

# **Development of GIS Tools for Integration of Coastal Fish Habitat Management\***

Final Report to the Ohio Coastal Management Assistance Grants Program

Project Number: Cycle 6 Contract 06-5.

by

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## **Project Summary**

The goal of the project was to improve the preservation of essential coastal fish habitat in the Lake Erie ecosystem by developing GIS databases and models needed to integrate watershed and coastal zone planning with the management of Lake Erie fisheries resources. The project pursued this goal through three primary objectives:

1. Construct a GIS-based habitat supply inventory for the Lake Erie tributaries,
2. Construct a habitat supply inventory for two fish species to test the concept,
3. Model the effect of upstream land-use changes and effects of non-point source pollution on downstream and coastal zone productivity.

Work on these objectives resulted in two main products:

1. GIS database of tributary reaches feeding Lake Erie identified by segment. Attributes will include: river segments, related to NHD by reach code; length; stream order (Strahler method); slope; sinuosity; and mean elevation. The geodata includes valley-segment specific statistics for fish habitat attributes (substrate, flow regime, and mean annual temperature), land use/land cover characteristics, slope, mean elevation, length, and shape ratio. We have provided the geodata in shapefile format, which is compatible with ArcView 3.x and ArcGIS.
2. A scientifically defensible protocol for linking land-use changes and non-point source pollution to productivity of Lake Erie coastal fish habitat. The protocol uses tools for constructing habitat supply inventories from the tributary GIS database and a database for habitat preferences of various fish species. The protocol also provides guidance on using GIS map modeling tools to analyze effects of land-use changes and/or non-point source pollution effects on habitat supply.

## **Narrative Description of Research Tasks**

We organized research work on the three objectives for this project into a set of five research tasks. These tasks, their subtasks, schedule, and completion are summarized in the Final Performance Report submitted with this narrative report. Below, we report on the activity, accomplishments, and problems encountered for each task.

### ***Task 1.***

This task involved development of the GIS base maps for all of the Lake Erie coastal watersheds in Ohio. Maps were derived from existing GIS databases using ArcView and ArcGIS mapping tools. Sub tasks included:

- 1.1. Creation of networks of river reaches using ArcView from hydrological Digital Line Graph (DLG) data supplied by USGS,
- 1.2. Acquisition and processing of Digital Elevation Model, and
- 1.3 Delineation of sub-basins using available ArcView extensions.

### **Activity Summary**

Work on Task 1.1 and 1.2 required acquisition of basemaps from various government agencies. We purchased Digital Line Graphs (DLGs) for the state of Ohio from the U.S. Geological Survey via the GIS DataDepot. This database consisted of vectorized hydrologic features of the 1:24,000 Digital Raster Graphics (DRGs) in the Standard Data Transfer System (SDTS) format. SDTS DLGs were then converted to shapefiles for ArcView compatibility. Because hydrology DLGs were not available for portions of the Upper Maumee watershed (in Michigan), these streams had to be digitized from the corresponding DRGs. To create

hydrologic networks, which are necessary for delineating watersheds, isolated streams, waterbody polygons and incomplete flow paths were corrected in the DLGs. We also purchased Digital Elevation Models (DEMs) in SDTS format from the GIS DataDepot for the State. DEMs were converted to ArcView grids and quads were transformed into a seamless mosaic for individual Hydrologic Unit Code (HUC) watersheds (Figure 1).



**Figure 1. USGS HUC watersheds for Ohio coastal zone.**

Work on Task 1.3 required use of existing map modeling software to delineate sub-basins and stream valley segments. Creation of stream valley segments from existing GIS databases was an essential task for this project. Of various alternative map-modeling tools, we chose to use the CRWR Pre-Processor designed for ArcView 3.x by Dr. Francisco Olivera at the Center for Research in Water Resources of the University of Texas at Austin. Using this ArcView extension, we delineated sub-watersheds within each HUC and segmented the stream file into ecologically relevant lengths. The Pre-Processor corrected for any imperfections in the DEM, calculated the flow path and flow accumulation based on elevation and the location of DLG streams, and generated a map of the local sub-watershed to each reach of stream. Linking these segments to upstream segments thus produced drainage networks and allowed us to calculate the drainage areas to the outlets of each reach. A useful product of the pre-processor was a new stream map that fitted the estimated flow path. These generated streams often included streams

that did not appear in the DLGs. These additional streams may not have appeared in the DLGs because they were extremely small or intermittent streams. We coded such streams by giving them a status of “I” (imaginary) as opposed to those that correspond to the DLGs, which were designated as “R” (real).

In addition to slope and drainage area, we quantified several other morphological characteristics for the streams and watersheds. Sinuosity, or the degree of stream meander, was calculated as the stream length divided by the linear distance between the beginning and end nodes, where length of each segment was calculated using X-Tools extension, Version 6/1/2001 (ESRI ArcScripts). Mean elevations were estimated as the DEM elevation at the centroid of the stream. Subwatershed area and perimeter were also calculated with X-Tools. Mean elevation and elevation range from the DEM were summarized for each subwatershed. A slope grid was derived from the elevation grid using ArcView’s Spatial Analyst extension, where slope is the maximum rate of change in degrees, from each cell to its neighbors. Mean slope and slope range were summarized for each watershed.

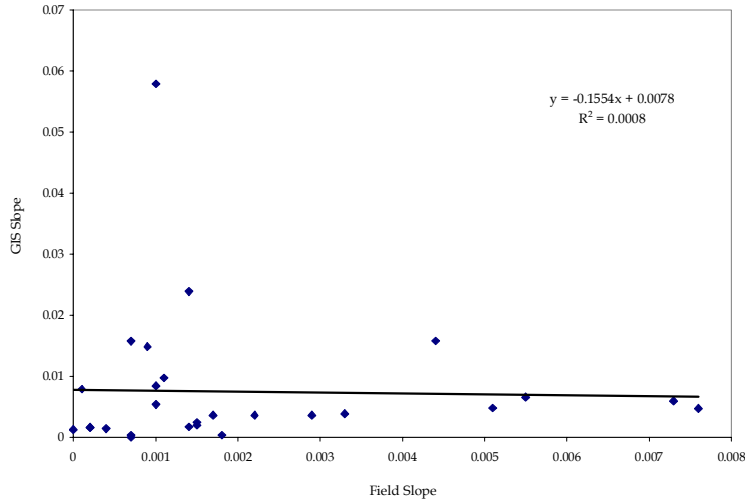
A layer of first dams to the mouth of each tributary was compiled from a shapefile provided by Ohio Department of Natural Resources and dam locations on mainstem branches from the State of the Lake Report. All rivers downstream from the first dam were classified as lake accessible reaches. The distance from the stream midpoint to the mouth was calculated for these lake accessible reaches using the FlowLength command in ArcView.

### ***Special Considerations or Problems Encountered***

Originally, we intended to use the National Hydrography Dataset (NHD) as our river basemap for the watershed delineations instead of the DLGs. The NHD required considerably

less editing to construct it into a usable network. However, after several delineations were complete it was obvious that NHD was not digitized at a fine enough resolution for the predictions that we were trying to make. The NHD datasets are prepared from 1:100,000 scale maps while the DLG data are derived from USGS Quad Maps at 1:24,000 resolution. Upon close inspection, it was apparent that slopes from the NHD generated inaccurate channel locations for stream segments. In other words, the NHD generated streams flowed up the sides of the bank, sometimes resulting in severely negative slope values. It was therefore necessary to use the higher resolution DLGs, whose flow paths fits within the natural channels.

Higher resolution datasets, however, generated additional problems that the NHD datasets had been designed to overcome. For example, additional steps were required to acquire the data and convert the DLGs from SDTS format to ArcView-compatible shapefiles. It was also necessary for us to purchase the DLGs (as opposed to downloading the NHD without cost), because of the manner in which the data is compiled. Next, the DLGs included flow paths around small ponds and lakes and double lines at wide river mouths and embayments, each of which had to be edited to create a single flow path. This work proved to be extremely time-consuming due to the vast geographic extent of the data. Lastly, drainage ditches were included as hydrologic features in the DLGs. The occurrence of these features sometimes resulted in incorrect flow direction grids, in turn, deriving incorrect drainage areas for some of the reaches in the Lower Maumee and Sandusky watersheds, which had to be manually edited on the mainstem branches. Finally, we discovered that the DLG channel resolution coupled with 30 m DEM data may still be too coarse to estimate slopes of river valley segments. The slopes of the DLG generated streams still do not compare well with those measured in the field (Figure 2)

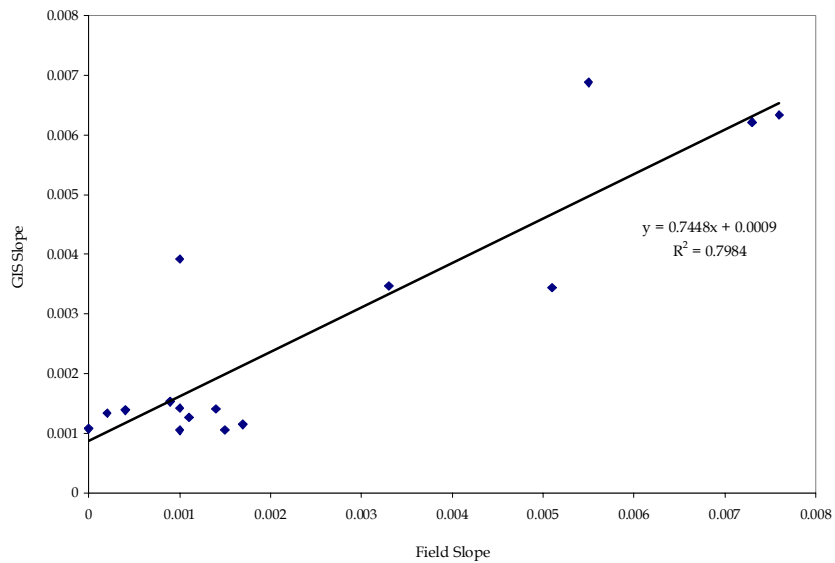


**Figure 2. DLG slope versus field slope estimates.**

There are several steps that we intend to take to modify our methods for future work. First, the removal of all manmade channels is required, because they do not follow the natural hydrologic principles and create incorrect estimates of drainage direction. Secondly, we will change our watershed delineation technique, so that the generated streams match the DLGs exactly. Currently, the generated streams are derived from a grid, resulting in a ‘boxy’ line (Figure 3) and inaccurate lengths. If we can use the DLGs directly, we will be able to make much more accurate estimates of length and sinuosity. Lastly, we plan to develop a method for deriving stream slope from the DLG hypsography files, which have proven to be a much more accurate predictor of slope when compared to those measured in the field (Figure 4).



**Figure 3. Angular pattern of generated streams from 30 m DEM grid.**



**Figure 4. Comparison of stream segment slope from field data and from intersections of DLG stream channel and DLG hypsography.**

### **Deliverable**

The product of work on this task is a set of map files with corresponding databases, which can be found on the attached CD:

1. “Coastal\_Streams\_OH” - The river segments generated from the watershed delineation provide the basemap for the fish habitat assessments.
2. “Coastal\_Subwatersheds\_OH”– The subwatershed maps generated from the watershed delineation provide catchments by which to summarize local characteristics such as landuse, watershed slope, elevation range, etc.

## **Task 2.**

The second task was concerned with the derivation habitat attributes for each of the stream segments in the watershed GIS. The method of analysis involved empirical estimates of stream segment channel morphology from fundamental principles of fluvial geomorphology and site-specific estimates to validate the empirical calculations. By using the Sea Lamprey as one of the test fish species, we were also able to make use of the extensive habitat surveys conducted by the Sea Lamprey Control Agents of the U.S. Fish and Wildlife Service and Canada's Department of Fisheries and Oceans. Work on this task was subdivided into five subtasks:

- 2.1. Relate attribute tables from GIS prepared in Task 1 to fish preference databases;
- 2.2. Acquire and process habitat data from Sea Lamprey Control Program;
- 2.3. Integrate habitat data into the GIS
- 2.4. Model habitats not included in the SLCP dataset
- 2.5. Ground-truth modeled habitats

## **Activity Summary**

The primary work in this task was to include fish habitat attributes in the stream valley segment databases. Although characterization of habitat preference of fish species is the primary focus of work on Task 3, we focused on two species, walleye and sea lamprey, which are

responsive to variation in substrate composition. Thus, work on Tasks 1.2 to 1.5, relied on the existence of well-established relationships in the geomorphic literature that link the morphological characteristics of a reach of stream and its corresponding watershed to the particle size classes found within the reach (Leopold and Maddock 1953; Montgomery and Buffington 1998; Whiting and Bradley 1993; Whiting et al. 1999). Our approach to these tasks involved first verifying and calibrating relationships established in the literature to a subset of the Lake Erie tributaries, and secondly, we derived relevant morphologic variables for the entire Lake Erie tributary system within Ohio using readily available digital datasets using GIS.

Geomorphic characteristics of stream reaches, such as water surface slope and bankfull width, were quantified using surveying techniques at each of 28 sites from May – August 2003 (Figure 5). Sites were often located within public lands for accessibility purposes. The length of the site was determined by 7-10 times the bankfull width. Pebble counts (N=20) were conducted at 5 or more cross-sectional transects at each site (total N per site = 100<sup>+</sup>) similar to Wolman (Wolman 1954). Pebbles were collected from the cross-section of stream that was expected to be wetted under bankfull conditions. Proportion of bedrock at each transect was also measured. These data were combined with a comparable dataset recently collected by Dr. Peter Whiting, Geology Department, Case Western Reserve University (unpublished data) at 17 sites in predominantly headwater streams of Lake Erie tributaries (Figure 5). Average stream slope, median particle size, proportion of fine material (<2mm) and proportion of cobble (20-100mm) were calculated at each of these sites. Mean annual discharge was collected for sites from nearby USGS gauging station datasets. The total contributing drainage area (DA) was collected for all sites from the flow accumulation maps derived during the watershed delineations in Task 1.

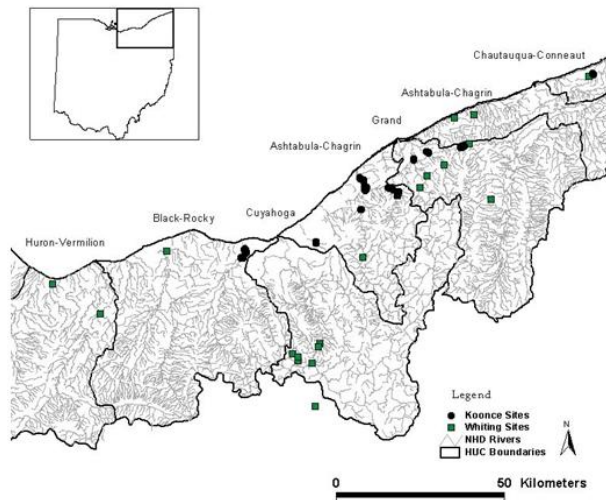


Figure 5. Distribution of field sites used to obtain calibration data for prediction of stream segment attributes.

Based on relationships established by Whiting et al. (1999) in Idaho streams, median bedsurface particle size ( $P_s$ ) is a function of stream power ( $\omega$ ), where:

$$\omega = \rho g S c k (A^{f+m})$$

such that  $\rho$  is the density of water,  $g$  is the gravitational acceleration,  $S$  is the stream slope  $A$  is the drainage area. Constants  $c$ ,  $k$ ,  $f$  and  $m$  are derived from relationships between bankfull depth and drainage area and velocity at bankfull and drainage area. Local values for these constants were derived from Whiting's data and our combined field data (Figure 6).

Using the outputs from the watershed delineations, we were able to calculate the drainage area to each of the 45 study sites. There was a high correlation between generated drainage areas and those provided by the USGS at gauging stations near the Whiting sites (Figure 7). Stream gradient for each reach was calculated from the DEMs using a script provided by Jeff Jenness, Jenness Enterprises, which takes the average elevation change between vertices for each stream

segment. We were then able to calculate  $\omega$  for each reach based on equation 1.1 using the GIS-estimated slope and drainage area and local constants. From  $\omega$ , we predicted Ps as:

$$\text{Equation 1.2 } Ps = 1.0845 \omega^{0.5124}$$

From our field data, we found a correlation between the median particle size and the proportion of fine material (<2mm) within the reach (Figure 8) as well as the proportion of cobble habitat (Figure 9). Using these relationships, we estimated the amount of fine habitats (Figure 10) and cobble (Figure 11) and in the lake accessible reaches.

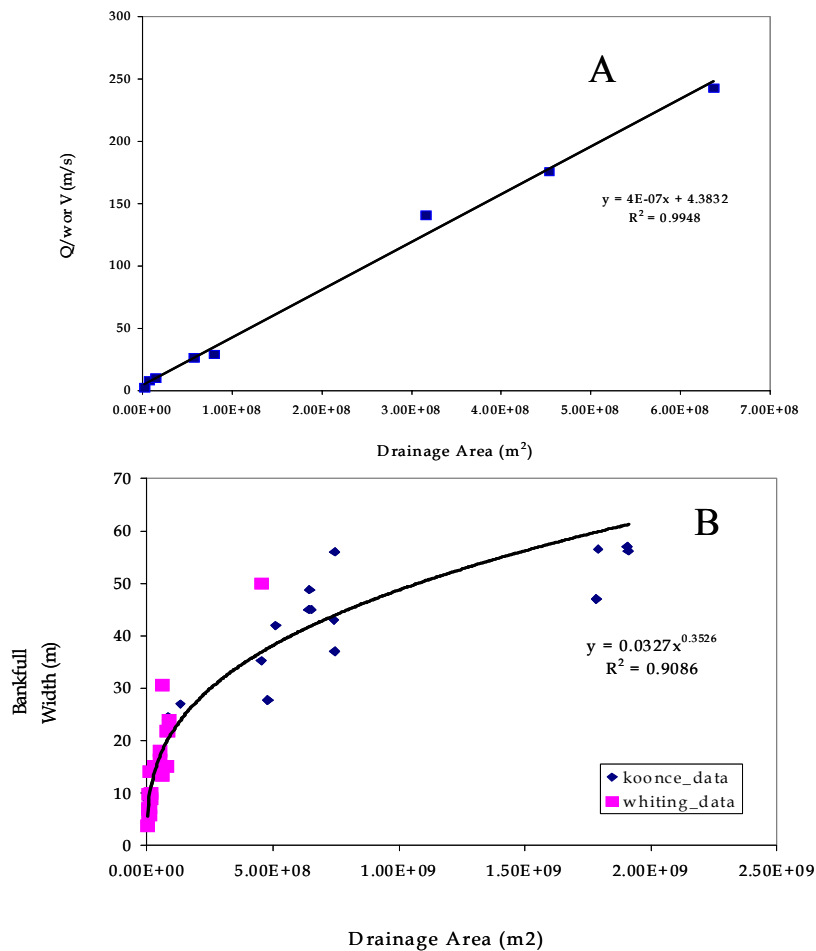


Figure 6. Calibration data for estimation of parameters in stream power functions. Panel A shows the relationships for estimating k and m, and Panel B the relation for parameters c and f.

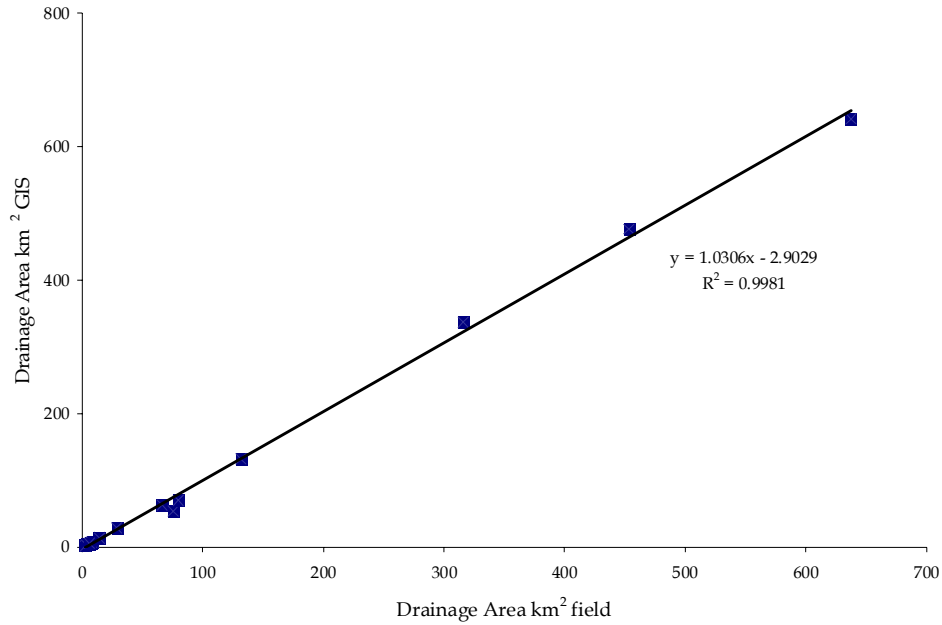


Figure 7. Comparison of estimated drainage area of watersheds from published USGS estimates and from watershed delineations.

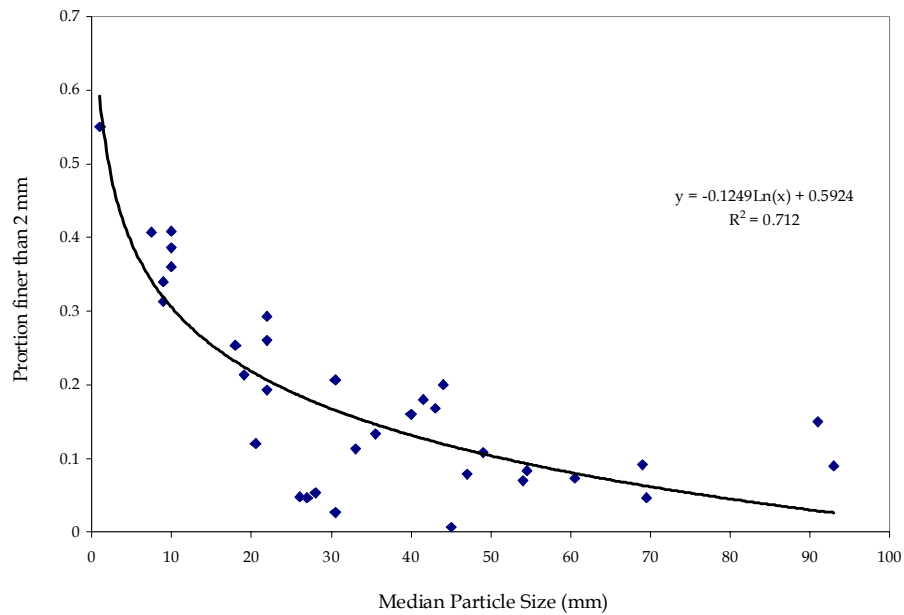


Figure 8. Relation between median particle size and proportion of stream bed with fine sediments preferred by larval sea lamprey.

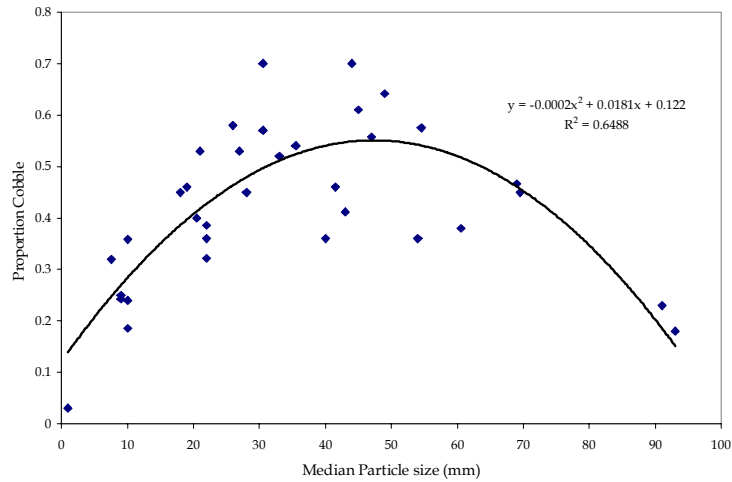


Figure 9. Relation between median particle size and proportion of stream bed with cobble sediments preferred by spawning walleye.

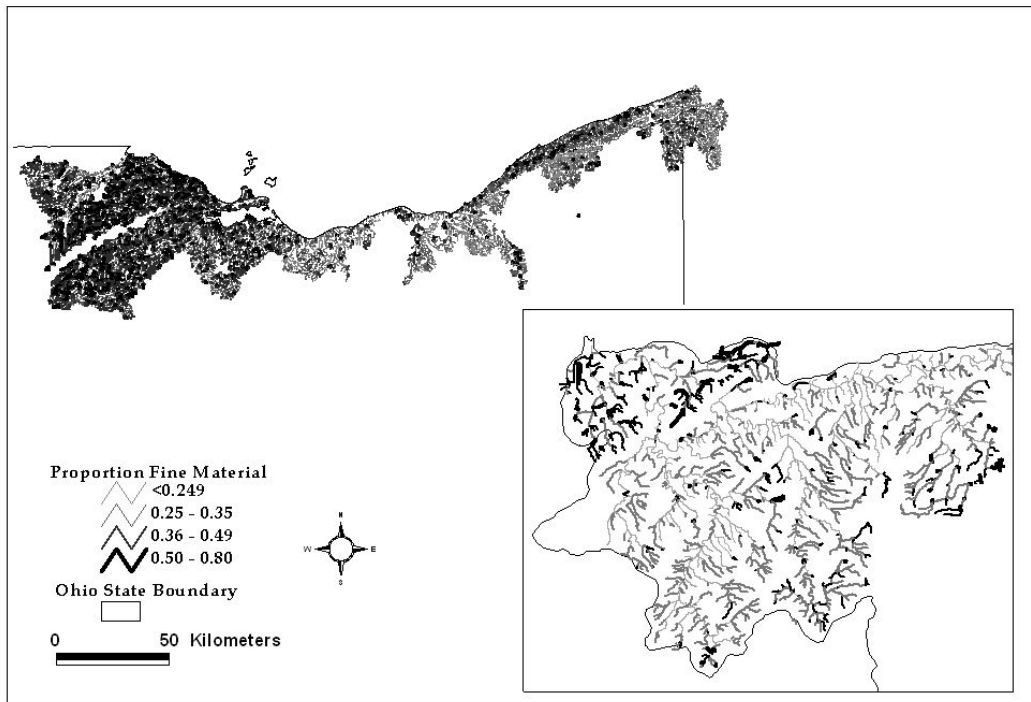


Figure 10. Predicted distribution of larval sea lamprey habitat in the Ohio coastal zone of Lake Erie.

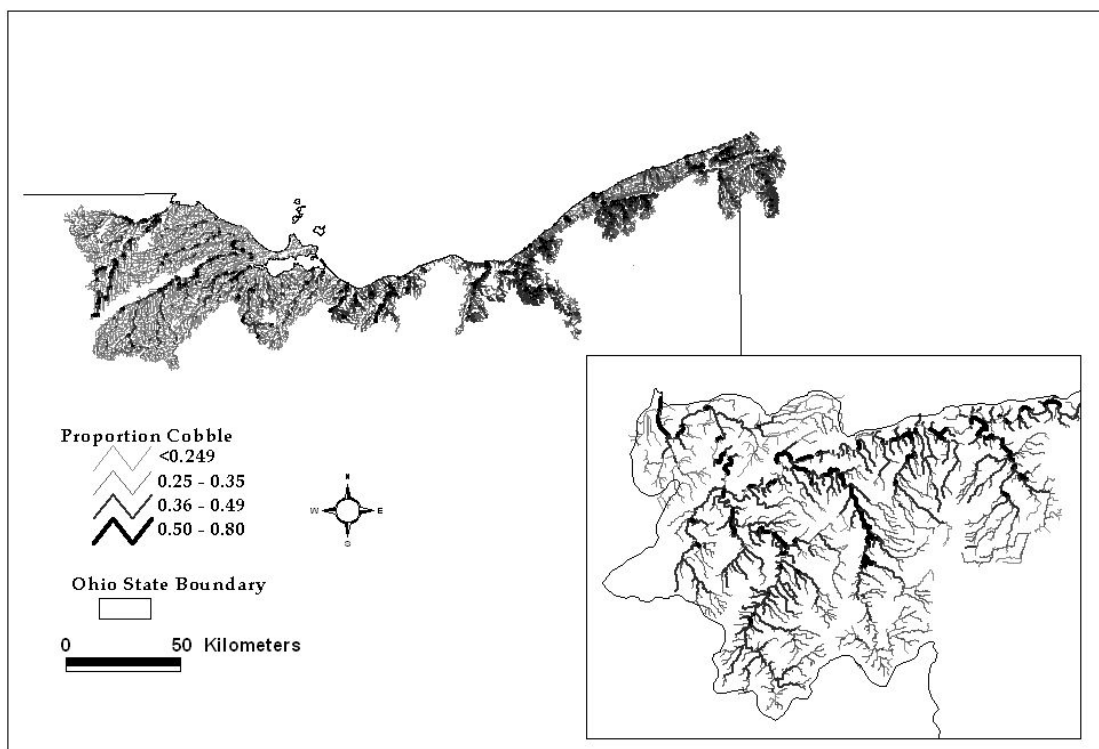


Figure 11. Predicted distribution of lake-accessible walleye spawning habitat in tributaries of the Ohio coastal zone of Lake Erie.

To obtain data on use of stream habitat by sea lamprey, we collaborated with biologists in the Sea Lamprey Control Program. In mid-September 2002, we attended the Annual Meeting of the Larval Assessment Task Force of the Sea Lamprey Control Program in Marquette, Michigan. At this meeting, we presented our GIS-based habitat models and acquired relevant lamprey abundance and habitat data from the Control Agents. For all sampling stations in the Lake Erie basin, we calculated the average proportion of Type I (preferred by ammocetes; usually fine sand and/or silt mixed with organic material) and Type II lamprey habitat (burrowable, but not preferred; coarser sand and less detritus) as well as the proportion of spawning habitat (cobble).

These variables were mapped using GIS for all georeferenced sampling stations, and GIS-generated estimates of proportion of fine material and cobble were related to the corresponding sites. Upon comparing field estimates of spawning and larval habitats with GIS estimates of fine material and cobble, we found no relationship (Figure 12). Issues associated with this lack of correlation are addressed below.

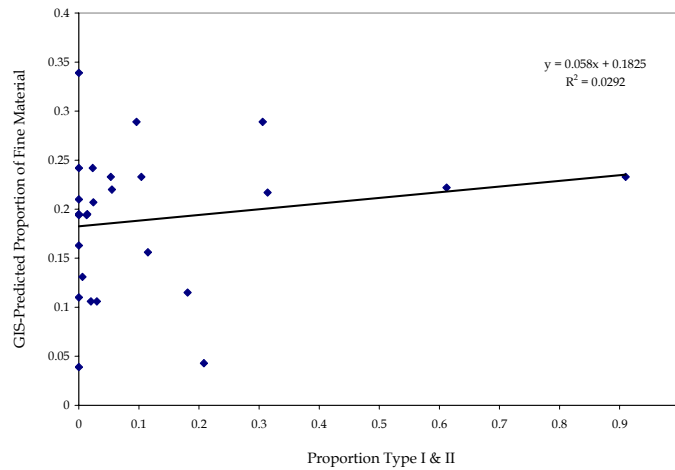


Figure 12. Comparison of SLCP assessment results on preferred ammocete habitat with estimates of proportion of fine sediments from GIS data for the same valley segments.

### ***Special Considerations or Problems Encountered***

There are several possible explanations for the lack of relationship between GIS habitat estimates and those derived from Sea Lamprey Control field collections. One of the fundamental problems may lie in our current method for calculating slope from GIS map data. As discussed above, we found poor correlation between field-estimated slopes and those generated from the DEMs, despite this being a standard technique (e.g. Meixler and Bain 1999). We attributed this to the coarse resolution of the DEM relative to that of the river dataset in addition to the fact that DEM grids are created from hypsography polylines. In other words, there is interpolation and

data aggregation involved in the conversion from line to grid format. These issues may be irrelevant over long lengths of stream (as in the GAP project), but the discrepancy between field and GIS slopes is magnified in the smaller reaches at the scale of our stream valley segments. At the end of this project, we have been able to modify the method by which we use GIS to estimate slopes. Better relationships between GIS and field estimates have been obtained when using the hypsography maps as opposed to the DEMs. Until we are able to automate the process, using this method to calculate slopes for all reaches in the Erie Basin is impossible due to the time required. A second source of complication is a possible dissimilarity between habitat estimates based on our characterization of Type I and Type II in terms of median particle size and amount of fine material. We plan to run these models using different values for the range of particle sizes that are likely to correspond with Types I/II. The third problem may be a result of the habitat assessment techniques used by the Sea Lamprey Control Program. It is also possible that the spatio-temporal scale at which they are performing these assessments may result in assessments that do not accurately reflect the amount of available habitat. Ultimately, it is for this reason that we are attempting to model habitat instead of surveying it. All of these problems are subjects on continuing work in projects leveraged by this grant.

### **Deliverable**

The product of task 2 is an extended GIS database for Lake Erie coastal watersheds. Results from the geomorphic field analyses allowed us to create:

1. A model of the proportion of fine material and cobble in each reach of the “Lake\_Accessible\_Stream\_Habitat\_OH” dataset (see Figures in Task 2), and

2. A map of reaches representing reaches likely to have larval lamprey habitat (e.g. Figure 10) and spawning habitat (e.g. Figure 11)

### **Task 3.**

Project work on the third task concerned the development of habitat preference profiles for two Lake Erie fish species with contrasting habitat requirements (Sea Lamprey, *Petromyzon marinus* and Walleye, *Sander vitreum*). Subtasks included:

1. Obtaining data summaries of walleye habitat preference and larval survival with respect to substrate, flow, and temperature regimes from published literature and other habitat preference studies;
2. Incorporating Sea Lamprey ammocete abundance patterns into GIS;
3. Analyzing relationship between abundance of Sea Lamprey ammocetes and habitat configuration; and
4. Analyzing relationship between abundance of Sea Lamprey ammocetes and spatial geometry of reach structures.

### **Activity Summary**

For Task 3.1, we relied on existing literature reviews of fish habitat preferences that have been compiled for Great Lakes fish species. Our primary source was a general review of fish habitat preference from Fisheries and Oceans Canada (Lane et al. 1995; Lane et al. 1996a; Lane et al. 1996b). Supplementing this information was a fish spawning atlas (Goodyear et al. 1982) and fish habitat database distributed by the Great Lakes Fishery Commission (Tewinkel and Dawson 1993). The basic protocol for applying these databases to classification and inventory

of Great Lakes fish habitat has also been previously documented in the literature (Minns and Bakelaar 1999; Morrisson et al. 2001).

We analyzed the lamprey abundance portions of the datasets obtained in Task 2 and determined that ammocetes tended to be longer and more abundant in sites in which the SLCP found more Type I and Type II habitat (Figure 13). We also found the extent of infestation to be greatest in stations with more Type I and Type II habitat (Figure 14). However, as discussed above, we found no correlation between these ammocete parameters and our GIS estimates of habitat (Figure 12).

### ***Special Considerations or Problems Encountered***

In addition to future methods to improve the model, which were discussed previously, it is important to consider the lampricide treatment rotation schedule into these abundance analyses. The problem is that some streams have been treated more recently and to a greater extent than others. Therefore, lamprey may not have re-colonized more recently treated stream to the same degree as those treated previously, resulting in lower abundances in more recently treated streams. By analyzing abundances measured  $x$  years after a treatment, we may be able to control for the re-colonization time. However, discrepancies may still exist due to the extent of any given treatment. Therefore, it may also be pertinent to incorporate some quantification of the degree of success of the treatment.

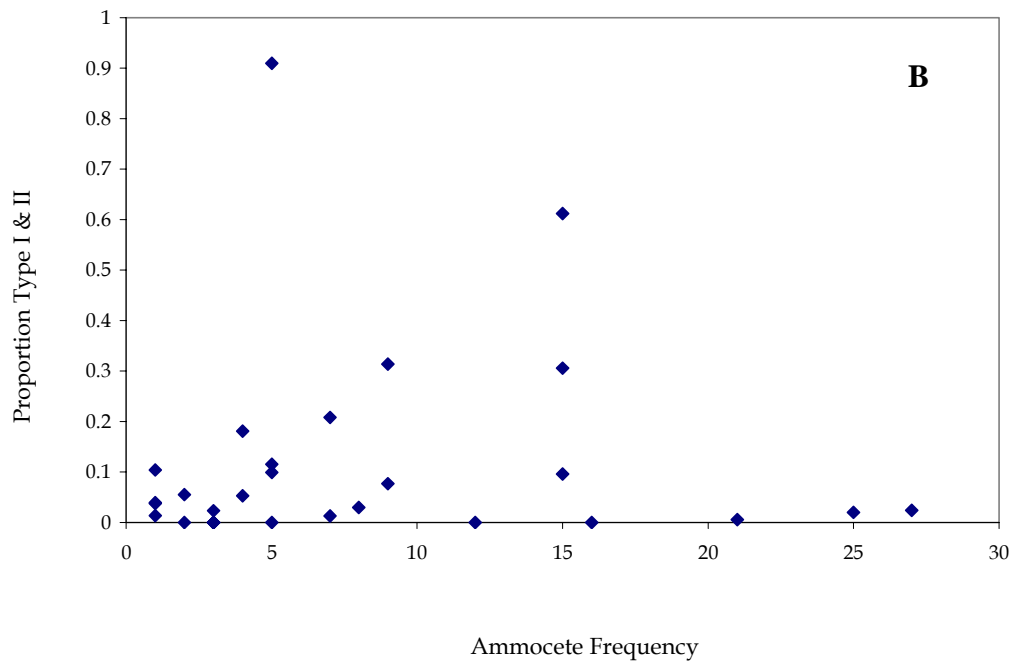
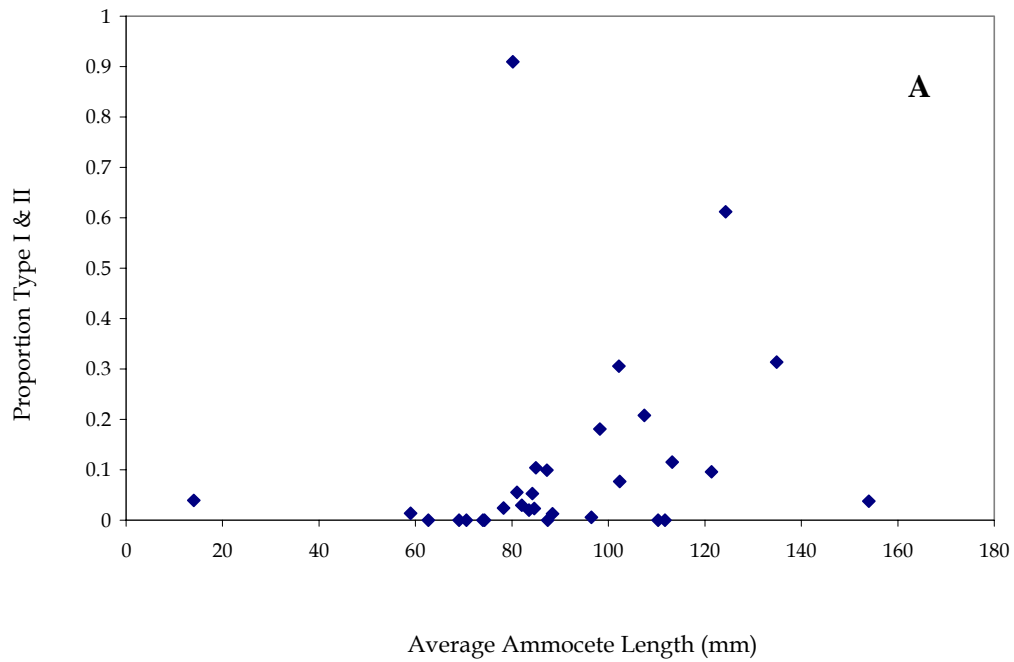


Figure 13. Relationships between ammocete length (panel A) frequency (panel B) and the proportion of Type I and II habitat as estimated by Sea Lamprey Control Program assessment biologists.

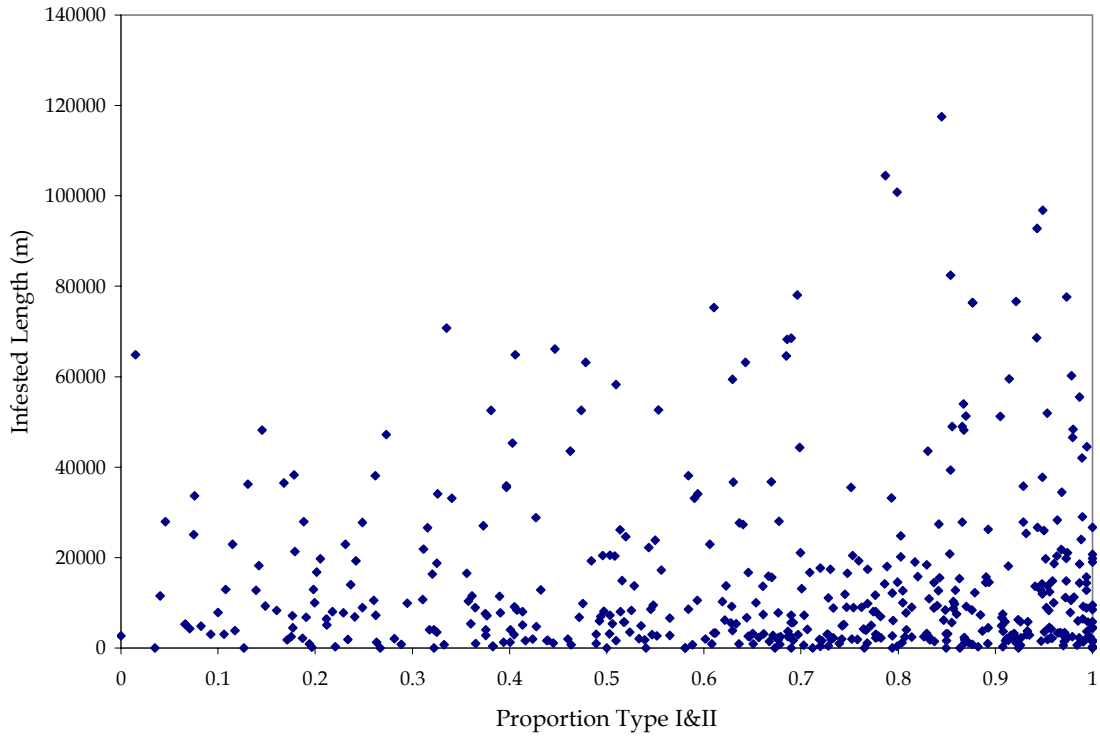


Figure 14. Relation between length of tributary infested with sea lamprey ammocetes and the proportion of the stream bed with Type I and II habitat as estimated by SLCP assessment biologists.

**Deliverable**

The linkage of assessment data from the Sea Lamprey Control Program and the valley segment database completed the habitat supply inventory for Sea Lamprey and Walleye in coastal watersheds of Lake Erie.

**Task 4**

Develop a protocol for linking land-use changes and non-point source pollution to changes in productive potential of coastal fish habitat. Subtasks will include:

- 4.1. Obtain land-use map overlays for sub-basin segments of the GIS tributary database constructed in Task 1.
- 4.2. Develop map modeling tools to relate land-use maps to fish habitat attributes in the GIS tributary database.
- 4.3. Develop links to stream segment database used in the BASINS model of non-point source pollution stress.
- 4.4. Develop protocol to predict effects of land-use changes or effects of non-point source pollution on the productivity of fish productivity in coastal watersheds.

### **Activity Summary**

Task 4.1 Landuse data, obtained from the EPA Basins files, were clipped to the subwatershed boundaries using ArcView's Geoprocessing extension and summarized by proportion of areal coverage of each landuse class for each subwatershed. See metadata table for data descriptions. Landuse data for each subwatershed could then be linked to their corresponding river reach via a unique identification code present in the reach and subwatershed shapefiles.

Tasks 4.2 and 4.3. The RF1 file of the BASINS dataset includes some morphological and biological information predominantly for the mainstem reaches of the Erie Basin. We were able to relate that information to our generated reach map by manually entering the RF1 identification code for corresponding reaches and linking the data with a relational join. Due to the coarse resolution of the RF1 maps compared to our generated streams, we were not able to conduct a simple spatial join to relate the RF1 BASINS data to the generated stream maps.

Task 4.4. Land use changes can have a wide range of effects on coastal watersheds. Because all effects will be associated on changes in runoff and associated erosion/sedimentation patterns, the focus of our protocol development was establishing a theoretical and empirical framework within which to relate changes in flow regime to habitat supply of Lake Erie fish populations. Although analysis of the consequences of land use changes was not an objective of this research project, the development of a linking-framework is necessary for assessment of the effects of land use changes on the aquatic ecosystems of the Lake Erie coastal watersheds and on the productivity of the Lake Erie fish community. As outline in our proposal, we chose to develop the protocol for two Lake Erie fish species that have different types of habitat requirements in coastal watersheds. Walleye (*Sander vitreum*) is an obligate piscivore in the Lake Erie fish community and a species of high importance to Lake Erie fisheries. River run subpopulations of walleye use tributaries for spawning and hatched larvae return to the lake for nursery habitat. In contrast, sea lamprey (*Petromyzon marinus*) use tributary for a major portion of their life history. Adults spawn in tributaries and larvae (ammocetes) burrow in soft sediments of the tributaries, where they will spend two to three or more years as ammocetes before undergoing a metamorphosis to a parasitic phase and migrating back to the lake.

#### Walleye Analyses

Walleye utilization of tributary habitat is restricted to short periods of spawning and egg hatch. Geological and fluvial processes affect availability of spawning habitat and successes in larval hatching are strongly influenced by temperature and flow. According to Minns et al. (1996), habitat availability exerts its influence on survival through a saturation curve. "In each life-stage, the density-dependent mechanisms are assumed to follow a saturation curve. The

basic form of the saturation curves uses actual suitable area scaled against predicted ideal requirements to predict proportional achievement of population process rates key to each life stage:  $\text{actual}/(\text{actual} + \text{required})$  declines as the required space increases relative to actual supply." Minns et al (Minns et al. 1996) use a general functional response curve to scale the shape of the saturation curve:

$$p = \frac{\text{actual}^b}{\text{actual}^b + a \cdot \text{required}^b}, \quad (1)$$

where "a" is a scaling factor for the required area and "b" is a power used to alter the shape of the curve.

To apply the approach of Minns et al.(Minns et al. 1996), we assume that the density-dependence of recruitment on habitat will be a function of the actual area available per individual, i.e. the inverse of the density of the first life-stage, which spans egg deposition, hatching, and early larval development. For each species, we assume that we can estimate the spawning and nursery habitat area and their suitability. Actual availability of habitat is thus

$$\text{actual} = \frac{\text{HSI}}{N}, \quad (2)$$

where HSI is the cumulative area of suitable habitat weighted by a quality index and N is the number of individuals using the habitat. Assuming that an optimum exists for the area per individual (R), the optimum number of individuals becomes:

$$N' = \frac{\text{HSI}}{R}. \quad (3)$$

Based on equations 2 and 3, we can modify equation 1 to obtain:

$$\begin{aligned}
 p &= \frac{\left(\frac{\mathbf{HSI}}{\mathbf{N}}\right)^b}{\left[\left(\frac{\mathbf{HSI}}{\mathbf{N}}\right)^b + \left(\frac{\mathbf{HSI}}{\mathbf{N}'}\right)^b\right]} \\
 &= \frac{\left(\frac{\mathbf{1}}{\mathbf{N}}\right)^b}{\left[\left(\frac{\mathbf{1}}{\mathbf{N}}\right)^b + \left(\frac{\mathbf{1}}{\mathbf{N}'}\right)^b\right]}
 \end{aligned}
 \tag{4}$$

With the formulation of the saturation curve in equation 4, N' becomes the abundance at which the first life-stage survival decreases to 50%. Figure 15 illustrates the effects of habitat availability on potential survival and recruitment of walleye.

Habitat exerts an influence at various stages of the walleye life cycle. Minns et al (Minns et al. 1996) have argued that habitat availability will produce an effect like Figure 15 at spawning, during larval and juvenile development, and during adult stages. However, only one stage will act as a "bottleneck" and provide the regulating density dependent mortality. At the larval stage, Mion et al. (1998) have shown that flow rates directly affect larval mortality of walleye. At high discharge rates, scouring appears to cause physical damage to fragile larvae, but at low discharge rates resident times in the river may exceed the interval available for yolk sac metabolism. If larval walleye do not reach nursery areas before yolk sac metabolism is completed, larvae will suffer starvation mortality.

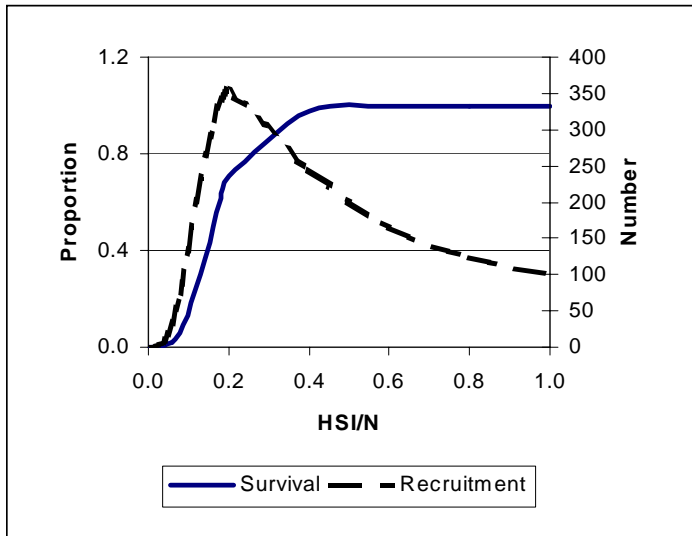


Figure 15. Effect of habitat availability on survival and recruitment of walleye.

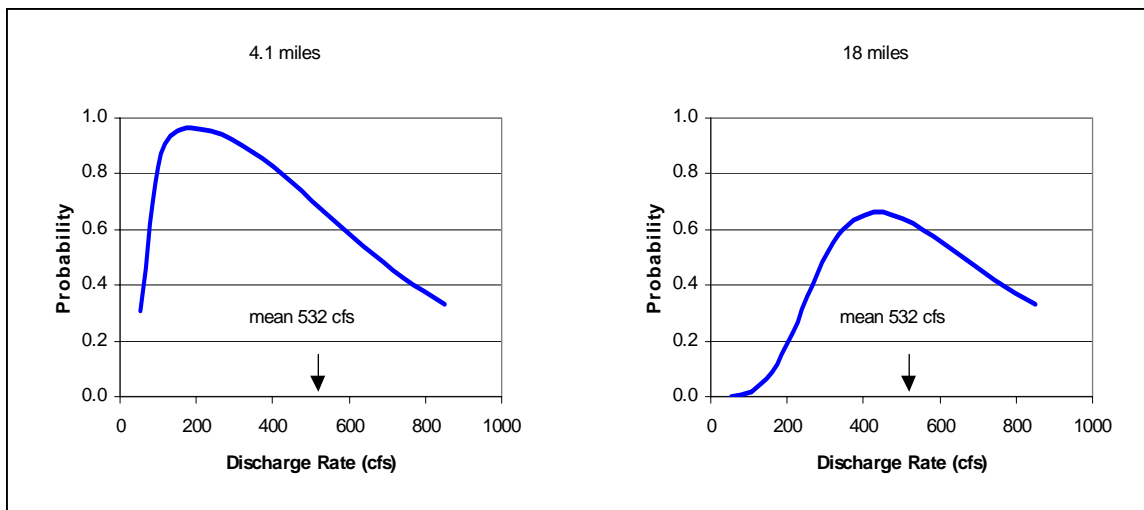


Figure 16. Illustration of the effect of river discharge rate on larval walleye. Calculations are based on observed flows in the Chagrin River and follow Jones et al. (Jones et al. in press) model based on the research of Mion (Mion et al. 1998). The curves are for two lo

## ***Potential Cumulative Impact of Habitat Alteration on Fisheries***

Recent research supports the existence of effect of habitat on fish population dynamics. The important factors are the availability of suitable habitat for various life history stages and the effects of tributary hydrology on the connection of spawning and nursery areas. The U.S. Geological Survey has data for mean daily flow rates in the Chagrin River from 1927 to the present. Figure 17 summarizes flow hydrograph data for spring periods for a dry year, 1935, and a wet year, 1984. The patterns of peak and base flow clearly vary with climate, but optimal survival occurs at moderate discharge rates, which are nearer base flow conditions. Because development within the watershed, particularly development that affects runoff intensity, can alter the base flows and flood frequency, the results in Figure 16 imply that land-use changes that increase impervious surface area of the watershed will adversely affect walleye reproduction. The impact of this effect may be small for any single tributary. The forces driving watershed development, however, are regional and there may be a cumulative impact of development in the Lake Erie watershed.

To judge the possible cumulative impact of alteration of available habitat and flow regimes of tributaries, we modified the Lake Erie Ecological Model (Koonce et al. 1999) to include an effect of habitat supply on walleye reproduction. The model developed by Minns et al. (1996) applies equation 4 to three life-history phases (spawning, fry, and age one and older). They estimate the individual area required for each stage, and implement the density-dependent mechanism implicit in equation 4. Applying habitat supply for each life-history stage provides a way of understanding habitat "bottlenecks" that limit population size. In their model, Minns et al. (1996) found only one bottleneck limits the population at a time.

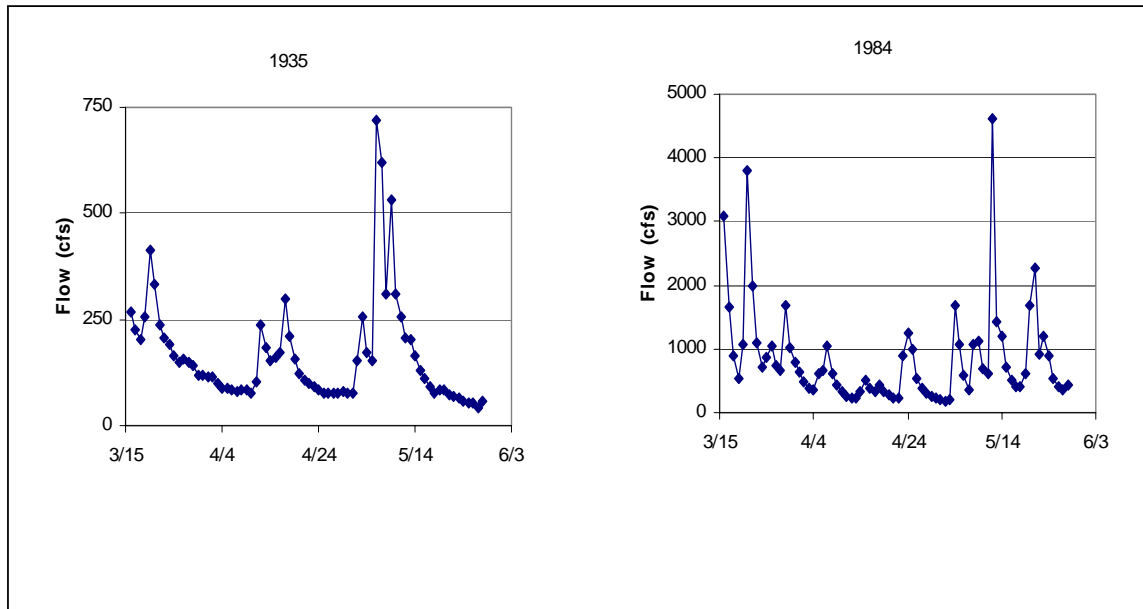


Figure 17. Examples of mean daily flow rates for the Chagrin River from mid-March until June. 1935 is a wet year and 1984 a dry year. Mean daily flow during spring is 532 cfs for the period 1927 to 1995.

LEEM is a more complex model than that of Minns et al. (1996). The density-dependent mechanism of equation 4, for example, already exists in the predator prey dynamics of LEEM. By contrast the Minns model is only for a single species, and the density-dependent regulation of growth and mortality of each age group must include equation 4 explicitly. However, the annual time step of LEEM does not adequately capture the dynamics of the regulation of growth and mortality of the first year of life of simulated fish species. We accommodate this shortfall by simulating YOY (Young-of-the-Year) feeding interactions as a function of the geometric mean size of YOY and by assuming that survival from egg to the fry stage is a stochastic function of habitat area for completion of spawning and larval development. Because a single bottleneck will emerge from these two types of habitat supply, we can apply equation 4 to estimate mean survival of the early life history.

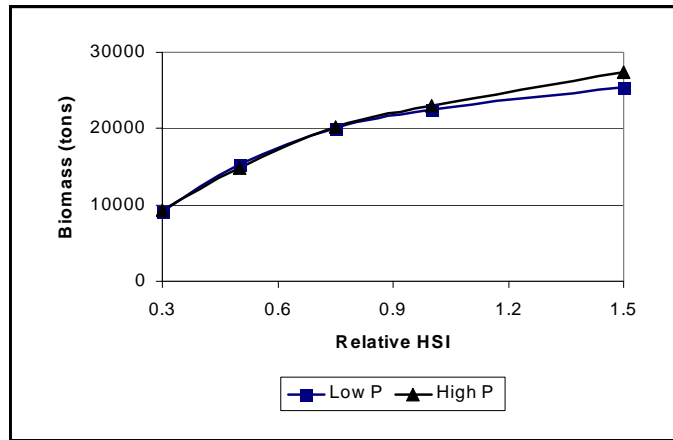


Figure 18. Comparison of LEEM predictions of mean annual walleye abundance for a 5-fold variation in habitat availability for 2 levels of phosphorus loading. Phosphorus loadings reflect a 5-fold range of variation.

Figure 18 is a comparison of 5-fold variation of phosphorus loading and habitat supply. Both ranges of variation are scalar multiples (0.5 to 2.5) using current conditions as a baseline. Phosphorus loading response relative to other variables had been reported by Koonce et al (1999) and Locci and Koonce (1999). These results suggest that walleye abundance may be far more sensitive to habitat supply than to phosphorus loading with nearly a 3-fold greater variation in mean annual abundance of walleye than in response to the same magnitude of variation in phosphorus loading. The magnitude of this difference in response to habitat changes and phosphorus loading, however, is uncertain. Without a complete habitat supply inventory for Lake Erie, estimates of the range of variation likely from changes in land-use practices is speculative. Nevertheless, these results suggest that walleye abundance is at least as sensitive to variation in habitat supply as phosphorus loading.

Using the protocol outlined above, it is possible to identify locations and amounts of the most productive walleye spawning habitat in Lake Erie coastal watersheds. Figure 19

summarizes the types of predictions possible with this protocol. Represented in the figure are the stream segments with high amounts of spawning habitat and the best probability of surviving transport to the lake under conditions of low flow. This figure shows the linkage of water quality data in the EPA RFI database with the stream segment database developed in this project.

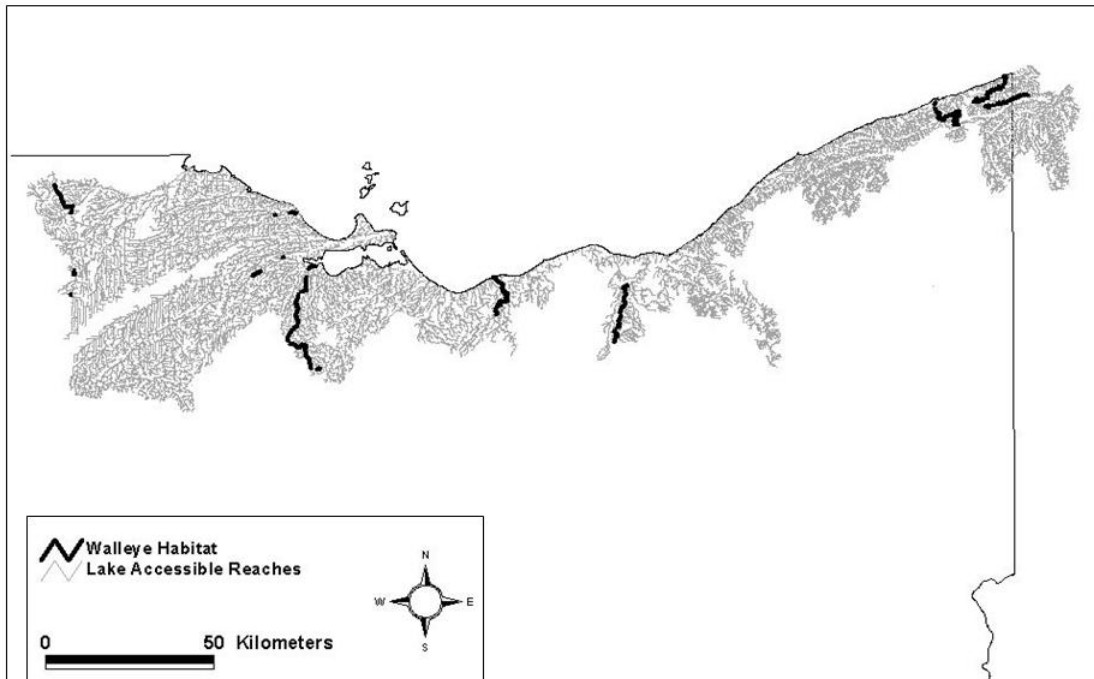


Figure 19. Figure showing distribution of walleye spawning habitat having high probability of larval survival at low flow conditions.

### Sea Lamprey Analyses

In contrast to walleye, the protocol for relating sea lamprey habitat to flow regime is much simpler. The distribution and abundance of sea lamprey ammocetes is directly related to the availability of fine sediments. As discussed above, we have developed estimates for the amounts and distribution of spawning and ammocete habitat from GIS map layers. Figure 20

shows the predictions of the distribution of these two categories of habitat in Ohio coastal watersheds.

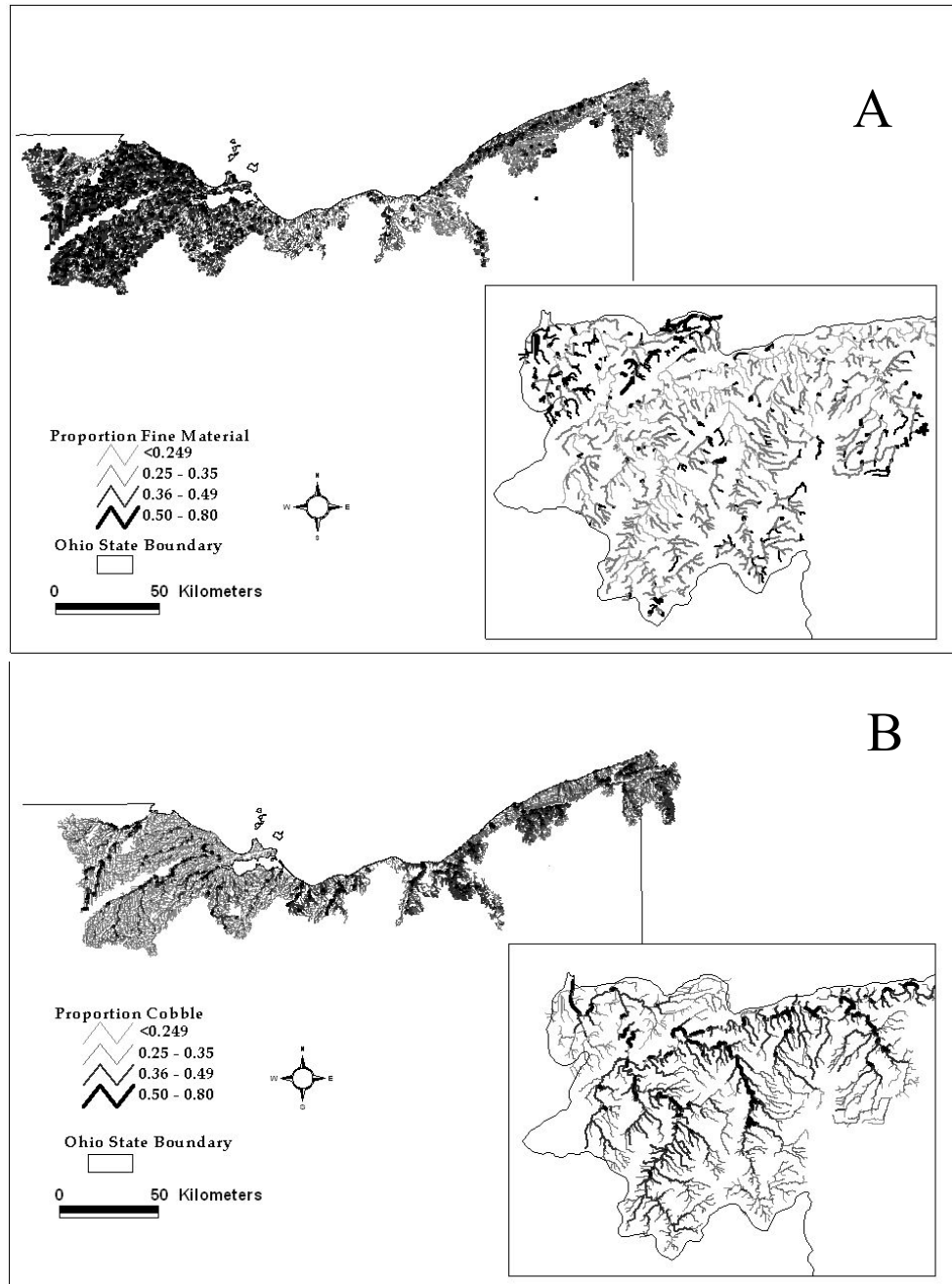


Figure 20. Prediction of larval and spawning habitat availability for sea lamprey in Ohio Lake Erie tributaries from GIS attributes of stream segments.

## **Deliverables**

The product of this work is a scientifically defensible protocol for linking land-use changes and non-point source pollution to productivity of Lake Erie coastal fish habitat.

Output files from Task4 include:

1. “Subwatershed\_Landuse\_OH” – a map of the subwatersheds generated for each reach with information about proportions of landuse class
2. “RF1\_Link\_to\_Generated\_Streams” – a table of the generated stream IDs with a field including the corresponding RF1 code
3. Lake\_Accessible\_Walleye\_Survival\_OH – a map of lake accessible stream segments with corresponding RF1 data; includes predictions of walleye survival for each reach

## **Task 5**

The final task of the project focused on transferring the GIS databases and protocols for linking land-use and effects of non-point source pollution on Lake Erie coastal fish productivity. We planned to communicate results through a series of workshop/demonstrations for local planning agencies and resource management agencies and through presentations at scientific meetings. Scientific publications of this work are in preparation.

## **Activity Summary**

The following list summarizes scientific and technical presentations of this research:

- Oral Presentation – *Evaluation of GIS-based habitat supply inventory of Lake Erie Tributaries*. Gorman, A.M., Y. Chang, J.M. White, and J.F. Koonce. Ohio Fish & Wildlife Conference, Columbus, Ohio. February 3, 2002.

- Oral Presentation – *GIS-based approach to predicting larval habitat in the Great Lakes tributaries*. Gorman, A.M., Y. Chang, J.M. White, and J.F. Koonce. Meeting of the Larval Assessment Task Force, Sea Lamprey Control Program, Marquette Biological Station, MI. September 17, 2002.
- Oral Presentation – *GIS-based approach to predicting lamprey habitat in the Great Lakes tributaries*. Case Western Reserve University, Cleveland, Ohio. Gorman, A.M., Y. Chang, J.M. White, and J.F. Koonce .October 17, 2002.
- Oral Presentation - *Modeling larval lamprey habitat in the Great Lakes tributaries using GIS*. Gorman, A.M., Y. Chang, J.M. White, and J.F. Koonce. Ohio Fish & Wildlife Conference, Columbus, Ohio. February 7, 2003.
- Poster Presentation - *Targeting Lamprey Habitat Using GIS*. Gorman, A.M., Y. Chang, J.M. White, and J.F. Koonce. Ohio Geospatial Technology Conference, Columbus, Ohio. March 24-26, 2003.
- Demonstration - *Using GIS for Smart Growth*. Koonce, J.F. and A.M. Gorman. GIS Technology Conference: Sustaining the Future & Understanding the Past, Case Western Reserve University, Cleveland, Ohio. October 9-10, 2003.

Our planning for public presentation of our work took an unexpected turn with the Dr. Koonce's participation in the Ohio Governor's Blue Ribbon Panel on Sustainable Development in the Lake Erie Basin. A major goal of this panel was to devise methods for identification of priority conservation areas and priority development areas. Designation of conservation areas requires methods for relating land use changes to effects on aquatic ecosystems generally and Lake Erie specifically. Project products and procedures were shared with staff of the Panel on several occasions and, in particular, we

Supplied data and maps to David Beach for the October 14, 2003 meeting of the Blue Ribbon Panel showing how the map overlays could be applied to use GIS for evaluation of Smart Growth alternatives.

Another unexpected outcome of the research in this project was its contribution to the successful funding of a major EPA project that integrated ecological risk analysis of the Lake Erie fish community with stresses of changing land use patterns in coastal watersheds. A project titled, "Developing Regional-Scale Stressor-Response Models for Use in Environmental Decision-making," was funded (\$750,000) by the EPA STAR program for a three-year joint project between Case Western Reserve University and Johns Hopkins University. The proposed work will allow full implementation of the protocols developed in this project.

The objective of this funded research is to develop a regional-scale, stressor-response model for the management of the Lake Erie ecosystem. Stressors addressed will include effects of land use changes and Total Maximum Daily Load (TMDL) targets for nutrients, habitat alteration, and natural flow regime modification at the scale of individual watersheds coupled with whole-lake ecosystem effects of invasion of exotic species and fisheries exploitation. Model predictions will focus on effects of stressors on production and abundance of Lake Erie

fish populations as indicators of the health of the Lake Erie ecosystem and will be incorporated into a multiobjective decision making tool for use by Lake Erie water quality and fisheries managers along with other resource planners.

The project builds on previous STAR funding (R825150) research on joining ecosystem modeling with multiobjective risk decision tools and the results of the Ohio Coastal Management Assistance Grants Program. The new project will engage research to: 1) link changes in watershed habitat and nutrient loading regimes proposed for the TMDL process to Lake Erie ecosystem health; 2) quantify uncertainties in model predictions and determine the effects of uncertainties on management decisions; 3) evaluate interaction of stressors, particularly focusing on cross-scale additivity of stressors; 4) develop tools to evaluate ecological risk of land-use changes in watershed of the Lake Erie ecosystem; and 5) identify and evaluate critical breakpoints in ecosystem integrity of the Lake Erie ecosystem and of its integrated management.

This research will result in improved understanding of the importance of habitat and nutrient loading constraints to productivity and biodiversity of fish populations in the Great Lakes. Using fish communities as indicators of ecosystem health, the model provides an essential element in linking habitat changes to ecosystem effects. This research will also contribute to more general understanding of how fine-scale processes develop into larger-scale phenomena. Models developed in this study will integrate habitat supply information in an ecosystem context, relating habitat constraints to important fishery resources. These models will be valuable tools for assessing the potential impacts of habitat management on fish community indicators. The indicators, methodologies, and applications developed will also contribute to the goal of improving ecosystem management by developing tools that will help environmental managers in the Great Lakes to understand the probable consequences and causes of changes in

landscape attributes and conditions, and by demonstrating how the understanding can be used in ecosystem management.

## References

- Goodyear, C. S., and coauthors. 1982. Of the spawning and nursery areas of great lakes fishes. U. S. Fish and Wildlife Service, FWS/OBS-82/52, Washington, DC.
- Jones, M. L., J. K. Netto, J. D. Stockwell, and J. B. Mion. in press. Does the value of newly accessible spawning habitat for walleye (*stizostedion vitreum*) depend on its location relative to nursery habitats? *Can. J. Fish. Aquat. Sci.*
- Koonce, J. F., A. B. Locci, and R. L. Knight. 1999. Contribution of fishery management in walleye and yellow perch populations of lake erie. Pages 397-416 *in* W. W. Taylor, and C. P. Ferreri, editors. Great lakes fisheries policy and management. A binational perspective. Michigan State University Press, East Lansing.
- Lane, J. A., C. B. Portt, and C. K. Minns. 1995. Nursery habitat characteristics of great lakes fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 0(2338):I-V 1-42.
- Lane, J. A., C. B. Portt, and C. K. Minns. 1996a. Adult habitat characteristics of great lakes fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 0(2358):I-V 1-43.
- Lane, J. A., C. B. Portt, and C. K. Minns. 1996b. Spawning habitat characteristics of great lakes fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 0(2368):I-V 1-48.
- Leopold, L. B., and T. Maddock. 1953. The hydraulic geometry of stream channels and some physiographic implications, volume 252. US Government Printing Office, Washington, DC.

- Locci, A. B., and J. F. Koonce. 1999. A theoretical analysis of food web constraints on walleye dynamics in lake erie. Pages 497-510 in M. Munawar, T. Edsall, and I. F. Munawar, editors. State of lake erie. Past, present, and future. Backhuys Publishers, Leiden, Netherlands.
- Meixler, M. S. and M. B. Bain. 1999. Application of GAP Analysis to New York State waters. Final project report by the New York Cooperative Fish and Wildlife Research Unit, Cornell University, Ithaca, NY to the U. S. Geological Survey, GAP Analysis Program.
- Minns, C. K., and C. N. Bakelaar. 1999. A method for quantifying the supply of suitable habitat for fish stocks in lake erie. Pages 481-496 in M. Munawar, T. Edsall, and I. F. Munawar, editors. State of lake erie. Past, present, and future. Backhuys Publishers, Leiden, Netherlands.
- Minns, C. K., R. G. Randall, J. E. Moore, and V. Cairns. 1996. A model simulating the impact of habitat supply limits on norther pike, *esox lucius*, in hamilton harbour, lake ontario. Can J. Fish. Aquat. Sci. 53(Suppl. 1):20-34.
- Mion, J. B., R. A. Stein, and E. A. Marschall. 1998. River discharge drives survival of larval walleye. Ecological Applications 8:88-103.
- Montgomery, D. R., and J. M. Buffington. 1998. Channel processes, classification, and response. Pages 13-42 in R. J. Naiman, and R. E. Bilby, editors. River ecology and management: Lessons from the pacific coastal ecoregion. Springer-Verlag, New York.
- Morrisson, H. A., C. K. Minns, and J. F. Koonce. 2001. A methodology for indentifying and classifying aquatic biodiversity investment areas: Application in the great lakes basin. Aquat. Ecosys. Health and Man 4(1):1-12.

Tewinkel, L., and K. Dawson. 1993. Fish habitat database great lakes fishery commission. Great Lakes Fishery Commission, Ann Arbor, MI.

<http://www.glfsc.org/fishmgmt/habitat/contents.htm>.

Whiting, P. J., and J. B. Bradley. 1993. A process-based stream classification system. *Earth Surf. Proc. Landforms* 18:603-612.

Whiting, P. J., J. F. Stamm, D. B. Moog, and R. L. Orndorff. 1999. Sediment-transporting flows in headwater streams. *Geol. Soc. of Amer. Bull.* 111(3):450–466.

Wolman, M. G. 1954. Method of sampling coarse river bed material. *EOS* 35:951-956.

## Final Financial Report: 8/1/03 -9/30/03

Category	Authorized Budget		Current Invoice		Invoiced to Date		Balance
	Costal	Match	Costal	Match	Costal	Match	Costal
Salaries	\$24,954.00	\$29,282.00	\$8,115.00	\$5,249.00	\$25,701.79	\$40,765.18	(\$747.79)
Fringe	\$3,949.00	\$7,027.00	\$2,069.32	\$1,338.50	\$4,109.07	\$10,230.22	(\$160.07)
Travel	\$2,050.00		\$876.30		\$2,132.50		(\$82.50)
Supplies	\$3,750.00		\$569.09		\$2,504.55		\$1,245.45
Equipment	\$3,550.00				\$3,522.80		\$27.20
Contractual							\$0.00
Other					\$10.03		(\$10.03)
Direct Costs	\$38,253.00	\$36,309.00	\$11,629.71	\$6,587.50	\$37,980.74	\$50,995.40	\$272.26
Indirect Costs	\$8,671.00	\$10,893.00	\$3,055.30	\$1,976.25	\$8,943.26	\$15,298.62	(\$272.26)
TOTAL	\$46,924.00	\$47,202.00	\$14,685.01	\$8,563.75	\$46,924.00	\$66,294.02	(\$0.00)

## CD Contents

### Tables

1. Metadata Table.xls
2. RF1\_Link\_to\_Generated\_Streams.dbf
3. Lake\_Erie\_Rf1s\_17\_Ohio.dbf

### Geodata (Projection UTM Zone 17, NAD27):

1. Coastal\_Streams\_OH.shp
2. Coastal\_Subwatersheds\_OH.shp
3. Subwatershed\_Landuse\_OH.shp
4. Lake\_Accessible\_Stream\_Habitat\_OH.shp
5. Lake\_Accessible\_Walleye\_Survival\_OH.shp