CHAPTER 56

GIS in Support of Ecological Indicator Development

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56.1 Introduction

Concern over environmental degradation has prompted establishment of ecological monitoring programs, but measuring and interpreting the myriad factors that influence or respond to environmental quality is impossible. Ecological indicators, defined as "a measure, an index of measures, or a model that characterizes an ecosystem or one of its critical components," have increasingly been used by monitoring programs to optimize their ability to detect environmental degradation (Jackson et al. 2000; Kurtz et al. 2001). Ecological indicators can be used to assess the condition of the environment, to provide an early warning signal of changes in the environment, or to diagnose the cause of an environmental problem (Dale and Beyeler 2001; Niemi and McDonald 2004). Indicators may characterize anthropogenic stress or ecological responses to stress, and may reflect biological, chemical, or physical attributes of ecological condition.

Geographic information system (GIS) technology can be instrumental in various aspects of the development and testing of ecological indicators (Johnston 1998). This chapter provides a case study of how GIS was used in the Great Lakes Environmental Indicators (GLEI) project, which had the overall goal of developing indicators of ecological condition for the US coastal region of the Laurentian Great Lakes. This chapter primarily illustrates the use of GIS in support of a massive field observational study designed to develop indicators from field measurements of a variety of many biota: plants, diatoms, fish, aquatic macroinvertebrates, birds, and amphibians. Particular emphasis was placed on the role of GIS in sampling design (deciding what sites to sample), response design (how to sample at a site), and calculating independent variables for statistical analyses. A secondary focus of this chapter is to demonstrate the use of GIS for landscape scale indicators.

Given that the Great Lakes basin is huge and spans four UTM zones (15, 16, 17, and 18) and 767,000 km^2, special consideration had to be given to a map projection that could be consistently applied across the region. An Albers Equal-Area Projection was adopted, which is a conic projection that uses two true-scale standard parallels, and is well suited for land masses that extend in an east to west orientation. All GLEI Project GIS databases used the following geographic format combination:

- Albers Equal-Area Projection
- North American Datum 1983 (NAD83)
- Geodetic Reference System of 1980 (GRS80), and
- Map units in meters

Custom parameter specifications used by the GLEI Project were:

- Central Meridian: – 96
- Reference Latitude: 23
- Standard Parallel 1: 29.5
- Standard Parallel 2: 45.5
- False Easting: 0
- False Northing: 0

All GIS analyses for the GLEI Project were done with ArcView™ 3.3 and ArcInfo™ (ESRI, Redlands, Calif.), with the aid of various extensions, Avenue™ scripts and macros written with the Arc Macro Language (AML).

56.2 Dividing Coast and Basin into Units for Study Site Selection

An initial challenge to developing ecological indicators was to subdivide the US Great Lakes shoreline into meaningful units for field sampling that could be used to develop indicators. This was a daunting task, given that the US Great Lakes shoreline spans a distance of 17,017 km (Botts and Krushelnicki 1987). An important starting point was to conceptualize the geographic extent of the coastal ecosystems being studied, as well as the geographic extent of areas that could influence coastal systems but were not necessarily part of the coast. The following terminology was developed:

- Sampling domain – the maximum extent of the area within which field sampling will occur.
- Field site – the target ecosystem actually sampled, usually an individual wetland.
- Sampling locations – points, quadrats or transects within the sampling unit where actual field measurements were made.
- Stressor domain – area that is a source of anthropogenic stress to the sampling domain, which usually extends beyond the sampling domain (such as a watershed or an airshed). Stresses are physical, chemical, or biological entities that can bring about adverse ecological changes in ecosystem properties (US EPA 1998).

For coastal wetlands, the sampling domain has a subaqueous component in shallow waters lakeward of the shoreline, and a shoreland component landward of the shoreline (Figure 56-1). In the GLEI Project, the limits of the sampling domain varied by the response organism being sampled. For example, the lakeward limit for the wetland vegetation team was the limit of emergent hydrophytic vegetation (Reed 1988), but the lakeward limit for the fish team was determined by water depth rather than the presence of vegetation. GIS databases depicting subaqueous features were less common than those depicting terrestrial features, so the availability of GIS data differed across the sampling domain.

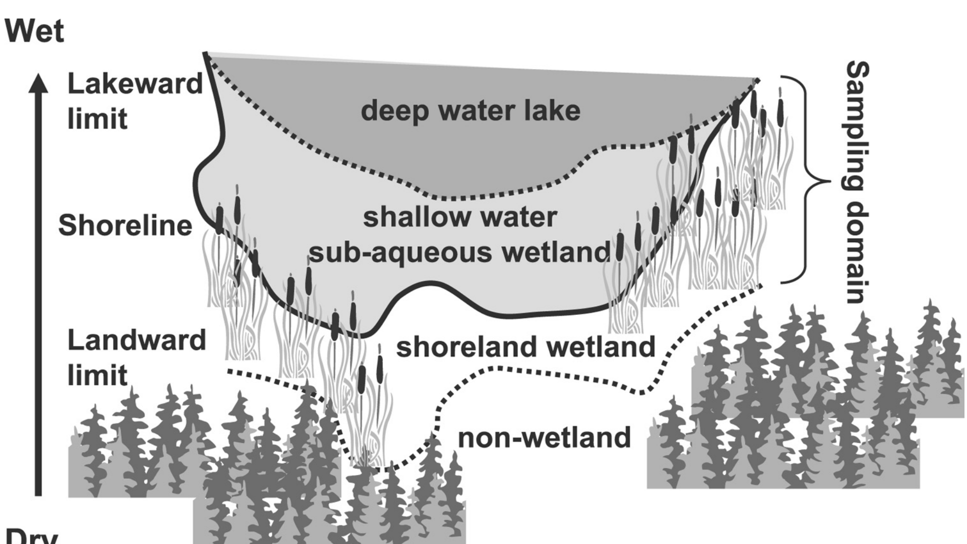

Figure 56-1 The sampling domain for coastal wetlands includes areas that are lakeward and landward of the shoreline.

56.2.1 Shoreline Segments

The shoreline between lake and land was a key feature of our sampling domain, and one which is depicted on multiple GIS data sources. The GLEI project utilized a shoreline depiction that was part of the US EPA River Reach File 3 (RF3, http://www.epa.gov/waters/doc/rfindex.html), modified to classify Strahler (1957) stream orders, obtained from the US Environmental Protection Agency National Health and Environmental Effects Research Laboratory in Corvallis, Oregon (Olsen 2001). This modified database allowed us to identify all streams of second order or larger that drained into the Great Lakes, which was why it was chosen over other possibilities (e.g., the National Hydrography Dataset). The nodes of intersection between stream mouths and the shoreline were used to subdivide the shoreline into reaches, and each reach was bisected using a custom computer program written in Avenue™ (ESRI, Redlands, Calif.). The two reach halves on either side of a stream mouth were then combined into a shoreline "segment" (Figure 56-2) This process resulted in 762 segments of the Great Lakes shoreline from the Minnesota–Canada border to Cape Vincent, New York-, on Lake Ontario.

56.2.2 Segment-Sheds

The stressor domain was considered to be all land draining to the shoreline, which was defined topographically using the National Elevation Dataset (http://ned.usgs.gov/) (Gesch et al. 2002). Stressor domain subdivisions, called "segment-sheds," were also defined topographically as the area of land draining to each shoreline segment (Danz et al. 2005). The segment-sheds ranged in area from a 0.3 km^2 segment-shed surrounding an unnamed stream on Lake Huron to the 16,938 km^2 Maumee River segment-shed in Ohio, Indiana, and southern Michigan, draining to Lake Erie.

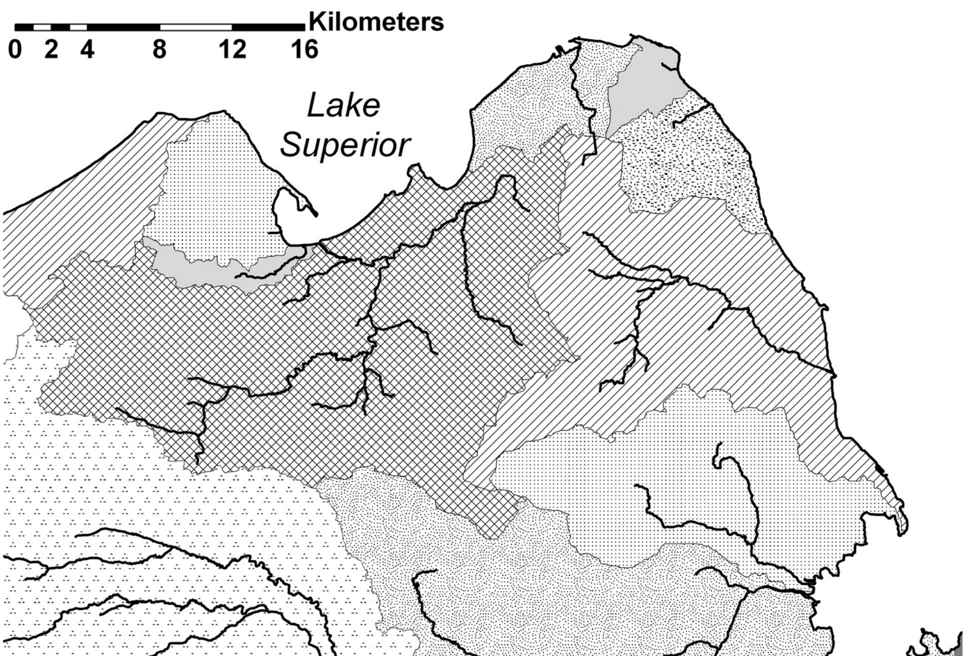

Figure 56-2 Example segment sheds draining to Lake Superior and the St. Mary's River near Sault Ste. Marie, Michigan. Each segment shed consists of the drainage area surrounding a second order-or-higher stream.

An online “segment browser” was developed as a graphical interface to provide the field biologists with a geographical context for each segment. Each shoreline segment and segment-shed was displayed in a GIS on a choice of two backgrounds, a digital raster graphic or a digital orthophotoquad, and converted to a jpeg snapshot of the composite image. The resultant four images were posted to a web interface that could be browsed online. Although the segment browser was not as versatile as an interactive map server, it provided a GIS-derived product that could be displayed quickly over the internet and required no GIS expertise.

56.2.3 Coastal Wetlands

Wetlands were the main coastal ecosystem of interest, so wetland databases were obtained for the eight Great Lakes states (Table 56-1). Digital products from the National Wetland Inventory (NWI) were deemed most useful because of their detail and relative consistency across the region. Digital versions of Michigan’s National Wetland Inventory maps were not available through NWI, but a preliminary digital version was available from the Michigan Geographic Data Library, in which quadrangle coverages had been mapjoined into county coverages. The state of Wisconsin had conducted its own wetland inventory, which was similar to NWI (Johnston and Meysembourg 2002), and digital copies of the Wisconsin Wetlands Inventory for the Great Lakes drainage basin were obtained through a cooperative agreement with the US EPA. The NWI maps for most of Ohio had not been digitized, so the raster Ohio Wetland Inventory (OWI) had to be used. The OWI was derived from 1987 Landsat Thematic Mapper satellite imagery, and utilized only six wetland classes: wet forest, open water, shallow marsh, shrub/scrub wetland, wet meadow, and farmed wetland. The digital wetland maps were used as a source of data in the selection of field sites because wetlands were the sampling domain for most of the teams studying the different biota groups.

Table 56-1 Wetland GIS databases used by the GLEI project.

State	Source	URL
Minnesota, Illinois, Indiana, New York, Pennsylvania, small portion of Ohio	National Wetlands Inventory	http://www.nwi.fws.gov/
Wisconsin	Wisconsin Wetlands Inventory	http://dnr.wi.gov/wetlands/mapping.html
Michigan	Michigan Geographic Data Library	http://www.mcgi.state.mi.us/mgdl/
Ohio	Ohio Wetlands Inventory	http://www.dnr.state.oh.us/gims

56.3 Characterizing Anthropogenic Stress Gradients for Study Site Selection

Understanding the relationship between human activity and ecological response is essential to the process of indicator development; an indicator is not useful unless it varies predictably across a gradient of stress (Dale and Beyeler 2001). Although potential indicators can be shown to be responsive to stress in laboratory or field experiments, for large observational studies the best way to demonstrate responsiveness is by evaluating the potential indicator at sites along a gradient from relatively pristine to highly disturbed (US EPA 1998). Thus, different levels of stress must be present in the sample.

The goal of site selection was to obtain an unbiased group of sampling units that were suitable for developing indicators of ecological condition and represented the full range of anthropogenic stress across the Great Lakes (Danz et al. 2005). The segment-shed was the geographic unit used as the basis for characterizing stress in the site selection process.

Environmental profiles were created for each segment-shed to ensure that field sampling sites were distributed across the stressor and environmental gradients in the Great Lakes basin. Using primarily public sources, we collected GIS data for seven categories of human disturbance and environmental variation (Table 56-2), summarizing values by segment-shed for a total of 207 variables. For each variable, a single value was computed for each of the 762 segment-sheds (Figure 56-3).

GIS methods for computing segment-shed values for the individual stressor variables varied according to the data aggregation of the original data source. Only one raster GIS database was used—the National Land Cover Dataset (NLCD), which is a continuous grid of 30 m × 30 m pixels. The original data were subdivided by segment-shed boundaries, and land cover classes were summarized as a proportion of segment-shed area (e.g., proportion of evergreen forest, proportion of high intensity residential).

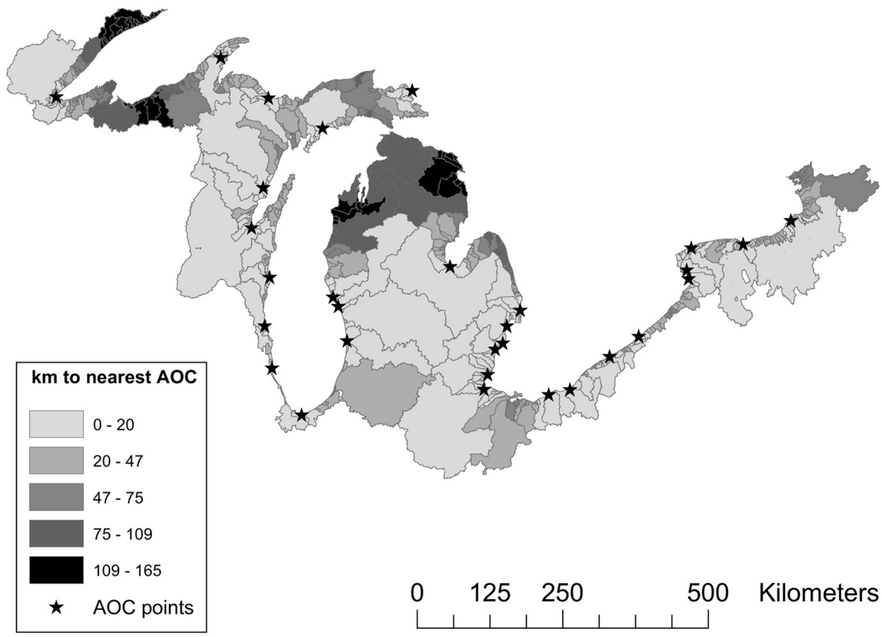

Figure 56-3 The 762 GLEI segment-sheds, categorized by distance to nearest Area of Concern (AOC).

Point data sets were summarized by segment-shed in several different ways, depending on point density and data type. Point data obtained from the US EPA Toxic Release Inventory (TRI) consisted of 5,681 facility locations (points) throughout the US Great Lakes basin, for which there were 1,789,063 records for discharges of 330 chemicals (Figure 56-4). The TRI and the EPA's National Pollutant Discharge Elimination System (NPDES) data set was summarized as a count of the number of facilities per unit area of segment-shed. Point locations of mines, mine processing plants, and electric power plants were summarized as a count of the number of facilities in the segment-shed divided by the unit length of shoreline segment. Point measurements of atmospheric deposition collected at monitoring stations of the National Atmospheric Deposition Program (NADP) (Figure 56-5) were obtained for the year 2000. Because these data were widely scattered, they were interpolated and averaged for each segment-shed (Kg ha^{-1} yr^{-1}). Point locations of Great Lakes "Areas of Concern" (AOC) were obtained from the US EPA Region 5 office in Chicago (Bolka 2001), and the Euclidean distance from each segment-shed to the nearest AOC point was calculated. AOCs were identified by the 1978 Great Lakes Water Quality Agreement (http://www.epa.gov/glnpo/aoc/index.html), and are areas where serious impairment of beneficial uses of water or biota (swimming, fishing, drinking, navigation, etc.) is known to exist, or where environmental quality criteria are exceeded to the point that such impairment is likely.

Table 56-2 Sources of spatial data sets used for the seven categories of environmental variation.

Category	Database	Aggregation of Source Data	Description or Source
Agriculture and agricultural chemicals	Spatial Data in Geographic Information System Format on Agricultural Chemical Use, Land Use, and Cropping Practices in the United States	county	http://pubs.usgs.gov/wri/wri944176/ (Battaglin and Goolsby 1995)
	Potential Priority Watersheds for Protection of Water Quality from Nonpoint Sources Related to Agriculture	8-digit hydrologic units	http://www.nrcs.usda.gov/technical/NRI/pubs/wqpost2.html (Kellogg et al. 1997)
	USDA NRCS 1997 National Resources Inventory	8-digit hydrologic units	http://www.nrcs.usda.gov/technical/NRI/1997/summary_report/ (USDA 2001a, b)
	USDA NRCS 2001 Nutrient Management	8-digit hydrologic units	http://ias.sc.egov.usda.gov/parmsreport/nutrient.asp (USDA 2001c)
	USGS SPARROW Total N, Total P	8-digit hydrologic units	http://water.usgs.gov/nawqa/sparrow/wrr97/results.html (Smith et al. 1997)
Atmospheric deposition	National Atmospheric Deposition Program (NADP)	points	http://nadp.sws.uiuc.edu/ (Dossett and Bowersox 1999)
Soils	State Soil Geographic (STATSGO) Database	STATSGO map units	http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/ (USDA 1994)
Land use and land cover	National Land Cover Dataset 1992 (NLCD 1992)	30 m × 30 m pixels	http://landcover.usgs.gov/natllandcover.php (Vogelmann et al. 2001)
Shoreline modification	Great Lakes Environmental Research Laboratory (GLERL) Medium Resolution Vector Shoreline Data	lines	http://www.glerl.noaa.gov/data/char/glshoreline.html (Stewart and Pope 1993)
Point and non-point pollution	USEPA Toxic Release Inventory Facilities in the United States	points	http://www.epa.gov/waterscience/ba-sins/ metadata/tri.htm
	EPA/OW Permit Compliance System for CONUS (NPDES permits)	points	http://www.epa.gov/waterscience/ba-sins/ metadata/pcs.htm
	Electric Power Plants of the United States (non-nuclear)	points	http://dss1.er.usgs.gov/ftp/appbasin/ap_Ppall.met (USGS 1997)
	USGS Mineral and Metal Operations	points	http://tin.er.usgs.gov/mineplant/ (USGS 1998)
Human population density and development	Distance to Nearest Great Lakes Area of Concern (AOC)	points	http://www.epa.gov/glnpo/aoc/index.html
	Census 2000 Census Block Data	census block	http://www.census.gov/geo/www/census2k.html
	Census 2000 TIGER/Line Files	lines, census block polygons	http://www.census.gov/geo/www/tiger/tiger2k/tgr2000.html

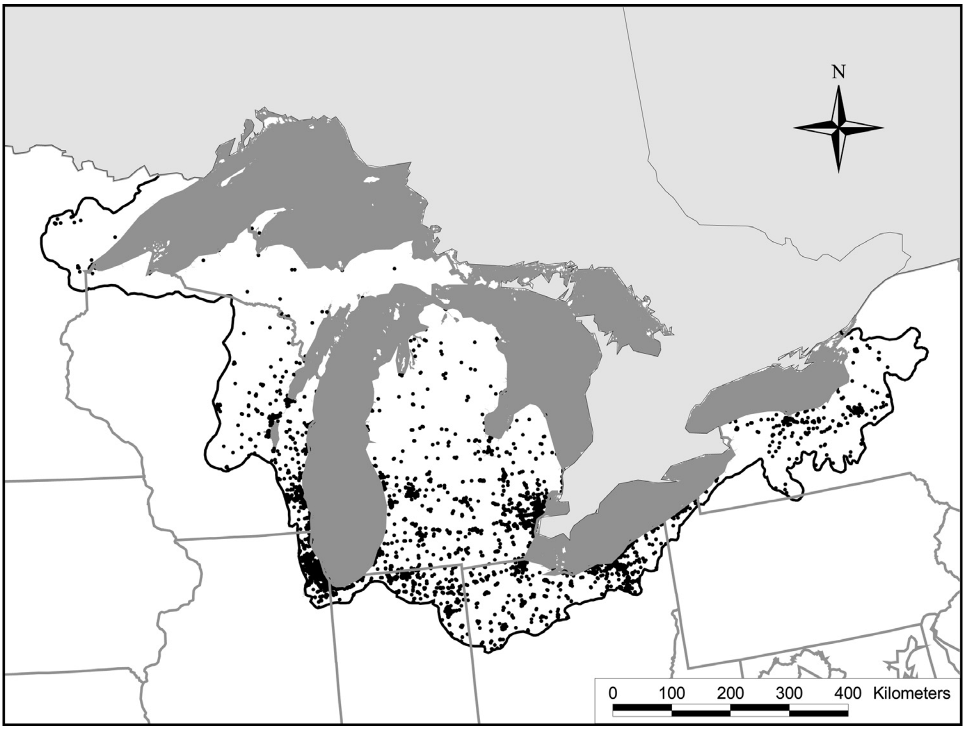

Figure 56-4 Point locations of 5,681 facilities listed in the Toxic Release Inventory data set for the US Great Lakes basin.

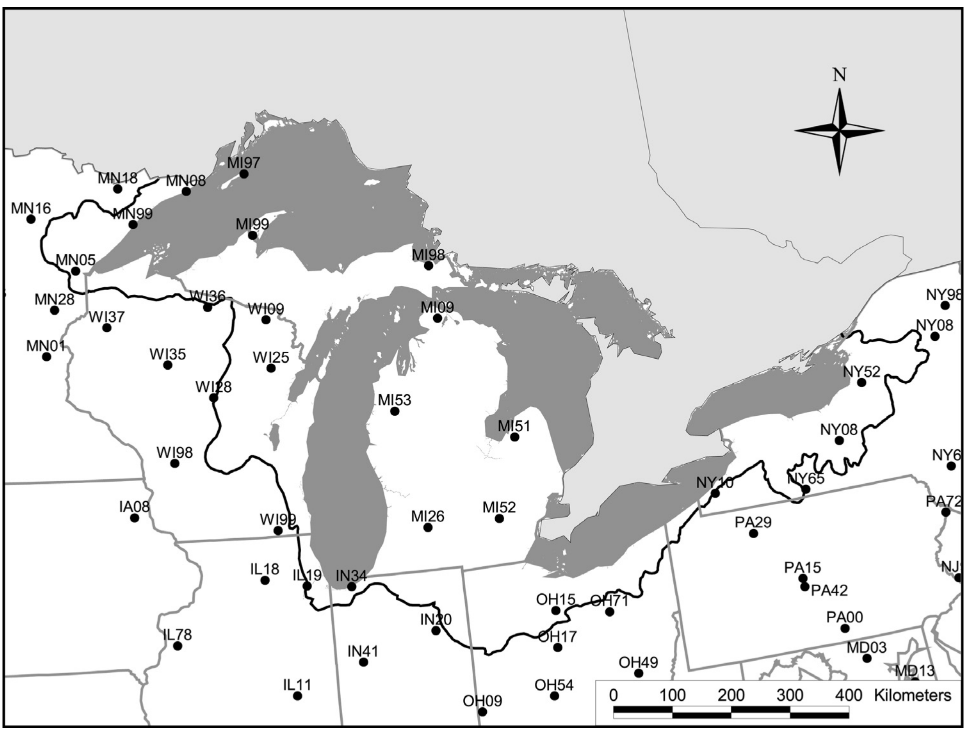

Figure 56-5 National Atmospheric Deposition Program monitoring sites near the Great Lakes.

Two types of linear data sets were used: roads and shoreline protection (Table 56-2). Linear road data were obtained from Census 2000 TIGER/line files, clipped with segment-shed boundaries, and summarized as length of roads per unit area of segment-shed. Shoreline protection had been mapped as linear segments of the Great Lakes shoreline (Stewart and Pope 1993), but those segments did not match the 762 segments developed by the GLEI project. Therefore, the different shoreline protection classes (no protection, minor protection, moderate protection, high protection, artificial shoreline, and non-structural protection) were summarized as length of protection class per unit length of GLEI segment.

Several data sources were aggregated by various types of polygons: counties, USGS hydrologic units, census blocks, and STATSGO map units. The US Census and STATSGO provide polygon boundaries for their map units as part of the data dissemination, but polygon boundaries had to be obtained from independent sources for counties and hydrologic units (Table 56-3). To calculate segment-shed values from these data sets, the polygons were intersected with the segment-shed boundaries, and area weighted averages were calculated for each variable of interest. The census block polygon data were rasterized prior to data analysis to simplify area weighting.

Table 56-3 Databases for geographic aggregation of stress data.

Database	Source	Description
Ecological Units of the Eastern United States	http://www.srs.fs.usda.gov/econ/data/keys/	Hierarchical ecoregion system developed by the US Forest Service (Keys et al. 1995).
County Boundaries	http://water.usgs.gov/lookup/getspatial?county100	1:100,000-scale base map of US county boundaries.
USGS Hydrologic Cataloging Units	http://water.usgs.gov/GIS/huc.html	Hierarchical regionalization system for major drainage basins developed by the USGS. Each hydrologic unit is numbered by a unique hydrologic unit code (HUC) consisting of two to eight digits based on the level of classification.

Because there was a large amount of redundancy in the full set of 207 environmental variables, principal component analysis (PCA) was used to remove redundancy and to reduce dimensionality within each category of environmental variables (Danz et al. 2005). Preliminary analysis of the environmental data had revealed major differences in primary environmental gradients between the two ecoprovinces (Keys et al. 1995) within the US Great Lakes basin, the Laurentian Mixed Forest and the Eastern Broadleaf Forest. Hence, the PCA analysis was done separately for those two ecoprovinces. A polygon file of the ecoprovince boundaries (Table 56-3) was used to assign segment-sheds to the two ecoprovince groups. Following this procedure, a cluster analysis was performed to group the segment sheds within each province into clusters with similar stress profiles. Segment sheds for sampling within each cluster were then randomly selected from available and accessible segment sheds within each cluster (Danz et al. 2005).

56.4 Establishing Sampling Locations within Field Sites and Providing Custom Maps for Field Use

Two fundamental sources of background information for field crews were Digital Raster Graphics (DRG) and Digital Orthophotoquads (DOQ). There are 563 1:24,000 quadrangles that intersect the Great Lakes coast from Minnesota to New York State, so the task of just compiling DRGs and DOQs for the Great Lakes coast required substantial effort.

After wetland field sites were randomly chosen within each segment-shed, GIS techniques were used to pre-select sampling locations within the wetlands. Randomization of sampling is required to obtain a statistically valid ecological sample, but the initial starting point used by field biologists is usually *not* random—it is often determined by the easiest access point to the field site (e.g., a road to a wetland, a boat ramp). For wetland vegetation sampling, we removed such bias by pre-selecting sampling transects and providing field scientists with the GPS coordinates to locate those transects within the wetland. An ArcView extension called Sample (http://www.quantdec.com/sample) was used to randomize transect placement within areas mapped by national and state wetland inventories as emergent wetland vegetation. Each transect intersected a randomly selected point generated by the Sample program (Figure 56-6a), and was oriented to be perpendicular to the perceived water depth gradient, extending from open water to the upland boundary or to a shrub-dominated wetland zone, if present (Figure 56-6b). Total transect length and target number of sample quadrats was determined in proportion to the size of the wetland to be sampled (20 quadrats/60 ha, with a minimum of 10–15 and 20 m of transect length/quadrat). Transect endpoint coordinates were uploaded into a handheld global positioning system (GPS) for use by wetland vegetation field crews (further described in section 56.5.2). Field crews were also provided with custom maps that depicted a regional context for the field site (e.g. roads, boat ramps, nearby towns) in the form of a clipped DRG (Figure 56-6c), as well as field site maps depicting transect locations on a DRG and a DOQ background. These were made available to widely distributed field teams via the website.

56.5 Georeferencing and Displaying Field Results

Documentation of sample location was provided by Global Positioning System (GPS) readings made by the field teams (Figure 56-7). This information was needed for future resampling of field sites, and to show which portion of a wetland field site was sampled by each of the field teams (Figure 56-8). The GPS readings also automatically provided the time and date of sampling. Consumer-grade handheld GPS units were used, which provided locational accuracy within a precision of a few meters; documenting sample locations more precisely would have required more expensive and bulkier GPS equipment.

A protocol was adopted that standardized collection and simplified processing of GPS data from the field teams. This protocol was designed primarily for Garmin GPS units, which were most commonly used in this project, but applied to other brands as well. This provided a consistent means to:

- Collect GPS waypoints representing sampling locations for each GLEI field team.
- Collect GPS tracking points for the entire time each team was at a particular study site.
- Link GPS waypoint IDs with field sample IDs.
- Maintain accurate date and time information for both waypoints and tracking data.
- Provide an interface to the GLEI database for uploading GPS tracking and waypoint data to the project website, thereby improving efficiency at processing GPS data.
- Supply GPS information rapidly to project investigators and other field teams who may be working in the same area.

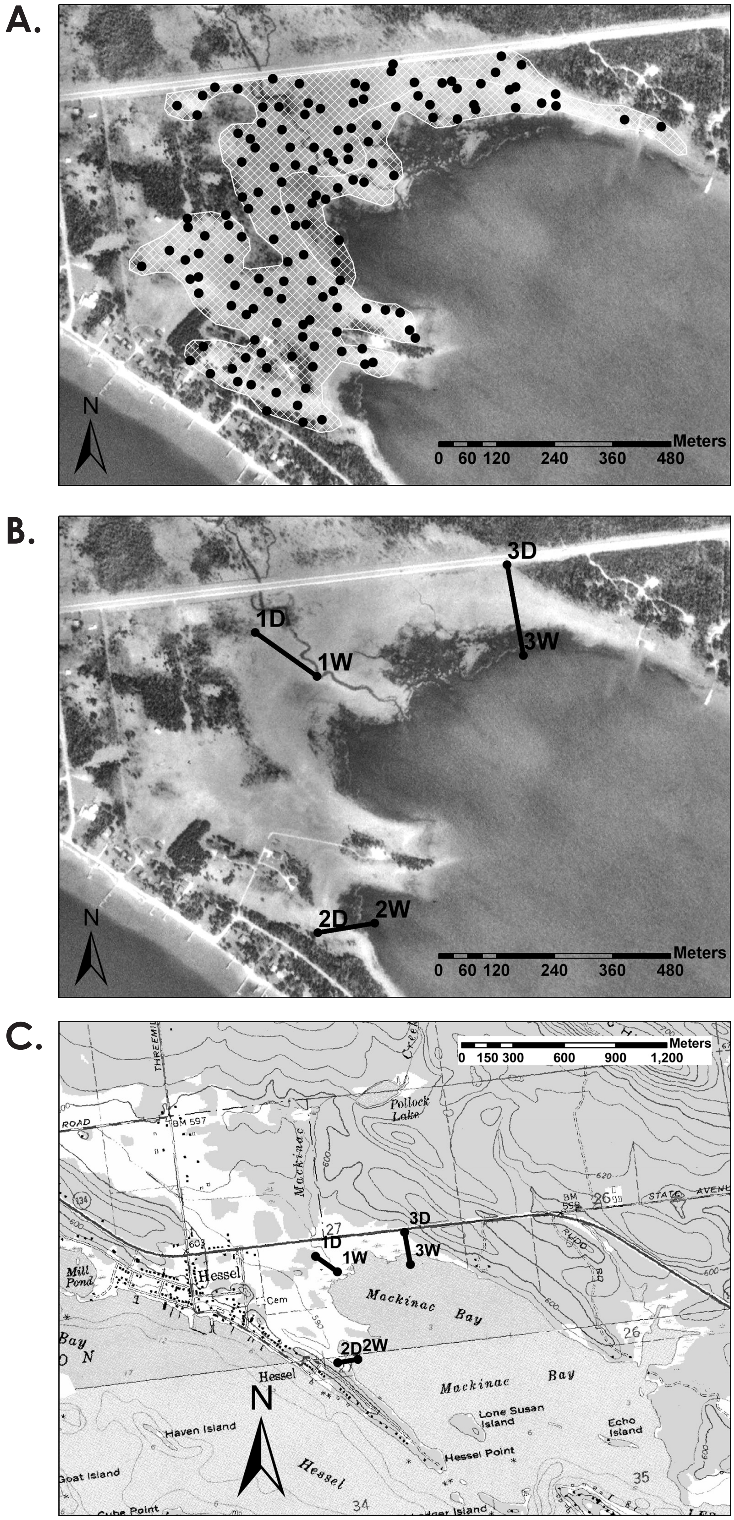

Figure 56-6 Establishing transects within selected field sites and providing custom maps for field use. A. Initial set of random sample points within areas mapped as emergent wetland. B. Transect that intersects a selected sample point and is perpendicular to the perceived water depth gradient. C. Clipped DRG that provides a regional context for the field site.

Figure 56-7 Field GPS unit attached to a tripod collects location data while field crew makes vegetation measurements.

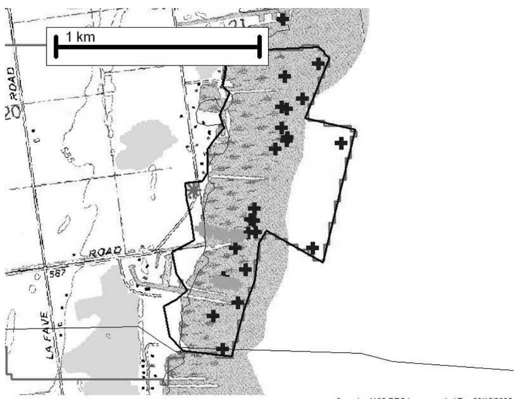

Figure 56-8 Sample locations of field crews sampling different response organisms. Asterisk indicates the single bird sampling location, scattered dark crosses indicate fish and macroinvertebrate sampling locations, and overlapping light crosses indicate vegetation sampling transects.

GPS Utility software, version 4.04.0, was used for uploading and downloading GPS data (current version as of 30 July 2008 is 4.94). This Windows-based program was compatible with the Garmin GPS MAP76 and Garmin 12 CX GPS units that were used in the field. The software is available for download at http://www.gpsu.co.uk (*GPS Utility* Limited, Hampshire, UK). A freeware version of *GPS Utility* is available with restricted storage and transfer capability (100 waypoints, 500 trackpoints), but registering the software for a nominal fee provided additional functionality. Although the following instructions were written for older GPS units that have a serial port interface between GPS and computer, the steps would be comparable for contemporary GPS units.

56.5.1 Settings for *GPS Utility*

To assure the accuracy and compatibility of collected GPS points, it was essential that they be downloaded using common settings in the *GPS Utility* software.

56.5.1.1 Set Datum to NAD 83

The NAD 83 datum was used during GPS data collection, as well as for final display. Thus, it was essential to set the datum to NAD 83 in *GPS Utility*. If NAD 83 was not the datum displayed on the tab in the upper right tab in the file box, it was set using the following steps (NOTE: the datum tab will only be present if a file, new or containing data, is open in *GPS Utility*):

a. With *GPS Utility* open, select NEW under FILE.
b. Under VIEW, select DATUM (otherwise click on datum display tab in upper right of box).
c. If NAD 83 is present in the left box, select it and click OK.
d. If NAD 83 is not present on the left, click on ADD, and scroll through the list of datums to NAD 83. Click on OK.
e. Once set, NAD 83 will remain on the *GPS Utility* run on a given computer. If changes to program have been made, however, the datum will need to be verified.

8.6.5.1.2 Export of Database Fields

The *GPS Utility* default settings for export of database fields did not include all of the fields needed for the GLEI data and had to be added manually.

a. With new file or file containing recently downloaded GPS points open in *GPS Utility*, select DATABASE FIELDS under OPTIONS.
b. There should be adequate width allocated to each of the 9 fields except "symbol." If any of the other fields have a "0" in the WIDTH column, highlight it and manually enter an adequate number (if unsure, enter 15).
c. When finished, click on OK and exit.

56.5.1.3 Set Coordinate Format to Decimal Degrees

a. Check to see that the Coordinate Format is set to Decimal Degrees in *GPS Utility* (denoted by D.dddddd in the drop down box in the upper right of an open file box).
b. If this is not the setting, click on the drop down arrow and select decimal degrees.

56.5.2 Loading Waypoints into the GPS Unit

Field teams requiring approximate sampling locations extracted from the GIS map data (e.g., transect endpoint coordinates) were given a text file (xxxx.txt) of target waypoints prior to field work. These waypoints were uploaded to their GPS unit(s) using *GPS Utility* as follows:

a. Plug GPS unit into serial port of computer.
b. Open *GPS Utility*.
c. In *GPS Utility* open text file of waypoints (xxxx.txt).
d. In *GPS Utility* select GPS, then UPLOAD ALL to load waypoints to GPS unit (it shouldn't matter what datum *GPS Utility* is set to, but for consistency set it to NAD 83). Waypoints are then loaded onto the GPS unit.
e. "Incompatible Symbol Sets" may appear; if it does, click YES to continue.

56.5.3 GPS Field Use

Two types of locational data were collected in the field: waypoints (e.g., points sampled, entry point into the field site) and trackpoints. Trackpoints provide a trace of the path followed within the field site and were useful for backtracking data, analysis of effort, and efficiency investigations. After setting the GPS to collect trackpoints, the field team started the GPS unit to collect locations for the duration of work at the study site.

56.5.3.1 Locate Target Waypoints

a. Turn GPS unit on, press page button to proceed past opening screens.
b. Press MENU, and MENU again for main menu.
c. Check to make sure that GPS unit is set to Garmin (default) mode (this is found off the Main Menu SETUP INTERFACE tab).
d. Scroll down to desired point and press ENTER.
e. If the point is not visible, switch from "search for nearest" to "search by name." Press MENU to select waypoints by name or nearest. Press ENTER.
f. Select desired waypoint and press ENTER.
g. Scroll to desired waypoint, and select by pressing ENTER.
h. Scroll over to "Goto" button and select by pressing ENTER.
i. Press PAGE button to select desired Goto interface, and follow bearing or compass heading.

56.5.3.2 Record Waypoints Identifying Specific Locations of Sampling Activities

a. At a desired sampling location, with GPS on, press and hold ENTER.
b. Mark Waypoint interface will appear. Press MENU and choose AVERAGE LOCATION, press ENTER.
c. Average Location interface will appear, counting measurements, wait for an acceptable estimated accuracy (less than 6 meters), and press ENTER to save.
d. Mark Waypoint interface re appears with the waypoint ID on the top. Record this ID with the date and time on the data sheet. It is possible to change this ID, but we recommend simply recording the ID number and allowing the GPS unit to increment the ID for each waypoint.
e. Move to next point.
f. To distinguish waypoints associated with each study site, record the ID, date and time for the first and last waypoint collected at each site. This information is needed when the points are uploaded to the GLEI database.

56.5.4 Export Data from GPS Unit to Portable Computer

Waypoints were downloaded from GPS units to a portable (i.e., laptop) computer each night as follows:

a. Plug GPS unit into serial port of computer.
b. Open *GPS Utility* (set *GPS Utility* settings as specified in Section 56.5.1).
c. Under GPS select CONNECT to connect to GPS unit.
d. In *GPS Utility* click GPS, then DOWNLOAD ALL to load waypoints and trackpoints from the GPS unit to the computer.
e. A record for each waypoint will appear in *GPS Utility*, if the waypoint view is selected. Trackpoints can also be viewed by selecting the trackpoint view.
f. Choose SAVE AS with the type set to "text (.txt)" and navigate to an appropriate directory and save downloaded GPS points with appropriate file name. For reference, file names should indicate the segment number, subcomponent team, the GPS unit and the date the data were collected.
g. Close this file before downloading new points from GPS unit (select CLEAR ALL under RECORD separately with Waypoints and Tracks selected under VIEW).
h. It is a good idea to clear all downloaded and saved data from *GPS Utility* before shutting down the program for the day.
i. Once points have been downloaded from GPS unit and saved through *GPS Utility*, clear all Waypoints and Trackpoints from GPS Unit (see instructions on following pages under appropriate unit).

56.5.5 Upload GPS Data to the GLEI Database

After GPS points from the field were downloaded and saved to a computer using *GPS Utility*, they were entered into the GLEI database as soon as an internet connection was available. A custom web interface was developed by the GLEI project for this purpose, but this function could be provided by conventional spreadsheet or database software.

56.6 Calculating Stressors at Specific Site Locations

Segment-sheds were subdivisions of the stressor domain used in the sample selection process, but indicator development required that stressors be quantified for the specific field sites sampled. Two new sets of boundaries were developed: boundaries circumscribing the actual sampling locations (Figure 56-9a), and boundaries circumscribing the land draining to each field site (Figure 56-9b). The field site boundaries were digitized interactively while displaying sampling locations over DOQs and/or wetland maps, and the land draining to each field site (i.e., field site watersheds) was computed using DEM data, using the same methods that had previously been used for the segment-sheds. These field site watersheds were smaller than segment-sheds, thereby tightening the coupling between stressor data and downslope wetlands, and hence the relationships between environmental stress and ecological response variables.

The same stressor variables computed for segment-sheds were also calculated for field site watersheds. A smaller set of variables was computed for the area within the field site boundaries, including new variables that would have been too time-consuming to gather for all of the segment-sheds. For example, an estimate of local hydrologic modification was developed by measuring the length of features that likely disrupt the natural flow and fluctuation of water (e.g., road beds, dikes, ditches) within wetland field site boundaries, and dividing by field site area (Bourdaghs 2004). These hydrologic modifications were identified from DRGs and DOQs, because there was no existing digital data set that provided such information.

A.

B.

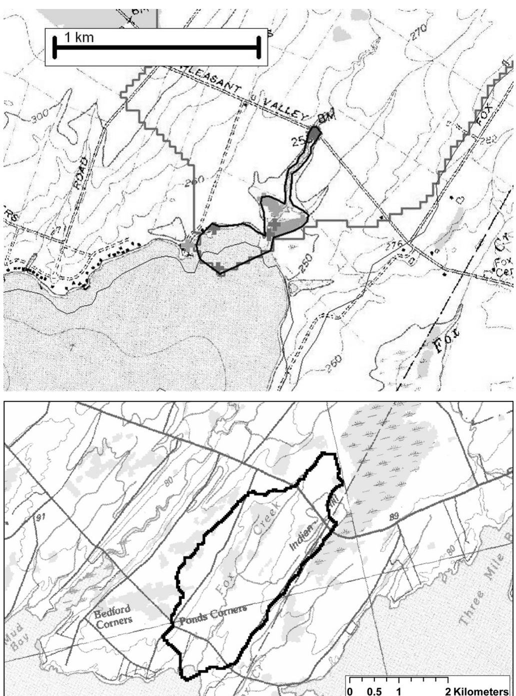

Figure 56-9 A. Boundaries of a coastal wetland field site at the mouth of Fox Creek on northern Lake Ontario. B. Boundaries of the watershed draining to the Fox Creek field site.

56.7 Developing Maps of Stressor Change (Land Use)

The US Great Lakes basin is experiencing land use changes that could greatly affect the condition of coastal and nearshore environments (Cummings 1978; Johnston 1992; Thorp et al. 1997). The pace of land use change, particularly in urban and suburban areas, far exceeds that predicted by population growth alone. Urbanization from 1970 to 1990 in the Chicago metropolitan area, for example, increased its developed area by 19.0%, with only a 2.2% increase in population (Auch et al. 2004).

Land use change over time is an important landscape scale indicator of development pressure. Land change results from changing human demographics, natural resource uses, agricultural technologies, economic priorities, and land tenure systems. Different land uses impose different environmental stresses on natural plant and animal communities, with consequent implications to water quality, climate, ecosystem goods and services, economic welfare, and human health (Gutman et al. 2004).

GIS provides the computational tools for quantifying land use change, but caution must be used with the use of existing data sets for land change calculations because differences are often due to map and registration errors rather than real change (Congalton and Green 1999). Differences in land use classification systems over time prevent quantitative comparisons of change, because differences between databases may merely represent different interpretations of land use.

We sought to measure decadal land use/land cover (LULC) change by comparing the 1992 National Land Cover Data (NLCD) with the 2001 Coastal Change Analysis Program (C CAP) data set for the Great Lakes basin (Vogelman et al. 2001; US NOAA 2003). The two data sets had 21 and 22 land cover classes, respectively, and were both derived from Landsat Thematic Mapper satellite imagery with a 30-m spatial resolution. Although this would seem like a routine process given the apparent similarities between the two data sets, a number of modifications were necessary to minimize spurious differences that were not true changes over time.

Although the number of classes used by the two LULC data sets was comparable, there was not a one-to-one correspondence between all classes in the two data sets. For example, the NLCD data set mapped more classes of agricultural land than did the C-CAP data set, and the C-CAP data set mapped more classes of wetland type than did the NLCD data (Figure 56-10). Rules had to be developed to cross-walk the two sets of classes.

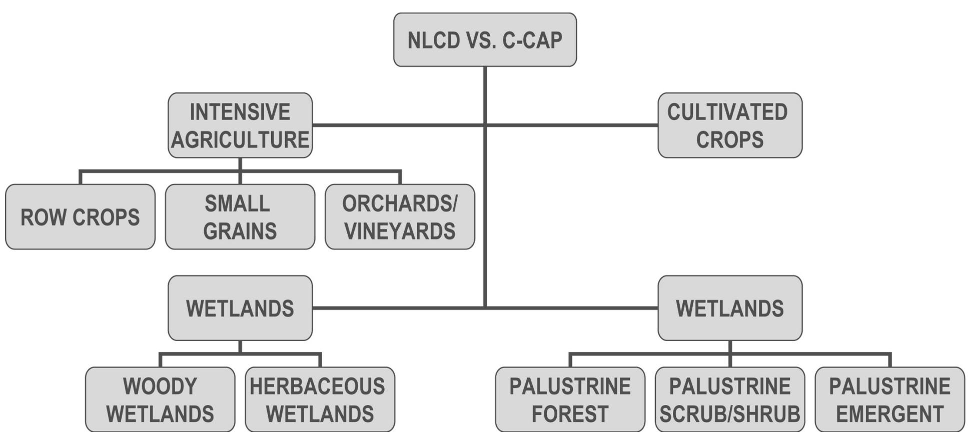

Figure 56-10 Comparison of NLCD (left side) and C-CAP (right side) classifications of agricultural and wetland cover types.

Additionally, it was apparent from inspection of the two data layers that ancillary data had been used to map roads on the C-CAP map but not the NLCD maps. To ensure that both maps were consistent in their depiction of roads, all major paved road vectors in the 1992 and 2001 TIGER databases were selected and converted to 30 m raster data, which were overlaid on the corresponding NLCD and C-CAP data sets. A final product was an enhanced US Great Lakes Land Cover 2001 data layer (Figure 56-11) that could be compared with the 1992 NLCD data layer to detect land cover change during the 1990s.

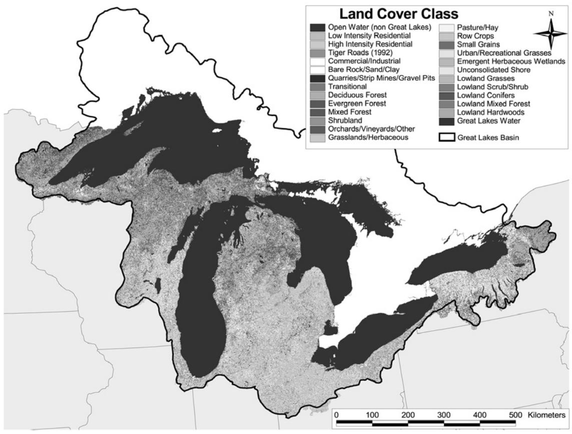

Figure 56-11 Enhanced US Great Lakes Land Cover 2001 data layer developed by GLEI for land cover change detection analysis. See included DVD for color version.

After the change detection matrix was computed for the two data layers, transition cases were examined for logical consistency and edited where needed. Vegetation transitions were checked to ensure that inferred succession rates were reasonable. For example, a time 1 to time 2 change from "transitional" to "hardwood forest" was deemed feasible, but a change from "grassland" to "hardwood forest" was not, because establishment of a mature forest is impossible over such a short time span within the climatic region of the Great Lakes. Details of the process used to develop the change map are detailed by Wolter and colleagues (Wolter et al. 2006).

56.8 Summary

GIS and GPS technologies were an integral part of the GLEI Project, and were used in many different ways:

- Subdividing the sampling domain into manageable and ecologically relevant units for study site selection.
- Characterizing anthropogenic stress gradients for study site selection.
- Randomization of sampling locations prior to field work.
- Georeferencing and display of final sampling locations after field work.
- Providing custom maps for use by field crews.
- Defining geographic extents of areas sampled and the watersheds draining to those areas.
- Calculating anthropogenic stressors within areas sampled and the watersheds draining to them.
- Developing landscape scale indicators from mapped data.

Existing GIS data were fundamental to the success of the project, ranging from base layers such as DRGs and DOQs to stressor data sources such as atmospheric deposition and pesticide runoff. Although the increasing availability of GIS data layers was very beneficial, there was still considerable effort required to use them for ecological indicator development:

data discovery, database acquisition, database manipulation (e.g., clipping, calculation, projection, edge matching, cross walking classifications, generalization), and quality assurance and quality control (QA/QC). This effort resulted in extensive GIS holdings that provided benefits to a number of subsequent ecological GIS applications, providing benefits beyond the GLEI project.

Most importantly, the GLEI GIS data set and its user interfaces provided a common framework to unify the work of dozens of GLEI investigators spread across the Great Lakes basin into a cohesive whole. Without this common framework, the development of integrated indicators of ecological condition would not have been possible.

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