when temperatures reached 35.6^{o}C despite adequate oxygen levels (Cited in Inskip, 1982). Under laboratory conditions, Hokanson, et al., (1973) concluded that water temperatures for normal embryo development should not fall below the lower TL_{50} (median) 7^{o}C or above the upper TL_{50} 19^{o}C for spawning. Temperatures in excess of 19^{o}C can be tolerated by larvae provided there are no abrupt changes, the durations are brief and larvae are acclimated. The 7-day upper TL50 increased from 25^{o}C to 28.4^{o}C from the time of hatch to free-swimming stage when acclimated to 17.7^{o}C.

Northern pike can withstand extended periods of low dissolved oxygen provided the change is gradual. Requirements for dissolved oxygen increase exponentially as temperature increases, with the lower incipient lethal concentration or concentration that pike can not survive indefinitely is 1.5 mg/l. Younger fish have a higher tolerance than older and larger bodied fish (cited in Inskip, 1982), however oxygen concentrations below 30-35% of air saturation result in greatly reduced survival of eggs and larvae (cited in Casselman and Lewis, 1996).

Pike embryo and yolk-sac larvae are intolerant of low levels of hydrogen sulfide. Sub-lethal effects in yolk-sac larvae included malformations and lower growth rates. The lowest measured concentration that reduced embryo survival resulted in an increase in malformations or decreased growth rates was 18 ug/l for eggs and 6 ug/l for yolk-sac larvae. Concentration for no sub-lethal or lethal effects on embryo and yolk-sac larvae were 14 ug/l for eggs and 4 ug/l for yolk-sac larvae. Hydrogen sulfide can not exist does not exist in the presence of free-oxygen (Adelman and Smith, 1970). Absent anoxic conditions in the water column, available hydrogen sulfide can exist at the sediment-water interface. Avoiding egg contact above the sediment interface and sufficient oxygen levels are critical for egg development and normal yolk-sac larvae. Casselman and Lewis (1996) included moderate circulation of water and layered matted vegetation as important spawning and nursery habitat criteria in order to remove metabolic waste and to prevent exposure of egg and larvae to hydrogen sulfide. Hydrogen sulfide is a natural by-product of plant decomposition. Ephemeral and perennial wetlands and backwater areas can produce high concentrations under warm water conditions. Eutrophication can increase plant production and during periods of decomposition, decreased levels of dissolved oxygen and increased levels of hydrogen sulfide.

Northern pike embryos have been shown to be very sensitive to siltation rates as low as 1 mm/day resulted in embryo mortality of 97% (Hassler, 1970). These rates of sedimentation are common in developed low watersheds and low-gradient streams and backwater areas.

Pike disappeared Devils Lake, North Dakota as salinity increased from 0.8% (8 ppt) in 1989 to 1.5 (15 ppt) in 1923. Salts other than chlorides predominate in these natural lakes supporting a biota somewhat different from inland chloride or saline waters (Cited from McCarraher, 1962).

Northern pike are known to grow and reproduce successfully in the brackish waters of the Baltic Sea and are classified as stenohaline. Adult pike populations that spend most of their time feeding in the brackish water environs divide during their spawning migrations to return to their natal spawning grounds that may be brackish or freshwater river and streams. In Danish waters of the Baltic Sea, populations of northern pike live there entire life in brackish water as these populations have no access to freshwater along the Danish coast. Jorgensen (2009) noted that eggs fertilized at four different salinity concentrations of 0, 3, 6, and 8.5 g/l (ppt). He reported the LC_{50} for pike egg and larvae to be 13.2 ppt at 15^{o}C, greater than the LC_{50} of 12 ppt at 14^{o}C reported for pike fertilized in freshwater. He also reported a decrease in growth rate in saltwater exposed eggs above 10.8-14.4 ppt and eggs fertilized in freshwater and exposed to saltwater at 6.4 ppt. He concluded that pike living their lives entirely in brackish water can tolerate higher concentrations of salinity compared to freshwater populations. Others (cited by Jorgensen, 2009) have reported that the larvae of freshwater pike were able to tolerate salinities of 11 ppt for short periods of time with the TL_{50} occurring after 72-hours at 11.2 and 12.2 ppt. Decreasing rates of mortality were reported under cooler water exposures (0% at 10^{o}C to 40% at 18^{o}C).

Others (cited by Jorgensen, 2009) suggest that the survivability of northern pike from European brackish waters is an evolved trait and tolerance to higher salinity concentrations than freshwater populations. If pike populations indigenous to the Great Lakes were in fact found to be more tolerant of elevated salinity concentrations than other fish species, northern pike populations may be more sustainable in urbanized watersheds with high concentrations of salinity from heavy use of salt for road de-icers. Studies by the USGS (Corsi et al., 2010) observed chronic and acute in Milwaukee metropolitan streams during winter months. Chloride concentrations routinely exceeded the USEPA water quality criteria of 860 mg/l acute and 230 mg/l chronic. Maximum observed chloride levels were 7300 mg/l (estimated salinity equivalent of 13.2 ppt). Among 37 whole water samples collected for bioassays, 72% of the water quality samples exhibited chronic toxicity and 43% of the samples exhibited acute toxicity in *Ceriodaphnia dubia* and *Pimephales promelas.* Watershed-specific bioassays using various northern pike life stages would be needed to ascertain if salinity/chloride in urban watersheds with high usage rates of salt for de-icers would be limiting to restoring northern pike populations.

Appendix 3. Historical fish community results for the Trinity Creek and Ulao Creek watersheds (Fago, 1992; WDNR, 2008; WDNR, 2010).

Stream / Common Name	Count	Date	RM	Lat	Lon	T	R	S	Q	QQ	Site Seq	Visit Seq
TRINITY CREEK WIBC 20400												
CREEK CHUB	1	1975-09-09	0.2	43.2	-87.97	N9	E21	35	NE	SW	4211	162627
WHITE SUCKER	27	1975-09-09	0.2	43.2	-87.97	N9	E21	35	NE	SW	4211	162627
GREEN SUNFISH	3	1975-09-09	0.2	43.2	-87.97	N9	E21	35	NE	SW	4211	162627
NORTHERN PIKE	**10**	**1975-09-09**	**0.2**	**43.2**	**-87.97**	**N9**	**E21**	**35**	**NE**	**SW**	**4211**	**162627**
GOLDEN REDHORSE	1	1975-09-09	0.2	43.2	-87.97	N9	E21	35	NE	SW	4211	162627
SUNFISHE UNSP.	1	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
SAND SHINER	36	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
JOHNNY DARTER	1	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
COMMON CARP	3	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
COMMON SHINER	3	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
SPOTFIN SHINER	72	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
WHITE SUCKER	3	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
BLACK BULLHEAD	1	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
BLACK CRAPPiE	1	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
PUMPKINSEED	3	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
GOLDEN SHINER	2	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
BLUNTNOSE MINNOW	37	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
GREEN SUNFISH	17	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
HORNYHEAD CHUB	1	1984-05-21	0.1	43.2	-87.97	N9	E21	35	NE	SE	4424	162561
ULAO CREEK WIBC 21200												
COMMON CARP	3	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
SPOTFIN SHINER	12	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
BLUNTNOSE MINNOW	9	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
YELLOW BULLHEAD	7	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
GREEN SUNFISH	10	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
GREEN SUNFISH X PUMPKINSEED	1	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
BLACK BULLHEAD	47	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
PUMPKINSEED	6	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
NORTHERN PIKE	**10**	**1975-09-10**	**0.6**	**43.27**	**-87.93**	**N9**	**E22**	**6**	**SE**	**SW**	**4862**	**162025**
WHITE SUCKER	22	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
BLACK CRAPPIE	1	1975-09-10	0.6	43.27	-87.93	N9	E22	6	SE	SW	4862	162025
WHITE SUCKER	7	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
GOLDEN SHINER	3	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
ROCK BASS	30	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
WHITE CRAPPIE	1	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024

GREEN SUNFISH X BLUEGILL	1	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
CENTRAL MUDMINNOW	48	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
BLACK BULLHEAD	24	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
GREEN SUNFISH X PUMPKINSEED	1	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
HORNYHEAD CHUB	8	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
COMMON CARP	2	1984-07-27	0.6	43.27	-87.93	N9	E22	6	SE	SW	20716	162024
NORTHERN PIKE	**12**	**1984-07-27**	**0.6**	**43.27**	**-87.93**	**N9**	**E22**	**6**	**SE**	**SW**	**20716**	**162024**

BLACK BULLHEAD	10	1984-05-16	1.7	43.28	-87.93	N10	E22	31	SE	SE	4864	162027
WHITE SUCKER	1	1984-05-16	1.7	43.28	-87.93	N10	E22	31	SE	SE	4864	162027
GREEN SUNFISH	3	1984-05-16	1.7	43.28	-87.93	N10	E22	31	SE	SE	4864	162027
CENTRAL MUDMINNOW	2	1984-05-16	1.7	43.28	-87.93	N10	E22	31	SE	SE	4864	162027

FATHEAD MINNOW	2	1994-06-08	0.7	43.27	-87.93	N9	E22	6	SE	SW	4863	162026
YELLOW BULLHEAD	1	1994-06-08	0.7	43.27	-87.93	N9	E22	6	SE	SW	4863	162026
GREEN SUNFISH	2	1994-06-08	0.7	43.27	-87.93	N9	E22	6	SE	SW	4863	162026
WHITE SUCKER	5	1994-06-08	0.7	43.27	-87.93	N9	E22	6	SE	SW	4863	162026
PUMPKINSEED	1	1994-06-08	0.7	43.27	-87.93	N9	E22	6	SE	SW	4863	162026
CREEK CHUB	1	1994-06-08	0.7	43.27	-87.93	N9	E22	6	SE	SW	4863	162026
BLUEGILL	2	1994-06-08	0.7	43.27	-87.93	N9	E22	6	SE	SW	4863	162026
NORTHERN PIKE	**21**	**1994-06-08**	**0.7**	**43.27**	**-87.93**	**N9**	**E22**	**6**	**SE**	**SW**	**4863**	**162026**
PUMPKINSEED	6	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028
BLACK BULLHEAD	1	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028
CENTRAL MUDMINNOW	920	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028
BLUNTNOSE MINNOW	2	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028
BROOK STICKLEBACK	1	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028
NORTHERN PIKE	**3**	**1994-06-08**	**1.9**	**43.28**	**-87.92**	**N10**	**E22**	**32**	**SW**	**SW**	**4865**	**162028**
GREEN SUNFISH	9	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028
YELLOW BULLHEAD	1	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028
JOHNNY DARTER	2	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028
COMMON SHINER	5	1994-06-08	1.9	43.28	-87.92	N10	E22	32	SW	SW	4865	162028

BLACK BULLHEAD	4	1997-07-28										128113
CENTRAL MUDMINNOW	183	1997-07-28										128113
COMMON SHINER	3	1997-07-28										128113
GOLDEN SHINER	3	1997-07-28										128113
GREEN SUNFISH	7	1997-07-28										128113
LARGEMOUTH BASS	8	1997-07-28										128113
NORTHERN PIKE	**10**	**1997-07-28**										**128113**
PUMPKINSEED	9	1997-07-28										128113
WHITE SUCKER	7	1997-07-28										128113

BLUEGILL	2	1984-06-08	
CENTRAL MUDMINNOW	177	1984-06-08	
CREEK CHUB	1	1984-06-08	
FATHEAD MINNOW	2	1984-06-08	
GRASS PICKEREL	21	1984-06-08	
GREEN SUNFISH	2	1984-06-08	
NORTHERN PIKE	**21**	**1984-06-08**	
PUMPKINSEED	1	1984-06-08	
WHITE SUCKER	5	1984-06-08	
YELLOW BULLHEAD	1	1984-06-08	

Appendix 4: Fish passage assessment at road crossing structures and other man-made structures along major tributaries of the Menomonee River (SEWRPC, 2009)

Subwatershed	Reach	River Mile	Structure I.D.	Major Tributaries	Fish Passage Obstruction?	Distance between structures (mile)
Honey Creek	MN-16					0.03
		0.03	Bike Trail Bridge		- -	
						0.12
		0.15	Honey Creek Parkway Drive		- -	
						0.34
		0.49	W. Portland Avenue		- -	
		0.58				0.10
		0.59	Honey Creek Parkway Drive		- -	
						0.30
		0.89	W. Wisconsin Avenue		- -	
						0.19
		1.08	Honey Creek Parkway Drive		- -	
						0.29
		1.37	Honey Creek Parkway Drive		- -	
						0.42
		1.79	S. 84th Street		- -	
						0.16
		1.95	IH-894 Tunnel Outlet		Yes	
					Yes	2.33
		4.28	W. Arthur Avenue Tunnel Inlet		Yes	
						0.24
		4.52	McCarty Park footbridge		- -	
						0.11
		4.62	W. Beloit Road		- -	
						0.42
		5.04	S. 76th Street		- -	
						0.16
		5.20	W. Oklahoma Avenue		- -	
						0.24
		5.44	S. 72nd Street		- -	
						0.18
		5.61	Channel Drop Structure		Yes	
						0.26
		5.88	W. Morgan Avenue		- -	
						0.22
		6.10	S. 68th Street		- -	
						0.37
		6.47	W. Howard Avenue (downstream)		Yes	
		6.50			Yes	0.05
		6.52	W. Forest Home Avenue (upstream)		Yes	
						0.39
		6.91	S. 60th Street (downstream)		Yes	
		7.01			Yes	0.10
		7.01	S. 60th Street (upstream)		Yes	
						0.13
		7.14	W. Cold Spring Road		- -	

						0.33
		7.47	IH-43/894		- -	
		7.56				0.09
Underwood Creek	MN-14 + MN-13					0.225
		0.23	Channel Drop Structure		Yes	
						0.58
		0.81	Channel Drop Structure		Yes	
						0.01
		0.81	Canadian Pacific Railway		- -	
						0.46
		1.27	N. Mayfair Road		- -	
						0.19
		1.46	Channel Drop Structure		Yes	
						0.00
		1.46	Union Pacific Railroad		- -	
						0.04
		1.50	Watertown Plank Road		- -	
						0.03
		1.54	Channel Drop Structure		Yes	
						0.10
		1.64	Channel Drop Structure		Yes	
						0.06
		1.70	Channel Drop Structure		Yes	
						0.18
		1.87	N. 115th Street		- -	
						0.70
		2.56	Confluence with South Branch Underwood Creek	South Branch Underwood Creek		
		2.57	UPS Driveway		- -	
						0.01
		2.58	Pedestrian Bridge		- -	
						0.09
Underwood Creek	MN-14 + MN-13	2.67	Private Drive		- -	
						0.02
		2.69	Private Drive		- -	
						0.04
		2.73	Private Drive		- -	
						0.10
		2.83	Private Drive		- -	
						0.27
		3.10	Canadian Pacific Railway		- -	
						0.02
		3.12	Private Drive		- -	
						0.13
		3.25	Wall Street		- -	
						0.06
		3.31	Parking Lot Tunnel Outlet		Yes	
						0.10
		3.41	Parking Lot Tunnel Inlet		Yes	
						0.02
		3.43	Watertown Plank Road		- -	
						0.07
		3.51	Private Drive		- -	
						0.04

		3.54	Private bridge		- -	
						0.01
		3.55	Canadian Pacific Railway		- -	
						0.12
		3.67	Juneau Boulevard		- -	
						0.09
		3.76	Elm Grove Village Hall Bridge		- -	
						0.72
		4.48	Marcela Drive		- -	
		4.67				0.34
		4.74				
		4.82	North Avenue		- -	
						0.66
		5.48	Private Drive		- -	
						0.11
		5.59	Clearwater Road		- -	
						0.29
		5.88	Private bridge		- -	
						0.11
		5.99	Santa Maria Court		- -	
						0.09
		6.08	Woodbridge Road		- -	
						0.12
		6.20	Indian Creek Parkway		- -	
						0.12
		6.32	Canadian Pacific Railway		- -	
						0.05
		6.37	Private bridge		- -	
						0.04
		6.41	Private bridge		- -	
						0.07
		6.48	Private bridge		- -	
						0.02
		6.50	Private bridge		- -	
						0.01
		6.51	Private Drive		- -	
						0.08
		6.59	Private bridge		- -	
						0.05
		6.64	Private Drive		- -	
						0.04
		6.68	Pilgrim Parkway		- -	
						0.002
		6.69	Pedestrian Bridge		- -	
		6.95	Confluence with Dousman Ditch	Dousman Ditch		0.55
		7.24	Wirth Park Bridge		- -	
						0.45
		7.69	Canadian Pacific Railway		- -	
		7.70				0.02
South Branch Underwood Creek	MN-14A	0.05				0.0525
		0.05	W. Bluemound Road		- -	
		0.15				0.10
		0.15	Canadian Pacific Railway		- -	
		0.57				0.42

		0.57	IH-94		- -	
		1.08				0.51
South Branch Underwood Creek	MN-14A	1.08	W. Schlinger Avenue Tunnel Outlet		Yes	
		1.66				0.65
		1.73	W. Greenfield Avenue Tunnel Inlet		Yes	
		1.73				0.004
Dousman Ditch	MN-13A	0.03				0.28
		0.03	Union Pacific Railroad		- -	
		0.05				0.03
		0.06	North Avenue		- -	
		0.11				0.14
		0.20	Pedestrian bridge		No	
		0.62				0.43
		0.63	Gebhardt Road		- -	
		1.26				0.63
		1.26	Private Drive		- -	
		1.62				0.36
		1.62	Private Drive		- -	
		1.85				0.23
		1.85	Private Drive		- -	
		2.36				0.52
		2.37	Lake Road		- -	
		2.44				0.07
Little Menomonee River	MN-11	0.08				0.088
		0.09	N. Lovers Lane Road (STH 100)		- -	
		0.42				0.42
		0.51	Pedestrian bridge		- -	
		1.11				0.62
		1.13	W. Silver Spring Drive		- -	
		1.46				0.33
		1.46	Union Pacific Railroad		- -	
		1.47				0.03
		1.49	Bike Trail Bridge		- -	
		1.58				0.10
		1.59	W. Appleton Avenue		- -	
		2.39				0.81
		2.40	W. Mill Road		- -	
		2.55				0.17
		2.57	W. Fond du Lac Avenue (STH 145)		- -	
		2.60				0.04
		2.60	W. Leon Terrace		- -	
		3.32				0.73
		3.33	Park bridge		- -	
		3.38				0.05
		3.38	Bike Trail Bridge		- -	
		3.67				0.30
		3.69	W. Good Hope Road (CTH PP)		- -	
		3.75				0.07
		3.76	N. Granville Road (CTH F)		- -	
		4.21				0.46
		4.22	W. Calumet Road		- -	
		4.83				0.62
		4.84	W. Bradley Road		- -	
		4.92				0.09
		4.92	Wisconsin & Southern Railroad		- -	

		6.07				1.16
		6.08	Union Pacific Railroad		- -	
		6.10				0.05
		6.13	W. Brown Deer Road (STH 100)		- -	
		6.46				0.38
		6.50	Park bridge		- -	
		6.76				0.26
		6.76	Footbridge		- -	
		7.15				0.39
		7.15	W. County Line Road		- -	
		7.24				0.19
		7.34	Private Bridge		- -	
						0.11
		7.45	Private Bridge		- -	
Little Menomonee River	MN-11	7.71				0.26
		7.71	Farm Bridge		- -	
		7.73				0.12
		7.83	Private Bridge		- -	
		7.92				0.39
		8.21				
		8.22	Donges Bay Road		- -	
		8.31	Confluence with Little Menomonee Creek	Little Menomonee Creek		0.85
		9.07	Private Bridge		- -	
		9.36				0.30
		9.37	Mequon Road		- -	
Little Menomonee River	MN-11	9.37				0.02
		9.38	Private Bridge		- -	
		9.42				0.04
		9.43	Farm Bridge		- -	
		10.44				1.02
		10.44	Freistadt Road		- -	
		10.45				0.01
						0.29
Little Menomonee Creek	MN-10	**0.29**	Private bridge (0.29)		- -	
		0.34				0.29
		0.58	Private bridge (0.58)		- -	
		0.82				0.24
		0.82	Granville Road		- -	
		0.83				0.02
		0.84	Private bridge (0.84)		- -	
						0.07
		0.91	Private bridge (0.91)		- -	
		1.03				0.12
		1.03	Mequon Road		- -	
		1.16				0.86
		1.47				
		1.89	Private bridge (1.89)		- -	
		2.25				0.36
		2.25	Freistadt Road		- -	
		2.26				0.01
Willow Creek	MN-4					0.0625
		0.06	Maple Road		- -	

						0.59
		0.65	Lannon Road		- -	
						0.50
		1.15	Appleton Avenue (STH 175)		- -	
		2.85				1.70
North Branch Menomonee River	MN-1	0.63				0.6315
		0.63	Holy Hill Road		- -	
		1.02				0.42
		1.05	Private bridge (1.05)		- -	
		1.27				0.22
		1.27	Rockfield Road		- -	
		1.60				0.33
		1.60	Dividion Road		- -	
		1.83				0.23
		1.83	Railroad		- -	
		2.89				1.06
		2.90	Maple Road		- -	
		3.36				0.47
		3.37	STH 145		- -	
		4.08				0.72
		4.09	Goldendale Road		- -	
		4.52				0.44
West Branch Menomonee River	MN-3	0.27				0.3315
		0.33	Freistadt Road		- -	
		0.39				0.06
		0.39	Private Drive		- -	
		0.48				0.12
		0.51	Private bridge (0.51)		- -	
		1.16				0.65
		1.16	Maple Road		- -	
		1.25				0.09
		1.25	Railroad		- -	
		1.63				0.38
		1.63	Private Drive-bridge		- -	
		2.05				0.42
		2.05	Private Drive-bridge		- -	
West Branch Menomonee River	MN-3	2.22				0.17
		2.23	Dalebrook Road		- -	
		2.33				0.11
		2.34	Goldendale Road		- -	
		2.52				0.19
		2.53	Freistadt Road		- -	
		2.74				0.22
		2.75	Goldendale Road		- -	
		3.01				0.27
		3.02	Goldendale Road		- -	
		3.28				0.27
		3.29	USH 41/45		- -	
		3.30				0.02
		3.31	Hilltop Drive		- -	
		3.60				0.30
Lilly Creek	MN-7				- -	0.4015
		0.40	Appleton Avenue			
					- -	0.44
		0.84	Good Hope Road			

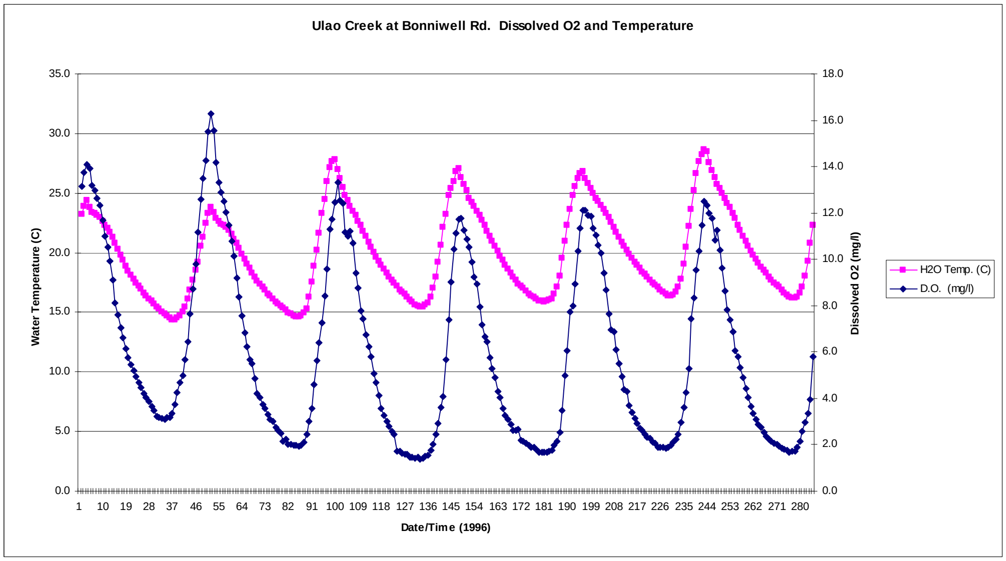
		0.85			- -	0.22
		1.06	Brentwood Drive			
		1.07			- -	0.41
		1.47	Daylily Drive			
					- -	0.33
		1.80	Lilly Road			
					- -	0.08
		1.88	Mill Road			
					- -	0.11
		1.99	private bridge (1.99)			
					- -	0.06
		2.05	private bridge (2.05)			
					- -	0.06
		2.11	Private Drive			
					- -	0.09
		2.20	Private Drive			
					- -	0.06
		2.26	Private Drive			
					- -	0.17
		2.43	Kaul Avenue			
					- -	0.05
		2.48	Bobolink Avenue			
					- -	0.07
		2.55	Private Drive			
					- -	0.04
		2.59	Railroad			
					- -	0.38
		2.97	Silver Spring Road			
		3.44			- -	0.47
Nor-X-Way Channel	MN-6	0.07				0.0725
		0.07	Fond du Lac Avenue		- -	
		0.08				0.06
		0.13	USH 45 Entrance Ramp		- -	
		0.14				0.04
		0.17	USH 45		- -	
		0.27				0.10
		0.27	Stanley Drive		- -	
		0.31				0.04
		0.31	Main Street		- -	
		0.45				0.14
		0.45	Patrita Drive/Fountain Boulevard		- -	
		0.73				0.28
		0.73	Private Drive		- -	
		0.82				0.09
		0.82	Wisconsin Southern Railroad		- -	
		1.31				0.49
		1.31	STH 145		- -	
		1.37				0.06
		1.37	County Line Road (CTH Q)		- -	
		2.10				0.75
		2.12	Railroad		- -	
		2.18				0.08
		2.20	Railroad		- -	
		2.49				0.30
		2.50	Culvert @ upstream end of pond		- -	

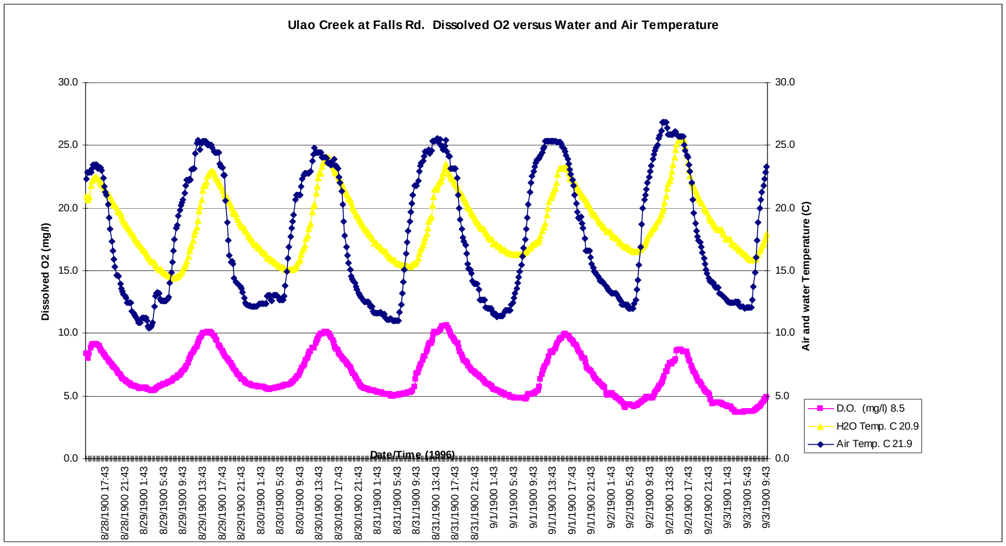
		2.64				0.15
		2.65	Donges Bay Road		- -	
		3.20				0.56
		3.21	Wasaukee Road		- -	
		3.27				0.06
Butler Ditch	MN-8	0.23				0.24
		0.24	Campbell Road		- -	
		0.64				0.41
		0.65	Overview Drive		- -	
		0.81				0.26
		0.90	Private bridge		- -	
		1.02				0.12
		1.02	Hampton Road		- -	
		1.03				0.33
		1.35	Lisbon Road		- -	
		1.36				0.41
		1.49				
		1.76	Lilly Road		- -	
		1.81				0.05
Butler Ditch	MN-8	1.81	Lilly Heights Dam		- -	
		2.50	Confluence with South Branch Butler Ditch	South Branch Butler Ditch		0.91
		2.72	Shamrock Lane		- -	
		3.40				0.69
		3.41	Lisbon Road		- -	
		3.99				0.59
Dretzka Park	MN-9	0.00				
		0.02				
		0.02				
		0.05	Fond du Lac Avenue			
		0.08				
		0.09				
		0.10				
		0.12				
		0.13	USH 41/45 downstream			
		0.19				
		0.27				
		0.31	USH 41/45 upstream			
		0.32				
		0.34				
		0.42				
		0.48				
		0.48				
		0.49	W. Bradley Road			
		0.50				
		0.51				
		0.55				
		0.58				
		0.62				
		0.65				
		0.66				
		0.66	Golf Course Bridge #1			
		0.66				
		0.69				
		0.72				

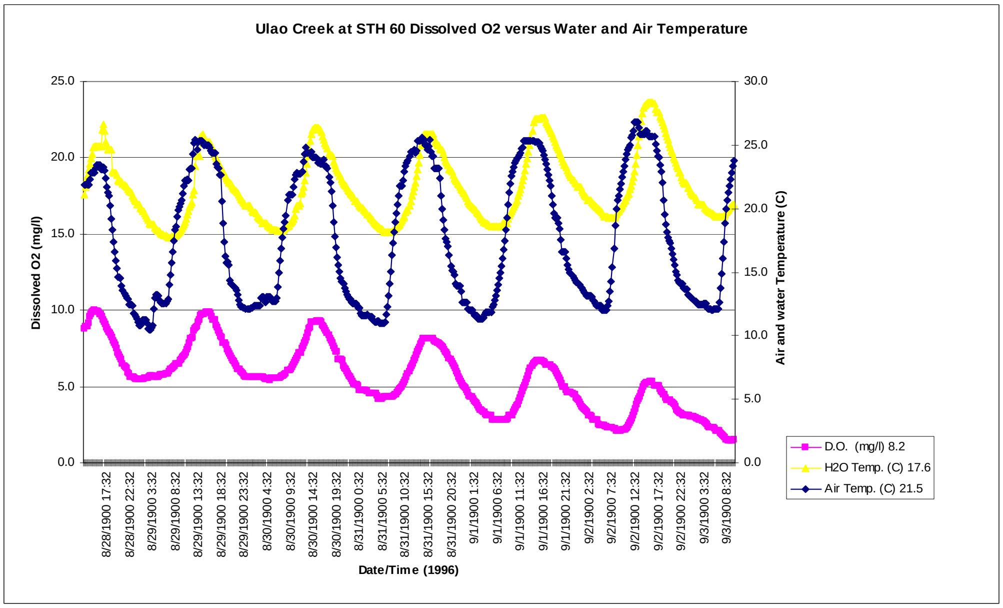
		0.75				
		0.79				
		0.79	Golf Course Bridge #2			
		0.79				
		0.86				
		0.92				
		0.92	Golf Course Bridge #3			
		0.92				
		0.95				
		0.98				
		0.99	Golf Course Bridge #4			
		0.99				
		1.02				
		1.05				
		1.10				
		1.15				
		1.15	Golf Course Bridge #5			
		1.15				
		1.18				
		1.18				
		1.18	Golf Course Bridge #7			
		1.18				
		1.19				
		1.23				
		1.24				
		1.24				
		1.24	Golf Course Bridge #8			
		1.24				
		1.28				
		1.33				
		1.34	Golf Course Bridge #9			
		1.34				
		1.37				
		1.37	Golf Course Bridge #10			
		1.37				
		1.47				
		1.48	Golf Course Bridge #11			
		1.48				
		1.55				
		1.55	Golf Course Bridge #12			
		1.55				
		1.61				
		1.66				
		1.78				
Dretzka Park	MN-9	1.83				
		1.85	N. 124th Street			
		1.86				
		1.89				
		1.98				
		2.00				
		2.02	W. Brown Deer Road			
		2.04				
		2.06				
		2.13				
		2.15				

		2.16				
		2.17	N. 124th Street			
		2.18				
		2.21				
		2.27				
		2.36				
		2.41				
		2.46				
		2.49				
		2.50				
		2.52				
		2.53				
		2.54	Private Drive			
		2.55				
		2.56				
		2.58				
		2.59	Abandoned Railroad			
		2.59				
		2.60				
		2.68				
		2.73				
		2.75				
		2.76	Wisconsin & Southern RR			
		2.76				
		2.77				
		2.79				
		2.80	Railroad			
		2.80				
		2.82				
		2.88				
		2.97				
		3.07				
		3.16				
		3.21				
		3.25				
		3.27				
		3.28	W. County Line Road			
		3.28				
		3.31				
		3.35				

Appendix 5. Diel dissolved oxygen (mg/l), water and air temperatures (C^o) for selected water quality monitoring stations along Ulao Creek. August-September 1996.







Appendix 6. Index of Biotic Integrity scores, ratings and metric values.

T-M Impoundment Headwater (Transition between impounded and free-flowing morphology)

Reach and Station	Species	No.	Weight (kg)	% Weight (kg)	IBI Score Rating	WPUE (excluding tolerant sp. & salmonids)	% WPUE	No. Native Species (n)	Sucker Species (n)	Intolerant Species (excluding non-native salmonids) (n)	Riverine Species (n)	% DELT (n)	% Riverine (n)	% Lithophilic Spawner (n)	% Insectivore (wt)	% Round suckers (wt)
U1	Pumpkinseed	1	0.06	0.2		0.06	0.2	1							0.24	
U1	Shorthead redhorse	1	0.10	0.4		0.10	0.4	1	1					1.4	0.41	0.41
U1	Green sunfish	4	0.15	0.6				1				1.4			0.61	
U1	Golden redhorse	1	0.23	0.9		0.23	1.0	1	1		1		1.4	1.4	0.93	0.93
U1	Largemouth bass	1	0.65	2.6		0.65	2.9	1								
U1	Walleye	1	1.19	4.8		1.19	5.3	1						1.4		
U1	Rock bass	15	1.71	6.9		1.71	7.7	1		1						
U1	Rainbow trout	1	2.25	9.1												
U1	Northern pike	6	2.41	9.7		2.41	10.8	1								
U1	Channel catfish	6	7.40	30.0		7.40	33.2	1								
U1	Smallmouth bass	36	8.55	34.6		8.55	38.4	1		1						
	Total	**73**	**24.68**	100.0		**22.28**	100.0	**10**	**2**	**2**	**1**	**1.4**	**1.4**	**4.2**	**2.19**	**1.34**
	Scoring Criteria				**15**	**5**		**0**	**0**	**5**	**0**	**5**	**0**	**0**	**0**	**0**
	Rating				**POOR**	**fair**		**poor**	**poor**	**good**	**poor**	**fair**	**poor**	**poor**	**poor**	**poor**
				Score	**Rating**											
				0	**Poor**	0-9.9		0-11	0-2	0-1	0-4	>3	0-10	0-25	0-20	0-10
				5	**Fair**	10-25		12-15	3-4	2	5-6	3-0.5	11-20	26-40	21-39	11-25
				10	**Good**	>25		>15	>4	>2	>6	<0.5	>20	>40	>39	>25

* State listed Threatened

Comments: Fish assemblage results as a result of outboard malfunction. Dipper estimated fishing effectiveness <95%

T-M Impoundment

Reach and Station	Species	No.	Weight (kg)	% Weight (kg)	IBI Score Rating	WPUE (excluding tolerant sp. & salmonids)	% WPUE	No. Native Species (n)	Sucker Species (n)	Intolerant Species (excluding non-native salmonids) (n)	Riverine Species (n)	% DELT (n)	% Riverine (n)	% Lithophilic Spawner (n)	% Insectivore (wt)	% Round Suckers (wt)
U2	Bluntnose minnow	1	0.002	0.0				1								
U2	Pumpkinseed	1	0.07	0.1		0.07	0.2	1							0.08	
U2	Black crappie	2	0.22	0.2		0.22	0.5	1								
U2	Largemouth bass	3	0.55	0.6		0.55	1.3	1								
U2	Shorthead redhorse	5	0.69	0.7		0.69	1.7	1	1			1.0		0.5	0.74	0.75
U2	Smallmouth bass	1	0.80	0.9		0.80	1.9	1		1						
U2	Walleye	1	0.85	0.9		0.85	2.1	1						1.0		
U2	Greater redhorse *	9	10.55	11.4		10.55	25.7	1	1	1				9.4	11.36	11.36
U2	Golden redhorse	47	27.35	29.5		27.35	66.6	1	1		1	1.0	49.0	49.0	29.45	29.45
U2	Common carp	26	51.79	55.8												
	Total	**96**	**92.88**	100.0		**41.08**	100.0	**9**	**3**	**2**	**1**	**2.1**	**49.0**	**62.4**	**41.63**	**41.55**
	Scoring Criteria				**65**	**10**		**0**	**5**	**5**	**0**	**5**	**10**	**10**	**10**	**10**
	Rating				**GOOD**	**good**		**poor**	**fair**	**fair**	**poor**	**fair**	**good**	**good**	**good**	**good**
				Score	**Rating**											
				0	**Poor**	0-9.9		0-11	0-2	0-1	0-4	>3	0-10	0-25	0-20	0-10
				5	**Fair**	10-25		12-15	3-4	2	5-6	3-0.5	11-20	26-40	21-39	11-25
				10	**Good**	>25		>15	>4	>2	>6	<0.5	>20	>40	>39	>25

* State listed Threatened

Comments: Catch rate and biomass of common carp under estimated due to shear numbers and size of specimens

T-M Dam Tailwater (Mequon Rd to Dam)

Reach and Station	Species	No.	Weight (kg)	% Weight (kg)	IBI Score Rating	WPUE (excluding tolerant sp. & salmonids)	% WPUE	No. Native Species (n)	Sucker Species (n)	Intolerant Species (excluding non-native salmonids) (n)	Riverine Species (n)	% DELT (n)	% Riverine (n)	% Simple Lithophilic Spawner (n)	% Insectivore (wt)	% Round suckers (wt)
D1	Logperch	2	0.01	0.0		0.01	0.0	1						1.0	0.01	
D1	Horneyhead chub	6	0.05	0.0		0.05	0.0	1			1		2.9		0.03	
D1	Common shiner	28	0.22	0.1		0.22	0.2	1						13.6	0.14	
D1	Black bullhead	1	0.25	0.2		0.25	0.2	1								
D1	Green sunfish	6	0.84	0.5				1							0.55	
D1	Bluegill	12	1.53	1.0		1.53	1.5	1							1.00	
D1	Rock bass	19	2.66	1.7		2.66	2.6	1		1						
D1	Shorthead redhorse	6	2.81	1.8		2.81	2.7	1	1					2.9	1.83	1.83
D1	Walleye	1	4.68	3.0		4.68	4.5	1						1.0		
D1	Rainbow trout	2	5.86	3.8												
D1	Smallmouth bass	8	10.46	6.8		10.46	10.0	1		1						
D1	Northern pike	10	15.07	9.8		15.07	14.5	1								
D1	Common carp	7	16.74	10.9												
D1	White sucker	39	26.20	17.0				1	1					18.9		
D1	Greater redhorse *	19	27.09	17.6		27.09	26.0	1	1	1				9.2	17.62	17.62
D1	Golden redhorse	40	39.28	25.6		39.28	37.7	1	1		1		19.4	19.4	25.55	39.28
	Total	**206**	**153.75**	100.0		**104.11**	100.0	**14**	**4**	**3**	**2**	**0.0**	**22.3**	**66.0**	**46.72**	**58.72**
	Scoring Criteria				**85**	**10**		**5**	**10**	**10**	**0**	**10**	**10**	**10**	**10**	**10**
	Rating				**EXCELLENT**	**good**		**fair**	**fair**	**good**	**poor**	**good**	**good**	**good**	**good**	**good**
				Score	**Rating**											
				0	**Poor**	0-9.9		0-11	0-2	0-1	0-4	>3	0-10	0-25	0-20	0-10
				5	**Fair**	10-25		12-15	3-4	2	5-6	3-0.5	11-20	26-40	21-39	11-25
				10	**Good**	>25		>15	>4	>2	>6	<0.5	>20	>40	>39	>25

* State listed Threatened

Comments: Dipper estimated that 75% of the fish catch at this station were collected within 75 m of T-M Dam spillway and tailwater

Range Line Rd to Schroeder Dr

Reach and Station	Species	No.	Weight (kg)	% Weight (kg)	IBI Score Rating	WPUE (excluding tolerant sp. & salmonids)	% WPUE	No. Native Species (n)	Sucker Species (n)	Intolerant Species (excluding non-native salmonids) (n)	Riverine Species (n)	% DELT (n)	% Riverine (n)	% Simple Lithophilic Spawner (n)	% Insectivore (wt)	% Round suckers (wt)
D2	Bluegill	1	0.01	0.0		0.01	0.0	1							0.01	
D2	Bluntnose minnow	3	0.01	0.0				1								
D2	Spotfin shiner	6	0.02	0.0		0.02	0.0	1			1		6.0		0.01	
D2	Black crappie	2	0.23	0.2		0.23	0.2	1								
D2	Green sunfish	2	0.24	0.2				1							0.19	
D2	Rock bass	4	0.33	0.3		0.33	0.4	1		1						
D2	Rainbow trout	1	2.50	2.0												
D2	Smallmouth bass	6	2.57	2.0		2.57	2.8	1		1		0.8				
D2	White sucker	7	3.69	2.9				1	1			0.8		7.0		
D2	Shorthead redhorse	12	8.07	6.3		8.07	8.7	1	1					12.0	6.33	6.33
D2	Northern pike	7	12.00	9.4		12.00	13.0	1								
D2	Greater redhorse *	13	19.74	15.5		19.74	21.3	1	1	1		0.8		13.0	15.47	15.47
D2	Common carp	13	28.50	22.3								1.5				
D2	Golden redhorse	55	49.67	38.9		49.67	53.6	1	1		1		55.0	55.0	38.94	38.94
	Total	**132**	**127.57**	100.0		**92.63**	100.0	**12**	**4**	**3**	**2**	**3.8**	**46.2**	**65.9**	**60.94**	**60.74**
	Scoring Criteria				**70**	**10**		**5**	**5**	**10**	**0**	**0**	**10**	**10**	**10**	**10**
	Rating				**GOOD**	**good**		**fair**	**fair**	**good**	**poor**	**poor**	**good**	**good**	**good**	**good**
				Score	**Rating**											
				0	**Poor**	0-9.9		0-11	0-2	0-1	0-4	>3	0-10	0-25	0-20	0-10
				5	**Fair**	10-25		12-15	3-4	2	5-6	3-0.5	11-20	26-40	21-39	11-25
				10	**Good**	>25		>15	>4	>2	>6	<0.5	>20	>40	>39	>25

* State listed Threatened