J. Great Lakes Res. 33 (Special Issue 3):253–268
Internat. Assoc. Great Lakes Res., 2007

Sixty-three Years of Land Alteration in Erie Township

Carol A. Johnston[1*], Tami Watson[1], and Peter T. Wolter[2]

[1]*Department of Biology and Microbiology*
South Dakota State University
110 Agriculture Hall, Box 2207B
Brookings, South Dakota 57007-0869

[2]*Natural Resources Research Institute*
University of Minnesota
5013 Miller Trunk Highway
Duluth, Minnesota 55811-1442

ABSTRACT. *Land use and land cover (LULC) was mapped using historical aerial photos (1940) and contemporary QuickBird satellite imagery (2003) for a 100 km^2 area covering portions of Erie Township, Michigan, and Toledo, Ohio on the western end of Lake Erie. This area serves as a microcosm of conditions elsewhere on the Great Lakes coast, containing a range of human-altered to natural landscapes. Geographic information system analysis was used to measure LULC change within the study area based on the 1940 and 2003 maps, and to illustrate the use of historical aerial photos and data to quantify changes in anthropogenic pressures to coastal ecosystems. Agriculture was and is the main land use in the study site, constituting 78% and 55% of upland area in 1940 and 2003, respectively. Most conversions to other land uses originated as agricultural lands. Transportation changes over the time period included the loss of two major railroad yards and the gain of an interstate highway. The area of commercial and industrial development increased 12-fold, from 20 ha in 1940 to 246 ha by 2003. Major industries built after 1940 included an electrical power plant and a sanitary landfill. Residential development approximately doubled from 353 ha in 1940 to 717 ha in 2003, consistent with an 80% increase in population. Coastal ecosystems within the study area included a coastal spit (Woodtick Peninsula) and a large, partially-diked wetland behind it (Erie Marsh), both of which changed extensively over the time period studied. This approach offers a means of incorporating long-term observations into the evaluation of environmental condition in coastal wetlands.*

INDEX WORDS: *Diked wetlands, erosion, Lake Erie, land use change, QuickBird, wetland loss.*

INTRODUCTION

The extensive lake plain on the western end of Lake Erie was once abundant with coastal wetlands, including the former Black Swamp that extended from coastal Ohio to New Haven, Indiana (Herdendorf 1987). After European settlement, the land was drained and converted largely to agriculture, destroying an estimated 90% of Lake Erie's coastal wetlands (Herdendorf 1992). Industrial development in Toledo, founded in 1837, put additional pressures on coastal ecosystems of western Lake Erie. More recently, residential development in the suburbs of major metropolitan areas, including greater Detroit, has been a major land use shift in the Great Lakes basin (Wolter *et al.* 2006).

Erie Township lies in the extreme southeastern corner of Michigan, just north of Toledo on the Ohio border. Land use changes over the past six decades in Erie Township and vicinity provide a glimpse into evolving pressures on Great Lakes coastal ecosystems. Although many of those changes have been detrimental to coastal ecosystems, some were intended to preserve and restore them.

The primary purpose of this study is to quantify land use and land cover change within a 100 km^2 area of Erie Township and northern Toledo between 1940 and 2003, based on aerial photography and satellite imagery. This area serves as a microcosm

*Corresponding author. E-mail: carol.johnston@sdstate.edu

of conditions elsewhere on the Great Lakes coast, containing a range of human-altered to natural landscapes.

In contrast to previous work by the Great Lakes Environmental Indicators (GLEI) project that quantified land cover change over the entire U.S. Great Lakes basin over a 10-year time period (Wolter *et al.* 2006), this study is not intended to be spatially or temporally comprehensive, but rather to provide a detailed "snapshot" of cumulative land use change within a defined area over a long time span.

A secondary purpose illustrates the use of historical aerial photos and data to quantify changes in anthropogenic pressures to coastal ecosystems. Other work by the GLEI project demonstrated the importance of contemporary land use on coastal condition (Danz *et al.* 2007, Brazner *et al.* 2007 this issue). A historical perspective provides insights into the trajectory of those anthropogenic pressures that can aid prediction of future environmental outcomes.

METHODS

Study Site

The 10 × 10 km study site is on North Maumee Bay of western Lake Erie, on the Michigan-Ohio border (83° 27′ 18″ W, 41° 45′ 05″ N). The site is primarily in Erie Township, Michigan (T 8 S, R 8 E; Monroe County), but also includes portions of Toledo, Ohio (Lucas County). The industrial city of Toledo (population = 313,619: U.S. Census 2003a) and the resort town of Luna Pier, Michigan (population = 1,483: U.S. Census 2003b) border the study area to the south and north. In the Michigan portion of the study area, named settlements include Erie, Luna Pier, Ottawa, Vienna, and Vienna Junction. The Ohio portion of the study area includes the Point Place neighborhood of Toledo and the Shoreland and Alexis Addition sections of Washington Township.

The terrain of Erie Township is low-lying and flat, and was predominantly wetland prior to European settlement (Herdendorf 1987). Erie Marsh, the township's largest remnant wetland, lies in the protected bay behind Woodtick Peninsula, a prominent coastal spit. Erie Marsh represents 11% of the remaining marshland in southeastern Michigan and is one of the largest marshes on Lake Erie (TNC 2007). Erie Marsh is owned by The Nature Conservancy and is jointly managed with the Erie Shooting and Fishing Club, which has used a portion of the property for more than a century.

Image Georeferencing and Interpretation

QuickBird 10 × 10 km images of the study area were acquired on 6 Sept 02 and 10 Apr 03 (Wolter *et al.* 2005). Both QuickBird images were orthorectified by the vendor to 1:24,000 base maps with a root mean square (RMS) error of 7.7 m. Field reconnaissance data were collected during Aug 02 in anticipation of QuickBird image acquisition on 6 Sept 02.

Black and white panchromatic 1:20,000 aerial photos taken in autumn 1940 were purchased from the U.S. National Archives, scanned at 600 dpi using a Microtek ScanMaker 9800XL, and georeferenced to the QuickBird image by selecting points common to both that had not changed over the 60-year time period, such as road intersections and old buildings. Georeferencing was done using image geometric correction with a polynomial geometric model in ERDAS Imagine 8.7 (LEICA Geosystems, Norcross, GA). The RMS error of the individual images was < 0.019 (Table 1).

Contemporary LULC was interpreted primarily using the Sept 02 QuickBird image, but the Apr 03 image was used to aid identification of residential lawns, permanent grasslands, wetlands, and the most recent land use changes. Image interpretation was done on-screen, using ArcMap 9.1 (ESRI, Redlands, CA) to digitize and classify LULC polygons. A custom classification system was used (Table 2), which incorporated concepts from existing LULC and wetland classification systems (Anderson *et al.* 1976, Cowardin *et al.* 1979, Vogelmann *et al.* 2001). The minimum mapping unit was 0.1 ha, em-

TABLE 1. Georeferencing of 1940 black and white aerial photos (1:20,000) taken by the Agricultural Adjustment Administration.

Photo ID	Photo date	# of points	Root mean square error
XW-2A-149	10/30/1940	24	0.018
XW-2A-151	10/30/1940	30	0.014
XW-2A-153	10/30/1940	27	0.010
XW-2A-181	11/2/1940	38	0.011
XW-2A-183	11/2/1940	40	0.012
XW-2A-185	11/2/1940	37	0.014
XW-1A-146	9/28/1940	28	0.007
XW-1A-148	9/28/1940	40	0.014
XW-1A-149	9/28/1940	13	0.011
XW-1A-151	9/28/1940	16	0.007
XW-1A-152	9/28/1940	32	0.012
Average		29.5	0.012

TABLE 2. Land use/land cover (LULC) classes used.

1	Urban or built-up land, exclusive of transportation
11	Residential, low-density: farmsteads, permanent homes, and seasonal cabins on lots > 0.4 ha
12	Residential, high-density: permanent homes and seasonal cabins on lots < 0.4 ha (includes roads within high-density residential areas)
13	Residential, trailer park
14	Commercial and industrial exclusive of power plants and landfills
15	Power plant
16	Solid waste disposal (landfill)
17	Urban/recreational grasses: non-agricultural upland grasslands associated with cemeteries, parks, and urban areas
18	Excavated pit: excavated pit with bare soil, not filled with water or waste
2	Transportation
21	Interstate highway
22	U.S., state, and local routes
23	Railroads and railroad yards
3	Agricultural land
31	Pasture and hay land: lands permanently used for harvesting hay or pasturing livestock (areas cut for marsh hay in 1940 included in class 63)
32	Cropland: agricultural lands plowed and planted to crops
33	Orchards, vineyards, and nurseries
34	Fallow grassland: grassland abandoned from agricultural production, usually associated with impending development
4	Upland natural woody vegetation (orchards included in agricultural land, woody wetlands included in wetlands)
41	Upland shrub: shrubs and trees < 6 m tall
42	Upland forest: trees > 6 m tall
5	Water and water-related development
51	Marina
52	Dike
53	Water, Great Lakes: includes waters of Lake Erie and undiked waters of North Maumee Bay
54	Water, rivers: waters of Halfway Creek, Shantee Creek, and the Ottawa River west of Summit Street
55	Water, diked: waters within diked areas of Erie Marsh
56	Water, excavated: excavated ponds and slips
57	Waste pits and ponds
58	Shoreline armorment: boulder rip-rap placed to protect shoreline from erosion
6	Palustrine wetland
61	Wetland, nonpersistent emergents:
62	Wetland, persistent emergents
63	Wetland, grass/sedge: wet meadow
64	Wetland, scrub/shrub
65	Wetland, lowland deciduous forest
66	Unconsolidated shore: unvegetated sandy beach

ployed primarily for distinct features such as excavated ponds and individual homesteads in agricultural areas. Two existing transportation data layers were used as the primary source of road and railroad data: the Michigan Geographic Framework Transportation Geographic Theme (MCGI 2007) and the Ohio Department of Transportation's Statewide Digital Data (ODOT 2007). The clipped transportation data for each state were merged and buffered at a distance of 20 m for roads and 15 m for railroads. Historical nautical charts of "Maumee Bay and Maumee River Including City of Toledo Ohio" from 1906 and 1919 (USACE 1906 and 1919, NOAA 2007a) were a source of information about Erie Marsh and the Woodtick Peninsula.

The shorelines of Lake Erie and North Maumee Bay are convoluted, and would have been difficult to digitize precisely using on-screen methods. Therefore, a normalized difference vegetation index (NDVI) was computed in ERDAS Imagine for the Sept 02 image, and a threshold NDVI value was selected to distinguish lake water from uplands and wetlands. A Lake Erie/Maumee Bay water polygon was created based on this threshold, and used as the

shoreline for Lake Erie, North Maumee Bay, and Ottawa River. Other possible shoreline depictions, including NOAA's Great Lakes Medium Resolution Vector shoreline (http://www.glerl.noaa.gov/data/char/glshoreline.html) and the National Hydrography Dataset (http://nhd.usgs.gov/) were rejected because of mismatch with the 2003 shoreline.

Digitizing of LULC from the scanned 1940 aerial photographs was also done on-screen using ArcMap 9.1, but interpretation was aided by stereoscopic examination of the original aerial photo prints. The 2003 polygons were used as a basis for the 1940 map to eliminate spurious differences that could have been caused by mismatched boundaries had the maps been prepared independently for the two dates. The 2003 polygons were split or new polygons were added to reflect 1940 conditions. Land use changes were computed by intersecting the two map dates using ArcMap 9.1, and summarizing the results in a data matrix.

Statistical data sets related to land use in the study area were obtained from U.S. government sources. Counts and densities for population and housing were obtained from the U.S. Census Bureau (U.S. Census 1943, 2003a, 2003b), and data about agricultural practices within Monroe County, Michigan were summarized from U.S. Census of Agriculture reports (U.S. Census 1942, USDA 2004).

RESULTS

Utility of Imagery for LULC Mapping

The 2.8 m pixel resolution of the QuickBird imagery was conducive to LULC mapping using conventional human interpretation because objects as small as buildings could be identified. Identification of anthropogenic features was also aided by the contrast in near infrared (NIR) reflection between unvegetated surfaces (low NIR) and photosynthesizing vegetation (high NIR). The Apr 03 image aided the identification of residential properties because maintained lawns were already photosynthesizing in April, in contrast to agricultural lands and minimally maintained grasslands that were still dormant in April. The two-date Quickbird imagery sequence also aided interpretation of non-persistent emergent wetlands (sensu Cowardin *et al.* 1979), which contained photosynthesizing vegetation on the Aug 02 image but which were open water on the Apr 03 image because the plants had not yet emerged.

Degradation of the 1940 photo negatives adversely affected the quality of the prints for photos in the western and middle portions of the study area (photos beginning with XW-2A). Small white dots speckled the image where emulsion had flaked off the negative, termed "measle syndrome" (personal communication from Jerry Luchansky, archives specialist, National Archives, Washington, DC). This type of damage to the air photo negatives is irreparable and progressive. The stereoscopic interpretation methods used in this study reduced confusion caused by these photo artifacts, because the dots appear in different locations on the two different photos that make up a stereo pair. The stereo interpreter can mentally interpolate information from the undamaged photo to visualize the entire image, albeit without the benefit of the three-dimensional view that an undamaged stereo pair would provide.

Transportation, Commercial, and Industrial Development

Toledo ranks as one of the top five rail hubs in the U.S. (Toledo-Lucas County Port Authority 2007), and three major freight lines traverse Erie Township. The tracks for these rail lines persisted over the 60-year period, although two large railroad yards associated with these lines were converted to other uses. The New North Yard, located on the state boundary northeast of Alexis (Anonymous 1951), was subsumed as of 2003 by industrial development and the Vienna Junction Industrial Park Sanitary Landfill. The Ottawa Yard, in sections 19 and 30 of Erie Township, had a standing car capacity of 3,589 and a 16-stall roundhouse built in 1924 (Berry 2007) but was overgrown by trees and shrubs as of 2003. The cumulative area of these two decommissioned railroad yards was 94 ha (Table 3). Construction of the Detroit-Toledo Expressway (I-75) was the major transportation addition to Erie Township between 1940 and 2003, displacing 84 ha of agriculture and 26 ha of other land uses.

Commercial and industrial development was a minor land use in 1940, covering only 20 ha, but increased 12-fold to 246 ha by 2003 (Table 3). Commercial development supplanted 172 ha of agriculture, 27 ha of residential land, and 16 ha of railroad land (the former New North Yard); most of the changes occurred in the Ohio portion of the study area.

A 27 ha power plant and a 65 ha landfill were also established in Erie Township between 1940

TABLE 3. Cumulative area by class (ha), 1940 and 2003. Values of 0 indicate trace amounts (areas < 0.5 ha). Cells with rectangular borders indicate areas that did not change LULC class between 1940 and 2003.

	LULC Class, 1940																		
LULC Class, 2003	11	12	14	22	23	31	32	33	41	42	53	54	55	61	62	63	65	Other*	Total, 2003
11 residential, low-dens.	101			0		28	153	32	10	2			0		0				326
12 residential, high-dens.	94	101	1			14	138	18		9	1				6	3		7	391
13 trailer park						2	36												38
14 commercial/industrial	22	5	19	2	16	9	159	4	2	1	1				5			2	246
15 power plant							19				0		1	3	4				27
16 landfill	4				10		44			6									65
17 urban/rec. grass	0			0		3	59	6		1		1			0			11	83
21 interstate	3			11		3	84	2				1	4		1	1		0	110
22 other roads	0			299	1		31	1	1	1			0		1	0	1		336
23 railroads				0	97											0			97
31 pasture/hay	1				1	10	100	13		0									125
32 cropland	13			0		69	2283	51	10	8						3			2437
33 orchards	0						21	10											31
34 fallow grassland					0	0	41									1			43
41 upland shrub	2			1	52	1	56	1	3	0			1		0	1			118
42 upland forest	4	1		0	21	12	92	5	29	56	4		0	0	2	4	0	1	232
51 marina							10	1		8	9				10	3	4	1	45
52 dike						2	1			5	25		3	3	22	2		7	71
53 water, Great Lakes		1				0	2		4	11	3576		1	83	260	21	27	0	3986
54 water, rivers							1					51			26	1			79
55 water, diked							8				17		13	24	30	8		2	104
56 water, excavated		1		0	0	1	35		1	5			1		5	1		4	54
57 waste pits & ponds						8	30			2	0			4	13	11			70
61 wetland, non-persist.						0			1	1	13	3	0	13	23	4	0		59
62 wetland, persist. emer.	0				0	10	39		1	13	101	1	26	29	227	82	7	2	538
63 wetland, grass/sedge	0			0		14	73			15	8		6	1	82	19		0	20
64 wetland, scrub/shrub						5	30			0	7		1	8	12	3			66
65 wetland, forested	1			0		4	13	3		1					7		11		39
Other (classes 18, 58, 66)		0			1		11			3	3				0	0			18
Total, 1940	**244**	**109**	**20**	**315**	**200**	**199**	**3571**	**149**	**61**	**147**	**3766**	**56**	**57**	**169**	**736**	**168**	**49**	**37**	**10054**

* includes classes 17, 51, 52, 56

TABLE 4. Selected agricultural statistics for Monroe County, Michigan (U.S. Census 1942, USDA 2004).

Item	1940	2002	change
LAND AREA:			
Land in farms (km^2)	1,190	880	–26%
Harvested cropland (km^2)	760	765	1%
Cropland fertilized (km^2)	*	686	*
Corn for grain (km^2)	216	245	13%
Wheat for grain, all (km^2)	124	75	–40%
Oats for grain (km^2)	127	5	–96%
Soybeans for beans (km^2)	45	388	758%
Forage—hay and haylage, silage, and greenchop (km^2)	157	28	–82%
Land in orchards (km^2)	9	1	–87%
BIOMASS PRODUCED:			
Corn for grain (Mg)	56	172	205%
Wheat for grain, all (Mg)	21	35	69%
Oats for grain (Mg)	17	1	–91%
Soybeans for beans (Mg)	4	87	2,228%
Forage—hay and haylage, grass silage, and greenchop (Mg, dry)	71	23	–68%
OTHER:			
Farms (number)	4,165	1,183	–72%
Land in farms—Average size of farm (ha)	29	74	161%
Livestock—Cattle, hogs, and sheep inventory (number)	57,985	8,838	–85%

and 2003 (Table 3). The 328 megawatt J.R. Whiting Power Plant operates three coal-fired units at the northern end of the Woodtick Peninsula (Consumers Energy 2007). In addition to the ~27 ha footprint of the power plant and its coal pile, lands associated with the power plant include cooling and wastewater ponds and a fly ash disposal pit. The Vienna Junction Industrial Park Sanitary Landfill occupies ~65 ha of land just north of the state boundary, and was Michigan's 12th largest disposal facility for municipal waste in FY2003, receiving 1.05 million m^3 of solid waste (MDEQ 2004).

Agriculture and Woody Vegetation

Agriculture was and is the main land use in the study site. Cropland constituted 78% and 55% of upland area in 1940 and 2003, respectively (Table 3). Given the abundance of agriculture, most conversions to other land uses originated as agricultural lands. Of the 3,571 ha of cropland that existed in 1940, about one-third was converted to non-agricultural uses by 2003.

The cumulative area mapped as pasture or permanent hayland in 1940 was 199 ha in 1940, decreasing by 37% to 125 ha in 2003 (Table 3). Many of these early pastures were on hydric soils that were too wet to crop, and 29 ha reverted back to wetlands as of 2003. Sixty-nine hectares of the 1940 pasture/hayland were converted to cropland, and 53 ha were converted to commercial or residential uses. Only 10 ha of land that had been mapped as pasture/hayland in 1940 remained in that category as of 2003, because most pastures/haylands were in different locations in 2003 than they had been in 1940.

Patches of upland shrub doubled in area from 61 ha in 1940 to 118 ha in 2003, but like pasture were in completely different locations in 2003 than in 1940. One-half of the land that had been shrub land in 1940 grew into upland forest, and the remainder was mostly converted to low-density residential or agricultural land. Shrub land in 2003 was primarily associated with the abandoned Ottawa rail yard and abandoned agricultural lands adjacent to the Toledo-Detroit Expressway.

Many orchards were scattered throughout the township in 1940, covering 149 ha (Table 3). Only 31 ha of orchards remained as of 2003, most having been converted to housing developments or other types of agriculture. Upland deciduous forest increased in area from 147 ha in 1940 to 232 ha in 2003, a 58% increase. About one-fourth of the upland forest area in 2003 had previously been forest in 1940; other previous LULC classes of the 2003

forest area were cropland (40%), shrubland (13%), and railroad yard (9%).

U.S. Census of Agriculture statistics for Monroe County as a whole (U.S. Census 1942, USDA 2004) indicated that the area of harvested cropland within the county was nearly constant between 1940 and 2000 (Table 4). However, statistics indicated dramatic changes in agricultural practices that relate to land use and environmental quality. Livestock numbers decreased from ~58,000 in 1940 to ~9,000 in 2002, accompanied by large decreases in land planted to forage and oats used for animal feed. The primary crops planted in 1940 were corn and small grains; the primary crops planted in 2002 were soybeans and corn. Total biomass produced increased for all crops except oats and forage. Corn biomass tripled despite an increase of only 13% in land area planted to corn, and wheat biomass increased by 69% despite a 40% *decrease* in land area planted to wheat. These crop yield statistics indicate an intensification of agricultural land use that is not reflected in the area statistics determined by remote sensing.

Residential Development

The population density of Erie Township, exclusive of Luna Pier, increased by ~80% over the six decade period, from 44 to 79 people/km^2 (U.S. Census 1943, 2003a). The total number of dwellings in Erie Township was 1,917 as of 2000, about 31 dwelling units per km^2. Washington Township, Ohio had 3,574 residents and 1,387 dwellings on its 2.3 km^2 of land area as of 2000 (U.S. Census 2003b).

Consistent with the increase in population was an increase in low- and high-density residential land, which approximately doubled from 353 ha in 1940 to 717 ha in 2003 (Table 3). Increases in residential area included creation of new housing tracts and strip development of single family dwellings along existing roadways. The strip development occurred mostly on the Michigan side of the study site; housing development on the Ohio side tended to be in larger contiguous tracts. Densification of existing housing tracts also occurred: 38% of the area that had been low-density residential became high-density residential by 2003. Most of the low-density residential area in 1940 remained residential as of 2003, although 9% was converted to commercial/industrial and 5% (primarily farmsteads) was removed to accommodate expansion of agricultural fields (Table 3). The study area's only trailer park was developed after 1940 and occupies 38 ha.

Coastal waterways were a magnet for residential development. The Point Place and Shoreland communities of northeast Toledo (Fig. 1), on peninsulas defined by Shantee Creek, the Ottawa River, and the Maumee River, supported dense housing developments that were initially platted in the 1940s. In Michigan, housing developments near coastal waterways include Luna Pier, Morin Point, and strip developments along Halfway Creek.

Wetlands and Shoreline Configuration

Water and wetlands constituted about half of the study area in both 1940 and 2003 (Table 3). The cumulative area of wetland decreased from 1,123 ha to 926 ha and the cumulative area of water increased from 3,885 ha to 4,292 ha between 1940 and 2003, with most of the gain in water area being due to wetland losses (Fig. 1). Changes in the water level of Lake Erie accompanied these changes in wetland area: lake levels were at historic lows during most of the decade preceding 1940, and were above average from 1992 to 1999 (Fig. 2). Extreme low (173.18 m) and extreme high (175.04) water levels for Lake Erie were recorded in 1936 and 1986, respectively.

The shape and width of the Woodtick Peninsula changed dramatically during the 63-year period of aerial photo record (Fig. 1). The southern tip of the peninsula, called North Cape, was much wider in 1940 than it was in 2003, decreasing from about 540 m wide in 1940 to only ~235 m wide in 2003. As of 2003, the peninsula was also 100 m shorter than it was in 1940, and a 19 ha area of lowland forest at North Cape had completely eroded away. The 1940 Lake Erie shoreline of the Woodtick Peninsula was buffered by a 50–200 m wide fringe of wetland, which was absent in 2003. The peninsula's eastern border as of 2003 was in 1940 a dirt road along the crown of the spit, extending 3.5 km from the mainland to a cabin located in the southern third of the peninsula. In addition, the previously straight configuration of the Woodtick Peninsula has been altered by a breach of the spit, which resulted in a C-shaped bend near its terminus (Fig. 1).

The study site currently contains two named islands within North Maumee Bay, Indian Island and Gard Island, which are of archeological significance due to their association with native American tribes of the Early Late Woodland period (Fig. 3). The islands are more elevated than the Woodtick

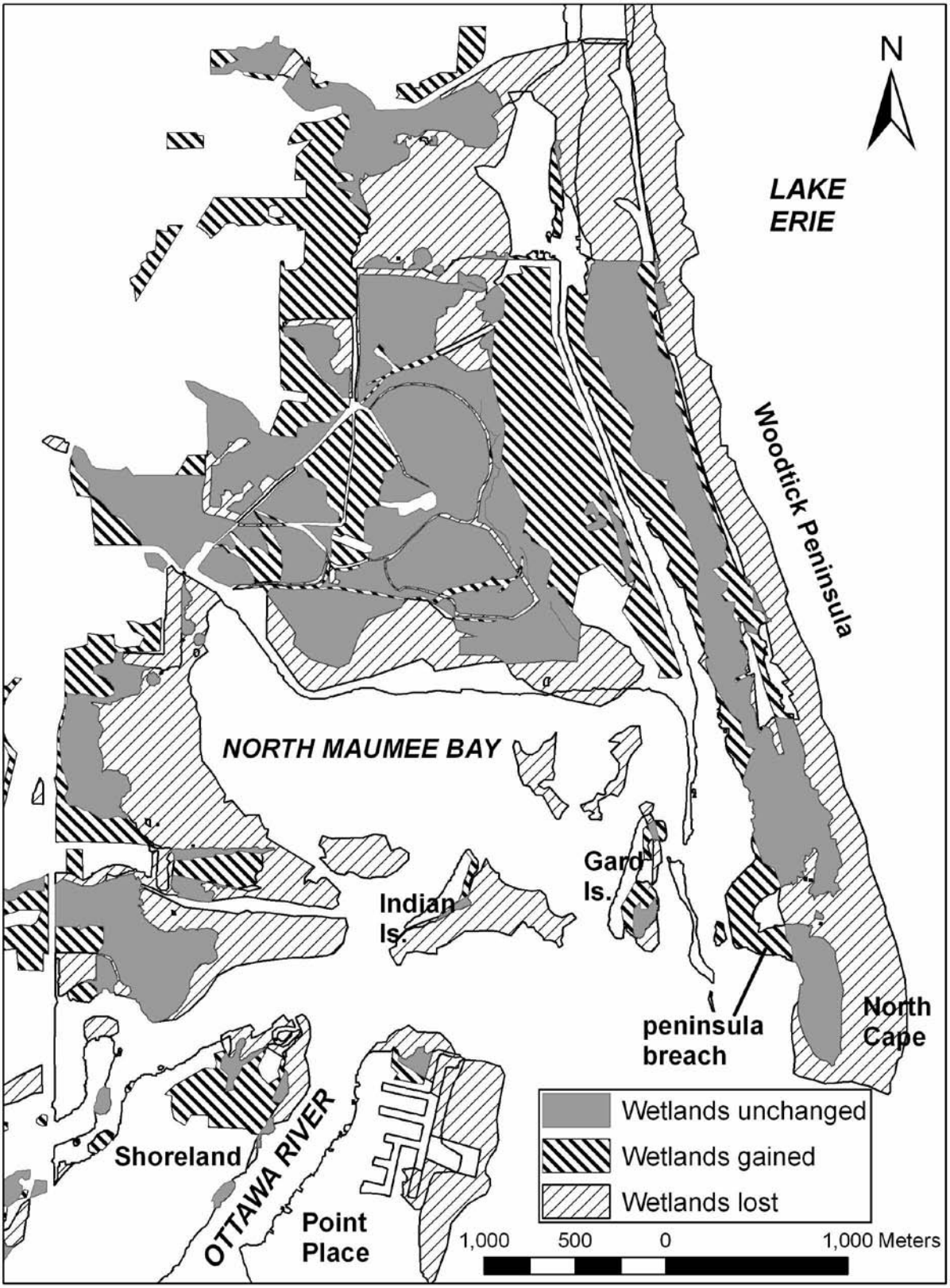

FIG. 1. Wetland gains and losses in Erie Marsh, 1940 to 2003.

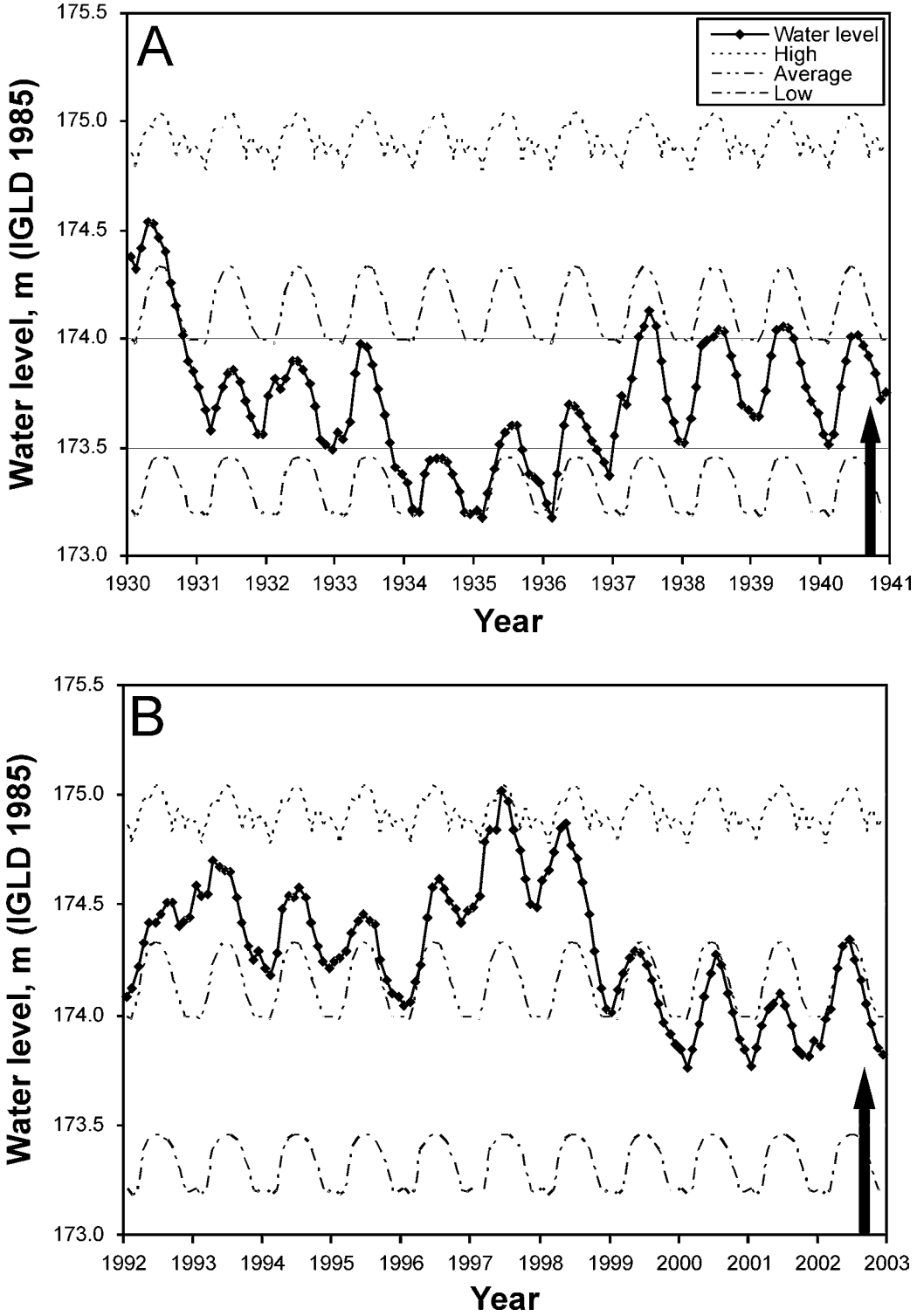

FIG. 2. Lake Erie measured monthly water levels (USACE 2007): A. 1930–1940. B. 1992–2002. Long-term average, record high, and record low levels shown for reference. Arrows denote dates of image acquisition.

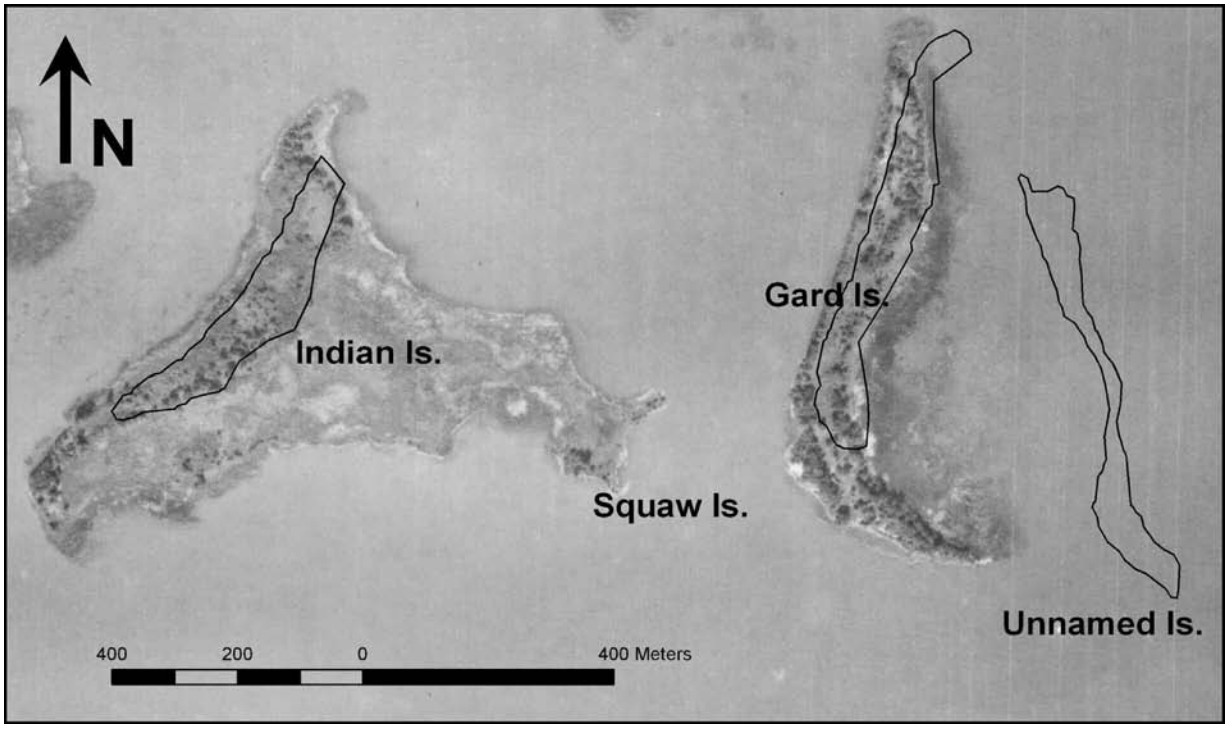

FIG. 3. Erosion and accretion of islands in North Maumee Bay, 1940 to 2003. Boundaries of islands in 2003 superimposed as black outlines on 1940 aerial photo.

Peninsula, and their boundaries on the 1940 photos (exclusive of surrounding wetlands) were relatively constant from the earliest nautical charts in 1906 (Fig. 4). As of 2003, however, Indian and Gard islands were much smaller than in 1940 (Fig. 3). A third named island, Squaw Island, was present in 1940 but was completely gone as of 2003. However, a new, elongated island appeared east of Indian Island and west of the Woodtick Peninsula breach, visible on the 2003 imagery (Fig. 3).

The wetlands of Erie Marsh have been extremely dynamic during the past century. The 1919 nautical chart of Maumee Bay showed extensive areas of open water west of Woodtick Peninsula, labeled as "North Maumee Lake" (Fig. 4). By 1940, stands of emergent wetland vegetation filled much of this area (Fig. 1), due in part to construction of dikes for water level control, termed "structural marsh management," which was initiated by waterfowl hunting clubs sometime before 1940. Dike construction was completed by the time the Erie U.S. Geological Survey 1:24,000 topographic map was published in 1979, and dike area totaled 71 ha as of 2003. Another source of wetland gain was the abandonment of wet agricultural lands around the landward periphery of Erie Marsh.

The "wetlands lost" category (Fig. 1) includes any area mapped as wetland vegetation in 1940 that became a non-wetland class as of 2003. Because most of these conversions were to open water, the term "lost" is *not* meant to signify "irreparably lost," because Great Lakes coastal marshes experience natural expansion and retraction as water levels change. By quantifying the fate of "wetlands lost" into change categories (Table 3), we can make inferences about the permanence of wetland losses.

Twenty-eight ha of wetland were lost to the construction of "waste pits and ponds" (Table 3), primarily the fly ash pit associated with the Whiting Power Plant on the north end of Woodtick Peninsula. Seventeen ha of wetlands were dredged between 1940 and 2003 to build marinas in three locations within the study site. Twenty-seven ha of wetland were converted to dikes. These three sources of loss are the only ones that have a direct human cause, and are deemed to be permanent. Elsewhere in Erie Marsh, extensive areas of wetland became open water as areas of emergent wetland plants died off due to submergence when lake

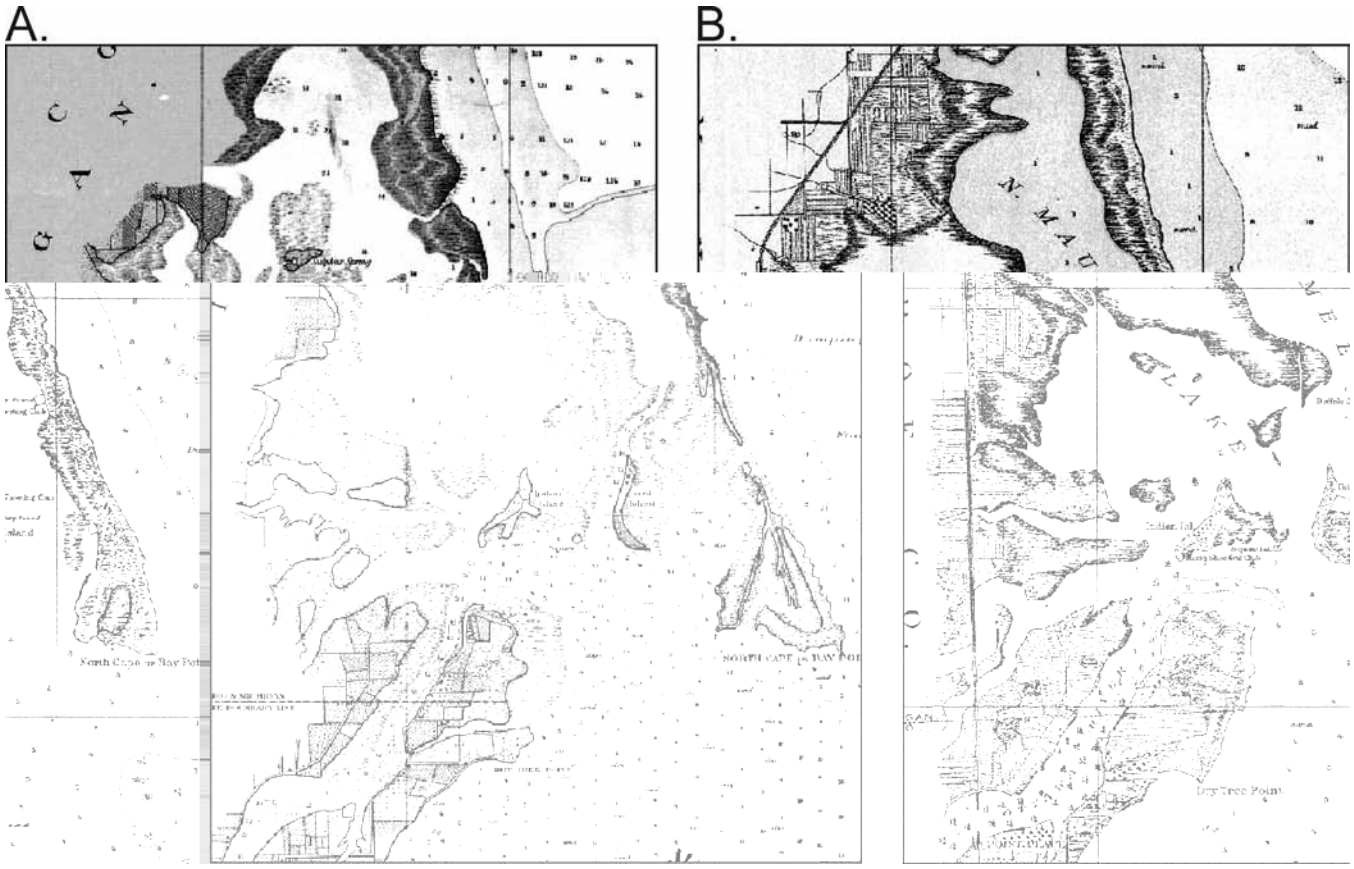

FIG. 4. Portions of Nautical Chart No. 374, Maumee Bay and Maumee River including city of Toledo showing Erie Marsh: A) issued 25 Jun 1906. B) issued 24 Apr 1919. Entire charts may be viewed using the online MrSID image viewer in the NOAA Historical Map & Chart Project Image Catalog (NOAA 2007a).

levels rose (Fig. 1). These areas include former wetlands on the western edge of North Maumee Bay, a large open-water area in the northern interior of Erie Marsh, and wetlands formerly adjacent to Indian Island and the Point Place peninsula. These "losses" are not necessarily permanent, because conversion to open water is more reversible than the dredging and filling associated with waste pit, dike, and marina construction. A number of ponds were also created by excavation, but most were located in areas that had previously been agricultural.

DISCUSSION

Potential Environmental Effects of Land Use Changes

Over the past 63 years, Erie Township and vicinity has experienced increased industrial, commercial, transportation, and residential development that is typical of the lower Great Lakes states. Analysis of LULC change for the entire U.S. Great Lakes basin showed that low intensity development, high intensity development, and roads were the three greatest sources of change between 1992 and 2001 (Wolter *et al.* 2006). In Erie Township, these developments have been at the expense of agricultural land, although agriculture remains the most extensive land use within the region.

The industry with the most direct impact on the coastal ecosystems of Erie Marsh is the J.R Whiting Power Plant and associated waste disposal pits, because construction of these facilities displaced preexisting wetland areas. The location of power plants was used as a consideration during site selection for the GLEI project (USGS 1997, Johnston *et al.* in press), and we observed that Great Lakes power plants were frequently located in or near coastal wetlands, probably because their need for cooling water required close proximity to the lakes. The Whiting Power Plant withdraws cooling water from