Stabilization of ravines, adjacent beaches, and bluffs on Lake Michigan

By

Charles W. Shabica, Ph.D., P.G.
Emeritus Professor, Department of Earth Science, Northeastern Illinois University, Chicago, IL 60625
President, Shabica & Associates, Inc., 550 Frontage Road, Suite 3735, Northfield, IL 60093
(847)446-1436; charles@shabica.com

James R. Jennings, Ph.D., P.G.
Research Fellow, Department of Earth Science, Northeastern Illinois University, Chicago, IL 60625
jennings_jr@verizon.net

Maynard Riley
Terrapin Geomatics, 807 Clover Street, Glenview, IL 60025
(847) 657-9427; mhr79@tgeo.com

Jeff Boeckler
Illinois Department of Natural Resources, One Natural Resources Way, Springfield, IL 62702
(217)785-4416; jeff.boeckler@illinois.gov

ABSTRACT

This report details the performance of four Illinois coastal restoration and stabilization projects constructed and monitored over 3-15 years. All include integration of native plants with stone into sustainable systems that protect ravines and adjacent coastal beaches from the intense erosional forces of stormwater runoff and storm waves. Prior to urbanization, ravines were metastable and bluffs and beaches eroded slowly. All supported unique plant communities. During the last 125 years, coastal and ravine erosion has accelerated due to loss of protective beaches and an increase in peak stormwater runoff flowing into the ravines. Most of these problems can be attributed to construction and maintenance of harbor entrance channels, impervious structures in the watershed and to the introduction of invasive plants like silver maple and buckthorn. Societal response has typically been to attack the coastal problems with hardened structures of wood, steel and concrete and ignore the problems in the ravines. The result is a lakeshore dominated by hard defensive structures including revetments, groins and seawalls, and ravines with a patchwork of retaining walls, storm sewers, and outfalls. Plant communities have been displaced and many of the structures have failed, in most cases due to flanking or foundation failure. This study quantifies the performance of alternative systems designed to function in concert with natural processes as compared to hardened erosion control structures. Study sites include ravines and beaches in fully urbanized areas of Lake Bluff, Highland Park and Glencoe, and eroding bluffs at Foss Park Beach in North Chicago. Systems were monitored for bacterial indicators of sewage pollution (*E. coli* bacteria), establishment of vegetation, and erosion and sediment loading to Lake Michigan. The most successful ravine projects include removal of invasive plants, restoration of appropriately-sized stream boulders and cobbles (stream armor) with streambanks and ravine slopes further stabilized with stone and native plants. Although water quality improved with reduction of fine sediments and repair of broken sewers, bacterial monitoring was inconclusive. Levels of *E. coli* bacteria were typically high in the ravines and beach sands and low in Lake Michigan, and appear to be due to diverse animal communities living in the ravines and not necessarily human sewage. Except for periods after heavy rains, the ravines had no effect on *E. coli* levels in the lake. The lakeshore adjacent to the ravines was successfully stabilized with rocky headlands and pocket beaches, wetlands, and native plants. Results of this report are intended to help planners better manage Great Lakes ravines and coasts with techniques that reduce erosion and restore diverse ecosystems. Based on criteria developed in this study, the Illinois Department of Natural Resources in cooperation with the Lake Michigan Watershed Ecosystem Partnership and Alliance for the Great Lakes has mapped all Lake County ravines to quantify stability and ecological viability. It is anticipated that with the success of the ravine mapping project, mapping the Lake Michigan shoreline for stability and ecological viability will soon follow.

ADDITIONAL KEYWORDS: Coastal restoration, bacteria, ecosystems, erosion, mapping, management, native plants, planning, sewage, streams, sustainability, watershed, wetlands.

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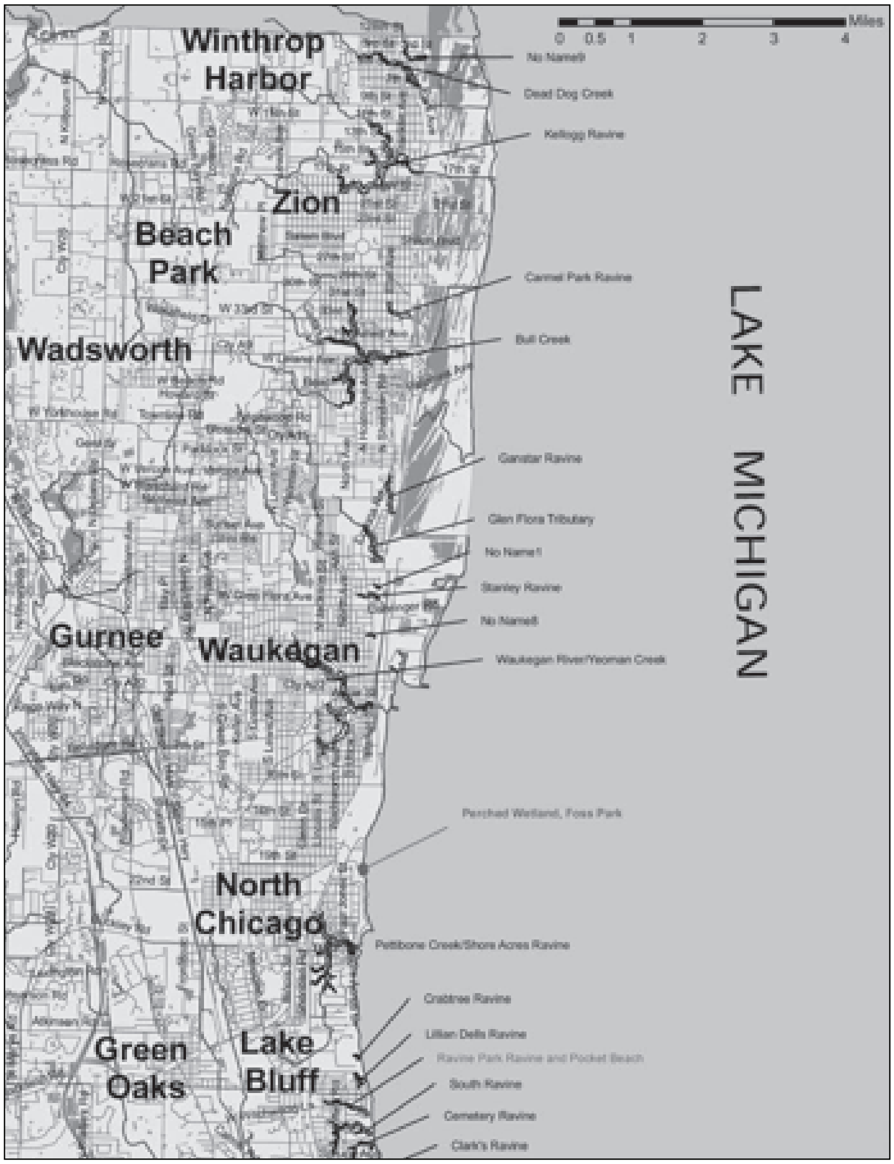


Figure 1A. Northern section — Illinois coastal ravines north to Wisconsin border. Map shows location of perched coastal wetland in North Chicago, and Ravine Park Ravine and pocket beach, Lake Bluff.

Lake Michigan shores and ravines represent some of the last relatively unspoiled wild ecosystems in northeastern Illinois (Robertson and Himelick 1977). But these are under threat due to intense urbanization, loss of sand beaches, and greatly increased stormwater runoff. Urbanization has led to reduction in plant species diversity and increased levels of sediment and non-point source pollutants entering the Great Lakes from actively eroding bluffs, wooded ravines and failed infrastructure. In Illinois, this is evidenced by loss of groundcover on the bluffs and in the ravines, bluff slides, sediment plumes in the lake, extensive algal growth on nearshore rocks close to ravine mouths, and high bacterial counts (resulting in the closing of nearby public beaches).

Shoreline and slope stabilization systems in the Great Lakes, if properly designed and constructed, can improve water quality, reduce ravine and shoreline erosion, and provide habitat for native plants and animals. These terrestrial and aquatic communities in turn support the ecological health of the lakes and lakeshores. Without proper coastal stabilization projects, the following problems are likely to continue unabated:

- Catastrophic failure of hardened erosion control structures and loss of sand beaches;
- Accelerated stormwater runoff and storm wave erosion of ravines, bluffs and habitats;
- Colonization of disturbed habitats by invasive species;
- Unimpeded flow of sediment and non-point source pollutants;
- Occurrence of high levels of pathogenic bacteria from broken or leaking sewers; and
- Degradation of native ecosystems and scenic values.

BACKGROUND

Designing sustainable systems that reduce erosion and non-point source pollution in order to maintain healthy ecosystems in the Great Lakes presents an ongoing challenge. Shabica & Associates Inc. has overseen the design and construction of more than 60 sediment control, and ravine and shoreline stabilization projects in the Lake Michigan basin. Of these, four were intensively monitored in conjunction with Northeastern Illinois University (Shabica 1996, 1998, 2004; Shabica and Keefe 1999). These projects include:

- Restoration of stream boulders and cobbles to stabilize ravine channels and streambanks;
- Construction of ravine riffles, ponds, waterfalls and plunge pools;
- Monitoring a variety of engineered structures for ravine erosion control;
- Planting native riparian species;
- Stabilization of coastal bluff slopes using boulders and native bluff and beach vegetation; and
- Installation of pocket beaches and wetland filter systems at the mouths of ravines.

STUDY AREAS AND HISTORY

The four Illinois study areas discussed in this report are Ravine Park Ravine in Lake Bluff, Ravine 10 in Highland Park, Glencoe Ravine and beach in Glencoe, and Foss Park in the city of North Chicago. These ravines, lake bluffs and beaches (Figure 1A, 1B) are part of the Lake Michigan drainage system that also includes northern ravines and stable bluffs adjacent to a wide beach ridge and swale ecosystem near Zion, Illinois. The ravines are cut into high, lake-terrace deposits underlain by Pleistocene Wadsworth Till of the Highland Park Moraine. The till consists of approximately 85% clay and 15% larger particles (sand, pebbles, cobbles, and boulders). After the deposition of the Highland Park Moraine, the glacier receded, and an ice-front lake developed, initially with a water level as much as 70 feet above the level of the present lake. Following further recession of the glacial ice approximately 10,000 years ago, lake level fell to an extreme low, about 260 feet below modern lake level, as an isostatically depressed lake outlet was opened in southern Canada. Runoff and streams draining the upland cut erosional ravines into the moraine in response to lowered lake level (Chrzastowski 2005). Subsequently, as the ravines deepened over several thousand years, cobble and boulder lag deposits (stream armor) accumulated in the streambeds. In most ravines this "stream armor" protected the streams against erosion from stormwater runoff. Soil creep (slow mass wasting caused by freeze/thaw on slopes), a minor component of ravine erosion, continued as evidenced by curved tree trunks. With streambeds, streambanks and slopes in a more stable condition, a mature ecosystem with trees, shrubs and herbs developed. Because of the cooling effects of Lake Michigan, the ravine plant communities include relict stands of paper birch (*Betula papyrifera*) and other species that are adapted to a more northerly climate. Along the lakeshore, sand and gravel from ravine, bluff and lakebed erosion accumulated as beach deposits at the bluff toe and ravine mouths.

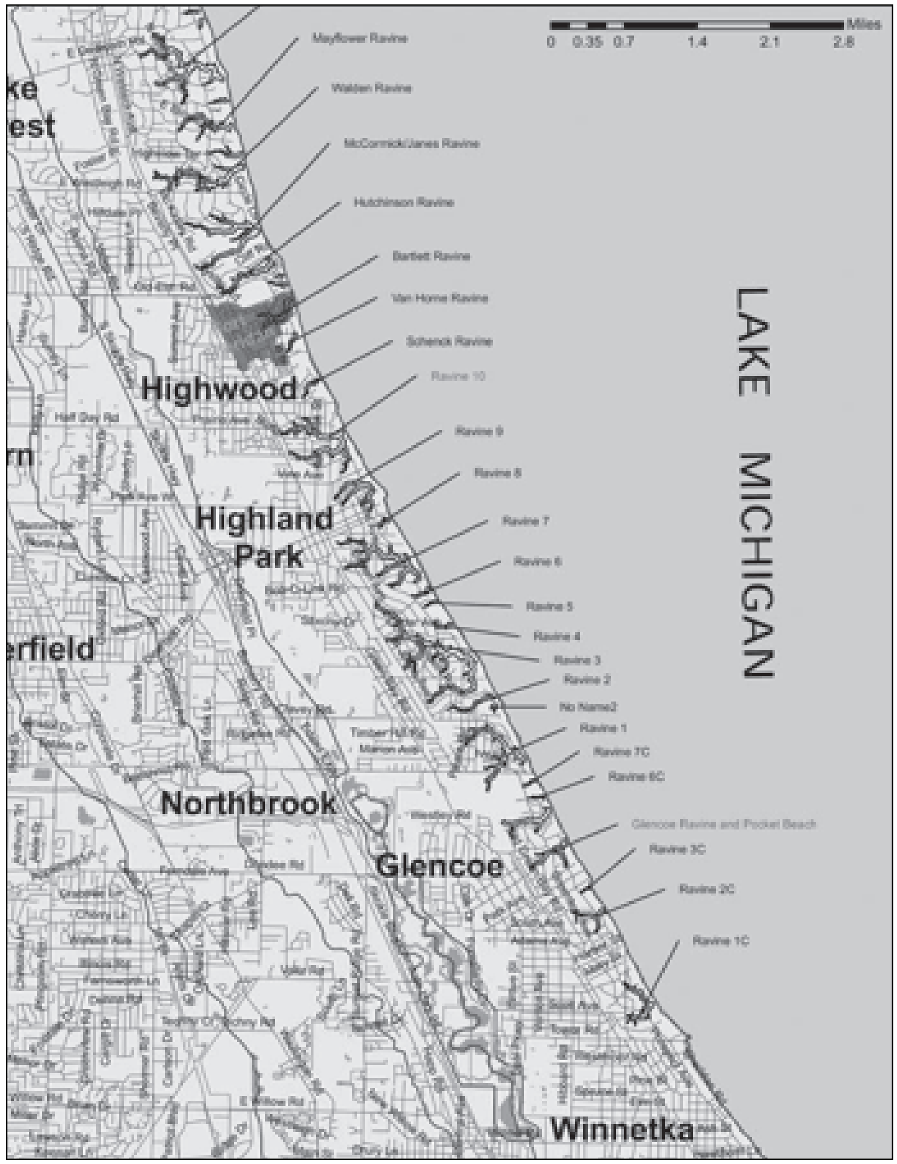


Figure 1B. Southern section – Illinois coastal ravines. Map shows the locations of Ravine 10 in Highland Park, and Glencoe Ravine and pocket beach.

The ravines, especially the northern ones "represent the only remaining natural drainage systems in the present-day Lake Michigan watershed in Illinois" (Illinois Department of Natural Resources 2007). While comparatively gently-sloped northern ravines flow through stable bluffs into the Zion beach ridge and wetland swale sand plain complex, the ravines of the study area flow directly into Lake Michigan and are steeper. This is a result of bluff recession and a consequent increase in stream gradient, a process that has been occurring for thousands of years.

The Lake Michigan bluff ecosystem was uniquely evolved to accommodate the slow but steady wave erosion conditions (estimated annual average bluff erosion rate of 8-10 inches per year [Jibson *et al.* 1994]). Forbs and low shrubs, for example common juniper (*Juniperus communis*) and russet buffalo berry (*Shepherdia canadensis*), dominated the bluff communities with large trees a rarity. As storm waves cut into the lower bluffs during high water stages, bluff sliding commenced with clays transported offshore, and sand, gravel, and cobbles left on shore as beach deposits. According to historic documents, the beaches were dynamic systems, wide under low lake-level conditions and narrow during high water stages.

Harbor entrance breakwaters constructed in the 19th and 20th centuries and sand mining depleted much of the beach sand. Coastal property owners responded and, in contrast to the ravines, nearly all of the coastal bluffs were protected from wave erosion (beginning in the late 19th century) by seawalls, groins and revetments. With wave-induced lake bluff erosion nearly arrested, a mature invasive tree-dominated plant community developed on the bluffs. This community is now considered "natural" by most coastal residents. Native bluff plant species are rare and are now found in only a few locations, notably on the bluffs at Fort Sheridan. With reduction of beach and nearshore sand deposits, lakebed erosion has accelerated and in many locations eroding till is exposed in the nearshore (Shabica and Pranschke 1994).

The sandy coastal beaches and wetlands played an important role, not only

Figure 2. Lake Bluff Ravine Park Ravine. Mouth of ravine and lakeshore prior to (1990, above) and after ravine and beach restoration (2009 Google photo, left). Note sediment plume from eroding ravine and adjacent bluffs. The pocket beach and wetland protecting the ravine mouth lie at the downdrift end of a series of pocket beaches that have replaced the poorly functioning groin field.

as bluff protection, but also as natural filters for surface runoff and ravine discharge. Under low-flow conditions, ravine water slowly percolated through beach sands and supported an active plant and bacterial community. During periods of peak discharge associated with rain storm events, ravine waters often cut temporary channels across the beaches. With a return to low-flow conditions, lake storm wave activity rapidly filled the scoured channels with sand, and percolation of rainwater through the beach resumed.

Today, stable and well-vegetated "natural" ravines, and slowly eroding, "natural" coastal bluffs and wide beaches are the exception and not the rule on the Illinois north shore of Lake Michigan. Intense urbanization of the coastal watersheds has dramatically increased peak stream flow in recent years, and many ravines are now eroding rapidly, including the unrestored sections of the Glencoe, Highland Park and Lake Bluff ravines. All of these ravines exhibit various stages of active stream downcutting (incision) and mass wasting along their banks (e.g. slumping, sliding). Development along the tops of the coastal bluffs and ravine slopes with associated fill, broken yard drains, sprinkler systems, improperly graded yards, and loss of deep-rooted plants has exacerbated the slumping problems. Due to the dense tree cover and inaccessibility, many property owners are unaware of these problems.

The challenge to ravine management is to cope with increased stormwater runoff in order to reduce mass wasting on the slopes and stream incision within the ravines. As most of the areas in the watershed are nearly fully urbanized, it is not anticipated that runoff will increase greatly in the future. However, it may take decades to reduce peak stormwater discharge through the use of a variety of methods including detention basins, rain gardens and roadside vegetated swales in the watershed. The practices described in our study are intended to reduce flow velocities in ravines in order to reduce erosion and increase groundwater recharge. These practices include widening the flow path, increasing the roughness and ponding ability of the ravine channels, and protecting the ravine slopes, streambed and streambanks with native plants and stone "stream armor."

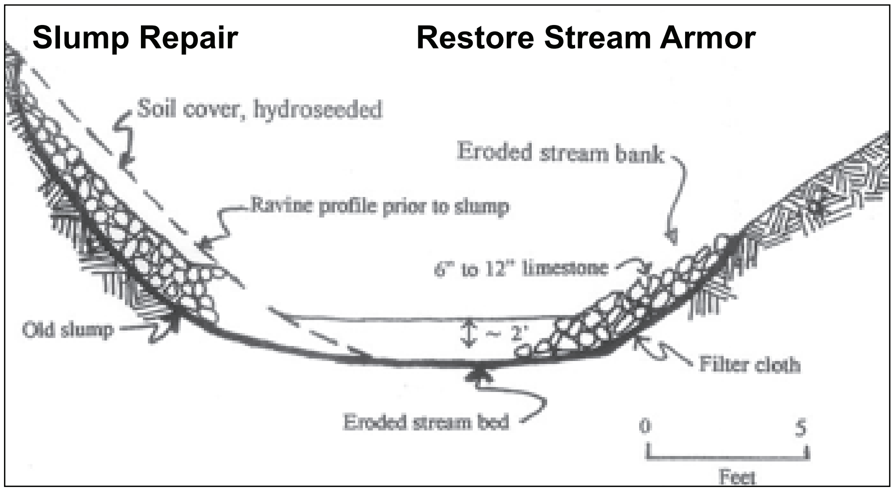


Figure 3. Ravine Park Ravine; 1992 restoration of natural stream armor and slump repair with 6-inch to 12-inch limestone cobbles and boulders and a small number of 18-inch to 24-inch boulders. Not to scale.

Figure 4. Ravine Park Ravine streambed and banks repaired with a 3-foot-thick layer of 6-inch to 12-inch limestone (stream armor) over geotextile (1992 photo). Concurrently, slumps were filled with limestone and concrete rubble and covered with hydroseeded soil. A subsequent survey showed that it took approximately one year for the void space between the new stream cobbles to fill with sand and gravel eroded from upstream slumps.

The challenge to coastal management at ravine mouths and adjacent bluffs is to cope with larger lake storm waves caused by beach sand loss and lakebed erosion. The ravine mouth is highly vulnerable to storm wave erosion where a lowering in stream grade here can undermine the entire ravine system. The solution is to restore beaches and wetlands as primary agents of shore protection with a stable ecosystem and improved runoff water quality. Practices include sand nourished pocket beaches and dune/swale wetlands that are stabilized with stone headlands.

Figure 5. Ravine Park Ravine four years after construction. Stream flow is now visible on the surface. In prior years, the water flowed below the top of the stone work. Note encroachment of vegetation over the new stone and steep slope on right that has not fully vegetated.

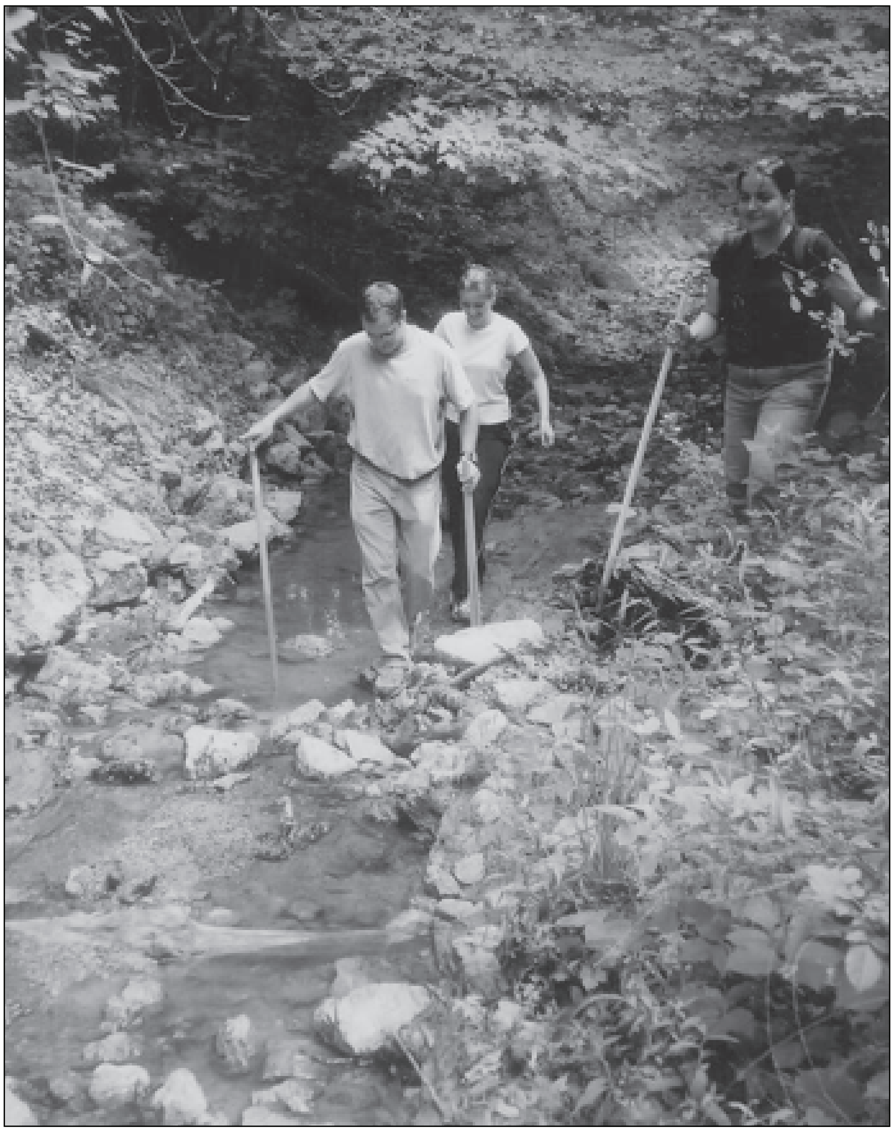


Figure 6. Ravine Park Ravine 13 years after construction with fully established vegetation. Sand and silt from the eroding upstream section of the ravine has filled the interstices of the stone in the ravine bed. Note 12-inch to 24-inch stones forming natural weir (check dam).

PROJECT MONITORING

To document the performance of the bluff and ravine restoration and stabilization systems, several monitoring schedules were developed to determine plant community health, water quality and erosion and sediment loss to Lake Michigan.

Water quality monitoring (Glencoe Ravine and beach, Ravine Park Ravine and beach) included *E. coli* sampling in unrestored and restored sections of the ravines, on downstream beaches and in Lake Michigan adjacent to the installations. Ravines were also inspected for broken or leaking sewers.

Sediment monitoring in all three ravines and two ravine mouth beaches included beach surveys, and ravine bed and bank surveys to determine surface topography in both restored and unrestored systems. Electronic total stations were used to measure horizontal location and elevation at all sites. Steel rods were installed in the ravines and recovered during later surveys to provide a reference for successive comparisons of the ground surface. Changes in ground surface elevation were measured over periods up to 15 years after installation. Unaltered sites within the ravines were included for comparison to the restored ravine sites. Ravine mouth beaches were regularly monitored by electronic total station surveys for possible impacts to adjacent coastal properties, prior to, and during this study. These data are used to quantify rates of sediment erosion and volumes of sediment lost from the ravines and transported into Lake Michigan.

Vegetation monitoring (Glencoe Ravine and beach, Ravine Park Ravine and Foss Park bluff, perched wetland and beach) included establishing a system of transects and standard-sized quadrats to identify and quantify plant growth at restored and control sites. Special attention was paid to the presence of invasive exotics and to the health of the newly planted species.

Figure 7. Newly constructed pocket beach at mouth of Ravine Park Ravine, Lake Bluff (2007 photo). Note well established vegetation on bluff stabilized in 1990. Periodic air photo surveys show the beach to be stable with no negative impacts on adjacent beaches.

Beaches were monitored by rod and transit surveys and also by comparison of historic air photos. Since 1990, Shabica & Associates has conducted annual air photo surveys of the lakeshore to show changes in beach morphology. These were supplemented by Illinois Department of Transportation air photos.

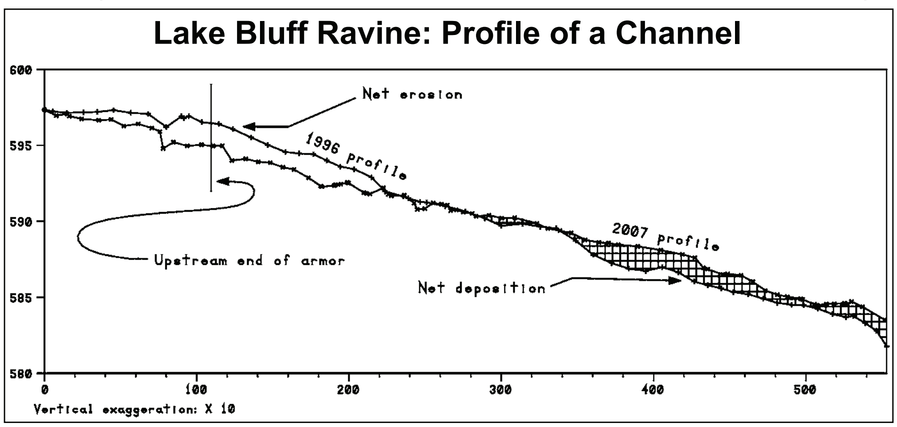
Ravine Park Ravine, Lake Bluff: The ravine studied in Lake Bluff is about 3,450 feet in length and runs through Ravine Park from the approximate center of town southeast, then across a new pocket beach into Lake Michigan (Figure 2). Active streambed erosion (incision), streambank erosion and mass wasting (slumps, and soil creep) was observed in most locations along the axis of this ravine. Prior to restoration, the mouth of the ravine was bordered by eroding lake bluffs and failed seawalls; no beach was present. In 1992, in response to requests from ravine property owners, deteriorated natural streambed armor and slumped and eroding streambanks were restored with quarried limestone in the lower 450-foot section of this ravine (Shabica 1996, 2004). Concurrent with this work, the bluffs and beach were also restored using stone breakwaters, sand fill and native plantings (Shabica et al. 2004). The restored section of ravine, beach and a 100-foot unrestored section upstream comprise the Lake Bluff study site. The average slope of the bed of Ravine Park Ravine is 1:42.

The objective of the ravine restoration was to augment natural streambed and streambank armor with quarried "limestone" (dolomite) cobbles and boulders of similar or larger size to those existing in the ravine. A hydraulic study was not performed as the watershed was fully developed with no increase in stormwater discharge anticipated. Evidence of extreme high water events, including cut banks, was used to estimate minimum elevations for streambank protection. Examination of existing stream cobbles and boulders provided an estimate for the minimum size range for new stone. Slumped areas were filled with limestone and concrete rubble (Figures 3, 4) and covered with a soil layer planted with a temporary annual grass matrix for reestablishment of native plants.

In 1992, irregularities in the streambed were graded to a uniform slope with a bulldozer. Geotextile was placed in the streambed and lapped up onto the sides of the ravine from 3 to 10 feet in areas where the streambanks had slumped. A three-foot-thick layer of quarried "limestone" (dolomite) was placed over the geotextile. No grade control structures were installed. The slumps were filled with rubble and quarrystone, top-dressed with soil, and hydroseeded with temporary annual grasses. The local vegetation was then allowed to reestablish itself on the slumps and the restored ravine banks (Figures 5, 6). Maintenance activities

Figure 8. Close-up of ponded ravine water in pocket beach at mouth of Ravine Park Ravine. During low-flow conditions, the ravine water is filtered through the sand beach. Unidentified species of algae have taken up residence in the pond.

Figure 9. Profile of streambed centerline, Ravine Park Ravine, Lake Bluff with 10x vertical exaggeration. Surveys from 1996 and 2007 are compared to show net erosion in the upper ravine and deposition (cross-hatched) in the lower section (vertical scale: five-foot intervals, horizontal scale: 20-foot intervals).



included restoration of smaller displaced stones and installation of a row of gabions placed directly on the stone layer at the base of a steep bank.

Prior to ravine restoration, the mouth of Ravine Park Ravine was flanked with eroding coastal bluffs, failed seawalls and a small ephemeral pocket beach (Figure 2). Beginning in 1990, the bluffs were stabilized with rubble fill, covered with soil and hydroseeded (Figure 7). Later, a larger, more stable pocket beach was established behind a stone headland breakwater to provide a higher level of protection for the ravine mouth (Figures 2, 7, 8). A total of 1,000 tons of sand fill was added to the beach, with all work completed by 2003.

Beginning in 2005, the ravine and beach were monitored for bacterial content. This research was supported by a grant from the Great Lakes Commission. Six water sampling sites were established in both the Glencoe and Lake Bluff ravines. The samples were cultured for bacteria by the Lake County Health Department. Results show that the ravine water and saturated beach sand typically carry elevated levels of *E. coli* bacteria even though no broken or leaking sewers were observed in the ravines. Sampling procedure and details are discussed in the Glencoe Ravine section.

Sediment survey measurements were made in Lake Bluff (25 September 1996 and 12 June 2007) to quantify ravine sediment erosion, using standard procedures with an electronic total station. Measurements included points along the axis of the channel, cross sections, and other points of interest. Survey markers established in 1996 were reoccupied in 2007 to provide a starting point and orientation for the comparative survey.

In general, the ravine slopes and stream in the restored section of ravine were stabilized while in the unrestored section, mass wasting and stream erosion continued unabated. Figure 9 shows changes in the center profile of the ravine that is a measure of streambed downcutting (incision) but does not show bank erosion or mass wasting. There was an average ravine bed net gain in elevation of +1.43 inches in the restored section of Ravine Park Ravine despite some loss of smaller armorstone; no mass wasting was observed. Conversely, disregarding sediment loss from extensive mass wasting in the unrestored section, there was an average net loss in elevation of 10.12 inches in the ravine bed. Assuming an average stream width of 8 feet, a net loss of 622 tons of sediment over the 11-year study period is calculated. Periodic air photo surveys of the beach showed minor seasonal sand losses and gains. No net gain or loss of sand on the new beach was observed on adjacent beaches as required by the IDNR permit for construction (Shabica 2004, 2008).

In monitoring plants in the Ravine Park Ravine, the goal was to identify the types of vegetation growing along the wet to mesic streamside, on the upland slope, and on the beach by the ravine mouth. There were a total of 27 species identified in 2005, from 55 randomly sampled quadrats. By 2007, the section of restored ravine was fully vegetated including native plants, such as the calico aster (*Aster latiflorus*) and white snake root (*Eupatorium rugosum*).

Ravine 10, Highland Park: The city of Highland Park has the most extensive urbanized ravine system along the Illinois shore with 10 separate ravines extending a total length of 11.7 miles. All flow directly into Lake Michigan. Approximately 50 years ago, interceptor sanitary sewers were installed in the streambeds of several Highland Park ravines including Ravine 10. Recently the sewers were replaced in several of the ravines because erosion had exposed the

Figure 10. Ravine 10, city of Highland Park, Illinois. Unrestored ravine with active streambed erosion and slope failure. Broken sanitary sewer can be seen at the lower center (1992 photo).

ductile iron sewer pipes, cracking some and breaking joint connections in others. An informal walking survey has shown that the ravines with sewers are eroding more rapidly than ravines that do not have sewers buried under the streambeds. One causative factor may be that the natural streambed armor (cobbles ranging in size from 6 to 18 inches) was disturbed when the ravines were excavated for sewer installation.

The central branch of Highland Park Ravine 10 flows northeast into Lake Michigan, is approximately 3,000 feet long, and is fed by a storm sewer at the head of the ravine immediately east of St. Johns Avenue. The interceptor sewer in the bed of this ravine was replaced by the city of Highland Park in 1987. Active streambed erosion, streambank erosion, soil slump and creep, and damaged sanitary sewer connections were observed in many locations along the axis of this ravine in 1992 (Figure 10). The study site includes approximately 900 feet of ravine beginning at the head of the ravine. Here, the average ravine slope is 1:53, a slightly lower slope than the stream gradient of 1:42 at Ravine Park Ravine in Lake Bluff.

In Ravine 10, a variety of erosion control structures had been installed before 1992 by adjacent property owners with little success. Among these, retaining walls made of treated timber ties placed on the upper slopes of the ravine are the most common. In 1992-93, as a demonstration project for the Great Lakes Commission, four types of erosion control structures were placed in the upstream section of a Ravine 10 channel by the city of Highland Park. Each type of structure was emplaced for a short distance along the channel. Intervening sections of the ravine received no protective structures. A list and description of the structures installed is given by Shabica 1996, http://www.glc.org/basin/pubs/projects/ILravine.pdf as follows:

Gabion Baskets — Gabion baskets are constructed from galvanized steel mesh similar to "chain-link fencing" and filled with 3-inch to 6-inch quarried "limestone" (dolomite). The 9- by 3- by 3-foot and 12- by 3- by 3-foot units were installed at the head of Ravine 10 along the toes of the ravine slopes adjacent to a storm sewer outfall (Figures 11, 12, 13). The gabion baskets appeared to be in generally good condition in 2007 and were still effective in retarding ravine slope erosion. However, they were undercut in some locations, and had sub-

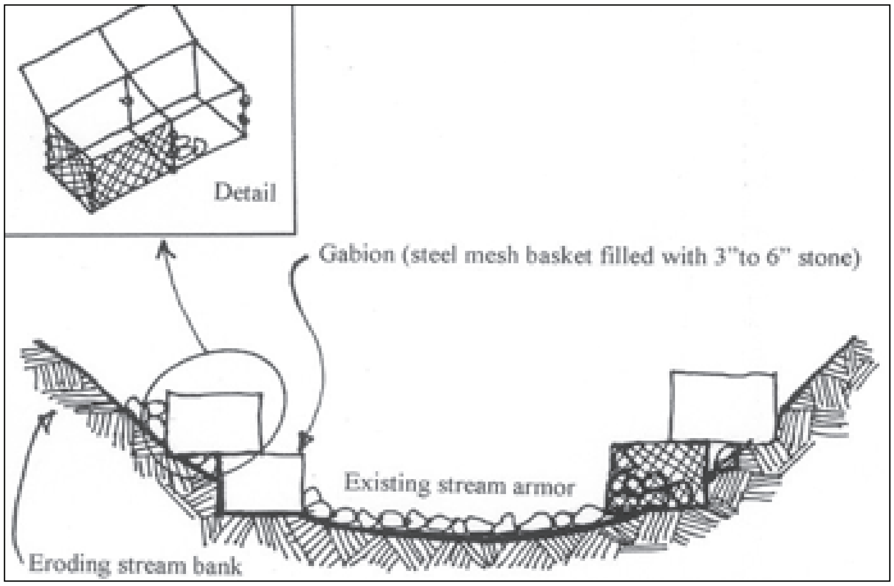


Figure 11 (top). Gabion streambank armor cross-section as installed in 1992 to protect eroding streambanks. Flank, crest, foundation and toe protection are critical for success. Note lack of stone foundation.

Figure 12 (middle). Gabion streambank armor installed in 1992 at storm sewer outfall at head of Highland Park Ravine 10. To the left is a sewer manhole (1996 photo).

Figure 13 (bottom). After 15 years, gabion baskets are intact but are undermined due to scour of stream armor (too small for flow conditions) and lack of foundation stone. Outfall concrete apron to left (2007 photo).

sided visibly from their original position (Figure 13). The existing streambed armorstone was not large enough to remain stable during peak-flow conditions and had washed downstream. The gabions also appear to have confined the flow in the ravine, thus increasing its velocity and erosive power. The area of greatest erosion in the study site lies within a short distance downstream from the gabions. A preferred alternative to gabions at an outfall is a system of large river stones and a large plunge pool (Figure 14).

Reno Mattresses — Reno mattresses are 6-foot by 9-foot by 9-inch thick galvanized steel wire mesh baskets filled with 3-inch to 6-inch quarried "limestone" (dolomite). The units were placed directly over geotextile fabric on the base of the streambed. Prior to installation of the geotextile, irregularities in the streambed were graded to a uniform slope with a bulldozer. Although the Reno mattresses were still in place in 2007 and had retarded downcutting, they were not installed far enough upslope to prevent lateral bank erosion (flanking) both upstream and downstream. Additionally, the erosive energy of the water is concentrated at the downstream edge of the Reno mattress where downcutting measured 1.5 feet or more in places. There was no indication of rust or other degradation of the wires (Figure 15).

A-Jacks — A-Jacks are cast concrete or plastic structures (Ex-Jacks) shaped like a child's six-arm toy jack. The A-Jacks were installed at the toe of the ravine slope on either or both sides of the streambed, or adjacent to and down-

Figure 14. A plunge pool protected by the proper size boulders makes a more natural energy dissipator at a stormwater outfall than one protected by gabions.

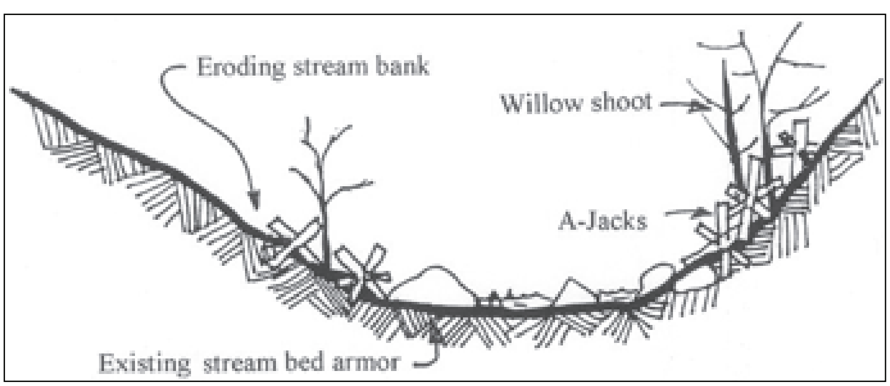
stream from a Reno mattress. Willow cuttings (*Salix sp.*) were then planted between the A-Jacks directly into existing soil or clay (Figure 16). By June 2007, A-Jacks were no longer a significant factor in preventing erosion in Ravine 10. It was difficult to see their original location, but broken pieces were observed among the cobbles of the creek channel (Figure 17). None of the willow trees planted with the A-Jacks (or elsewhere) could be found alive. While willow is well adapted to environments with a shifting substrate, the deep shade conditions found in most sections of the ravines apparently limited the viability of the willow shoots.

Geoweb — Geoweb is a plastic textile that is "honeycombed" to allow cobblestones to fill the voids and hold the material in place. Installation was in areas of actively eroding clay in the streambed. After the clay was graded with a bulldozer, the Geoweb was placed directly on the streambed and extended approximately 3 feet up both sides of the ravine. 3-inch quarried "limestone" (dolomite) was placed in the voids immediately after installation (Figures 18, 19). Geoweb plastic showed some signs of deterioration and minor stone loss, but was sufficiently intact in 2007 to function in retarding downcutting (Figure 20). In a manner similar to that of the Reno mattress, the Geoweb is subject to flanking and also acts as a check dam, concentrating energy downstream. Note loss of stream armor downstream.

In summary, in Ravine 10, the A-Jacks failed completely but the gabions, Reno mattresses and Geoweb installations were essentially intact after 15 years. Problems include loss of stone streambed armor downstream from the structures, foundation scour, flanking, and minor loss of Geoweb fill-stone. Planting of willow shoots as bank protection was unsuccessful due to failure of the A-jacks and the dense shade in the ravine. While the gabions, Reno mattresses and Geoweb installations remained intact, flanking or undermining nevertheless caused system failure. Areas without any streambed and bank protection showed the greatest erosion over the study period. Sections of

Figure 15. Reno mattress streambed armor installed over a layer of filter cloth in eroding bed of Ravine 10. Note streambed erosion scour and flanking on right (2007 photo).

Figure 16. Diagrammatic cross-section in Ravine 10 showing A-Jacks streambank armor with willow shoots.



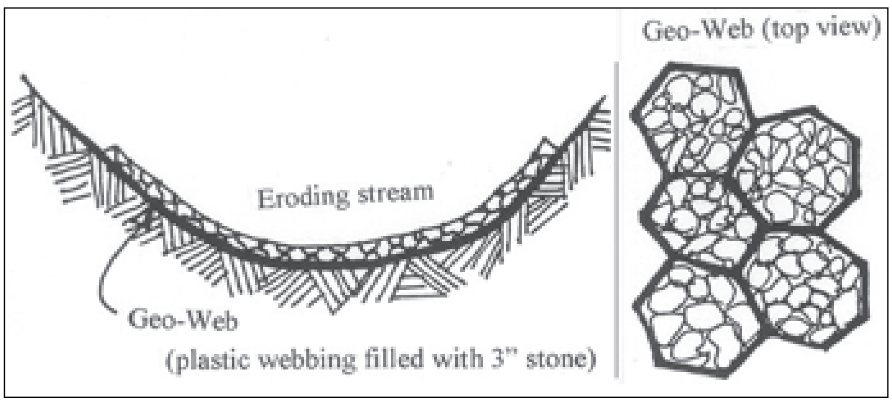


Figure 17 (top). A-Jacks streambank armor flanked after 15 years. Structural integrity of system is lost because of high stream flow velocities and scour. Note eroded slope has retreated approximately 2.5 feet back from row of A-Jacks (2007 photo).

Figure 18 (middle). Diagrammatic cross-section showing Geoweb streambank and streambed armor. After installation, the plastic webbing was filled with 3-inch "limestone" (dolomite).

Figure 19 (bottom). Geoweb streambank and streambed armor in Ravine 10 (1996 Photo). After streambed and banks were graded, the plastic webbing was installed and filled with 3-inch "limestone" (dolomite).

ravine between the structures continued to erode through 2007.

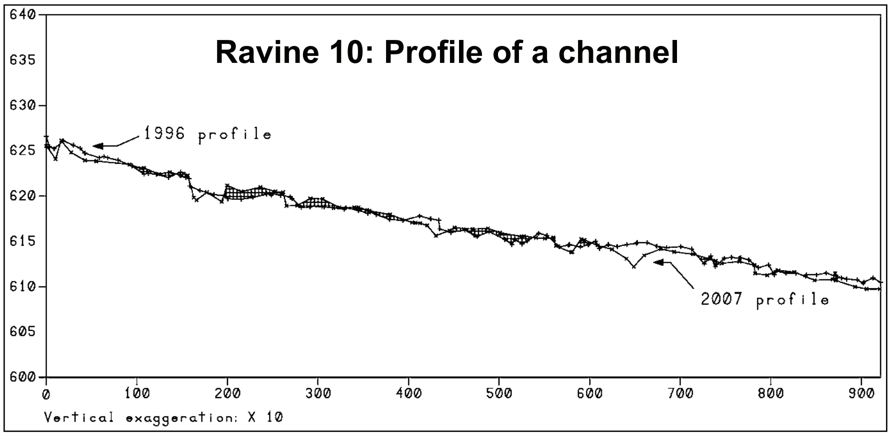
Surveys of the ravine centerline in 1996 and 2007 are compared in Figure 21. Deposition of sediment upstream from the Reno mattresses and Geoweb sites was already noted by Shabica in 1996 (http://www.glc.org/basin/pubs/projects/ILravine.pdf) and has continued through the following years. The "grade-control" effect of the structures reduces the effective gradient upstream and therefore overall flow velocity. The negative impact is that a sharp drop (waterfall effect) results in increased streambed scour immediately below the structure. A plunge pool with larger stone (minimally 1 foot in diameter) placed downslope of such structures would reduce erosion and increase surface roughness. While it appears that some protection is better than no protection, a continuous, full-ravine plan would assure long-term stability of the system. The average elevation change of the study site ravine channel was -1.6 inches from 1996 to 2007. Calculations of volumetric change based on 1996 and 2007 surveyed ravine profiles show an average change of -3.1 cubic yards per linear foot of ravine during the 11-year study period. This represents a total of 2,801 tons of sediment eroded from this section of Ravine 10.

The rate of ravine channel downcutting is greatest for the unarmored part of Lake Bluff's Ravine Park Ravine (10 inches over 11 years), is less for the partially armored Ravine 10 in Highland Park (1.6 inches over 11 years), and is lowest for the section of Ravine Park Ravine with restored streambed armor. The armored part of Ravine Park Ravine shows an aggregate increase in elevation, which does not mean that no downcutting has occurred, since a modest amount of material has been transported from the upper part of the armored section to the lower part. As stream downcutting is a primary factor driving ravine erosion, the total sediment loss is regarded as following the same trends. A visual survey of the unarmored portion of Ravine Park Ravine indicates a higher sediment loss than the 3 cubic yards per foot loss from Ravine 10. This may be due, in part, to the steeper gradient of the Ravine Park Ravine system.

Ravine 10 provides an illustration of the need for a comprehensive approach to ravine management. Alerted to the problems of leaking sewers, the city of Highland Park stepped-up sewer maintenance in the ravines and in 2008 installed quarried limestone stream armor with a gabion grade control check-dam over the entire study area of Ravine 10. Although it is too soon to quantify the success of the new system, it appears to be performing well. It is noteworthy that Highland Park beaches, frequently closed in the early 1990s due to high bacteria counts, had the lowest number of *E. coli* swim bans in 2007, along with Lake Bluff's Sunrise Beach (Lake County Health Department 1992, 2007).

Figure 20. Geoweb armor intact in 2007. Note loss of natural streambed armor and fill-stone.

Figure 21. Profile of streambed centerline, Ravine 10, Highland Park. Surveys from 1996 and 2007 are compared to show net erosion downstream of structures and accretion (cross-hatched) upstream (vertical scale: five-foot intervals, horizontal scale: 100-foot intervals).



Glencoe Ravine and Beach, Glencoe: The Glencoe Ravine, approximately 2,500 feet in length, is similar in many ways to Lake Bluff's Ravine Park Ravine. Active streambed erosion, streambank erosion, soil slump and soil creep were observed in several locations along the axis of this ravine. Prior to restoration, the mouth of the ravine was bordered by eroding Lake Michigan bluffs with no beach. In a project funded in 2003 by the Great Lakes Commission, vegetated retention basins ("beaver ponds") were installed in the ravine (Figures 22, 23). The intent was to increase stormwater retention and use plants for bank stabilization and nutrient uptake. Two retention ponds/wetlands were installed in the lower reaches of the ravine. The work included regrading steep slopes and construction of two low-profile stone and concrete block check dams. Planting of shade tolerant wetland species along the banks and in the shallows of the ponds was conducted in the summer of 2004. These retention ponds provide greater storage capacity and are intended to reduce sediment and pollutant loading to Lake Michigan. Buchanan Consulting Inc. (BCI) supplied and installed three native-seed mixes designed for the three community types present at the project site: shaded streamside, upland wooded slope, and sandy-clay upper beach. The streamside mix included 40 species, the upland mix 28 species, and the beach mix 43 species.

After seed placement, a light-weight erosion control fabric was placed on both streambanks to further stabilize the soil and promote successful seed germination. Following seed and erosion control blanket placement, BCI installed approximately 200 live plant plugs along the streamside to achieve immediate cover and stabilization.

Another task completed in the spring of 2004 was thinning the tree canopy on the south slope of the ravine to promote growth of surface vegetation. BCI completed this work, which included the selection and removal of exotic tree species. Individual trees selected for removal were less than 8 inches in diameter and were primarily Norway

Figure 22. Glencoe Ravine. Newly constructed east check dam after rainstorm (3 May 2004 photo). Falls have added benefit of aerating the stream water.

maple (*Acer platanoides*), common buckthorn (*Rhamnus cathartica*), and exotic species of honeysuckle (*Lonicera sp.*). Larger trunks and branches were cut with hand tools and placed horizontal to the slope, generally where felled, and staked with cut branches. Smaller stems and branches were bundled and removed from the site. In 2005, additional seed mixes were planted to restore the beach prairie area (procedures in Packard and Mutel 1997), along the wet to mesic wooded streamside and in the mesic wooded upland. The survival of the seed and plants was monitored during periodic site visits, including the fall 2007 survey. The 2007 survey shows the slopes and stream sides completely covered with vegetation and stabilized soils. A few invasives were observed, including trees from the wooded upland. Invasive species should be aggressively removed. The beach community, including little bluestem (*Andropogon scoparius*), is doing well. The Appendix includes plant lists (to species level).

In 2003, a quarrystone breakwater and 3,000 tons of clean sand were installed to create a stable sand beach at the ravine mouth. The project was funded by the adjacent property owner who also contributed to the local cost-share for the ravine restoration and project monitoring (Figures 24, 25). Beginning in 2005, ravine, beach and lake shallows were monitored for bacterial content at the Glencoe and Lake Bluff Ravine sites. This research was supported by a grant from the Great Lakes Commission. Six water sampling sites were established including an upper unrestored section and two sites within the restored ravine stream channel. Ravines were also inspected for broken or leaking sanitary sewers. Three samples were collected in the beaches including ponded areas at the mouth of the ravines and two from shallow pits dug into the beach sand. One sample was collected in the adjacent swash zone in Lake Michigan. The sites were sampled randomly at two-week to three-week intervals in 2005 and 2006 for a total of seven fall visits and six spring visits to each ravine. The samples were cultured for bacteria by the Lake County Health Department. Results show that the ravine water and saturated beach sand typically carry elevated levels of *E. coli* bacteria (Figures 26, 27). Searches within the ravines for point sources for bacteria like broken sanitary sewers, were unsuccessful. The *E. coli* levels measured in adjacent waters of Lake Michigan were unexpectedly low except after heavy rain and high stream flow in the ravines. There were no swim bans reported for Sunrise Park Beach (located approximately 200 feet north of the Lake Bluff ravine mouth) while the sampling for *E. coli* was in progress during the month of August 2005 (Lake County Health Department 2007). In sharp contrast, beaches at Illinois Beach Park had 17 swim bans during the same time period (Lake County Health Department 2007).

A detailed post construction topographic survey of the Glencoe Ravine restoration project site was conducted

Figure 23 (top). New east retention pond in Glencoe Ravine with erosion cloth and new plantings (upper check dam in background). Note steel survey rods (20 October 2004 photo).

Figure 24 (middle). Glencoe Ravine mouth (immediately left of stone groin), prior to installation of retention basins and beach (2000 photo).

Figure 25 (bottom). Glencoe Ravine mouth with new check dam and new beach/wetland filter system. New stone breakwater on left. Note healed scour channels adjacent to ravine mouth (2007 photo).

on 2 December 2004. Monitoring of sedimentation in the ponds was continued through fall 2007. Measurements of accumulated sediment were recorded adjacent to steel monitoring rods inserted into the ravine bed in the retention ponds (Figure 23). Measurements were made by Terrapin Geomatics using a stadia rod and recorded to the tenth of a foot. Detailed results are presented in the Appendix.

The construction of the Glencoe Ravine retention basins produced a net reduction in ravine channel slope, resulting in accumulation of sediment upstream in areas that were once eroding. No evidence for new streambank or streambed erosion was observed immediately upstream from the structures. The retention basins continue to trap sediment but were nearly full after five years. The volume of material trapped exceeded 60 tons in the first year, averaging five tons per month.

In summary, the check dams filled with sediment, upstream banks have been stabilized, seeds germinated, and new vegetation is growing well (Figures 28, 29), though the large quantity of sediment eroded from the upper reaches of the ravine was not fully anticipated. Incipient flanking downstream from the upper check dam began during an intense rainstorm (Figure 30) and should be repaired as soon as possible. Monitoring of ravine water shows increased levels of *E. coli*, especially after rainstorm events, although no evidence of broken or leaking sanitary sewers was observed.

Foss Park Restored Bluff and Wetlands, North Chicago: Foss Park is a pub-

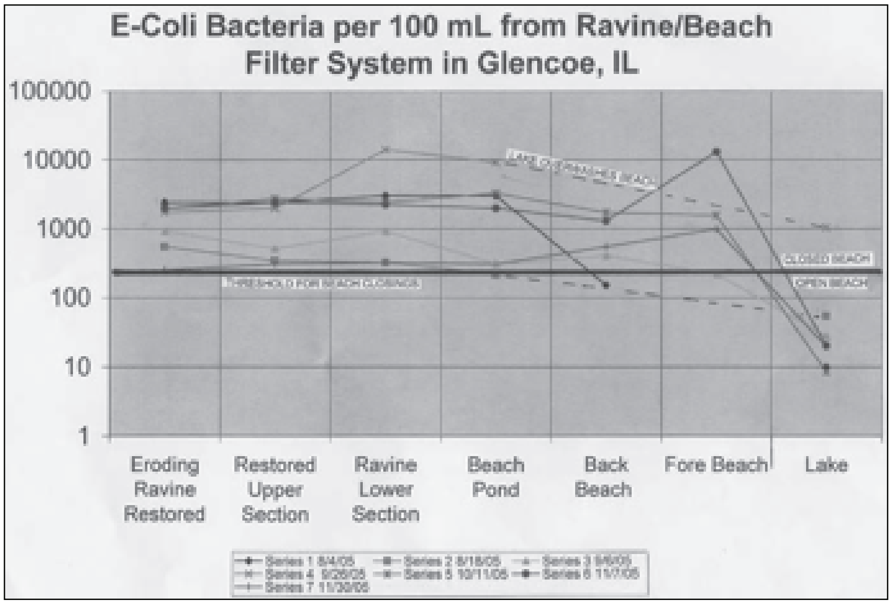
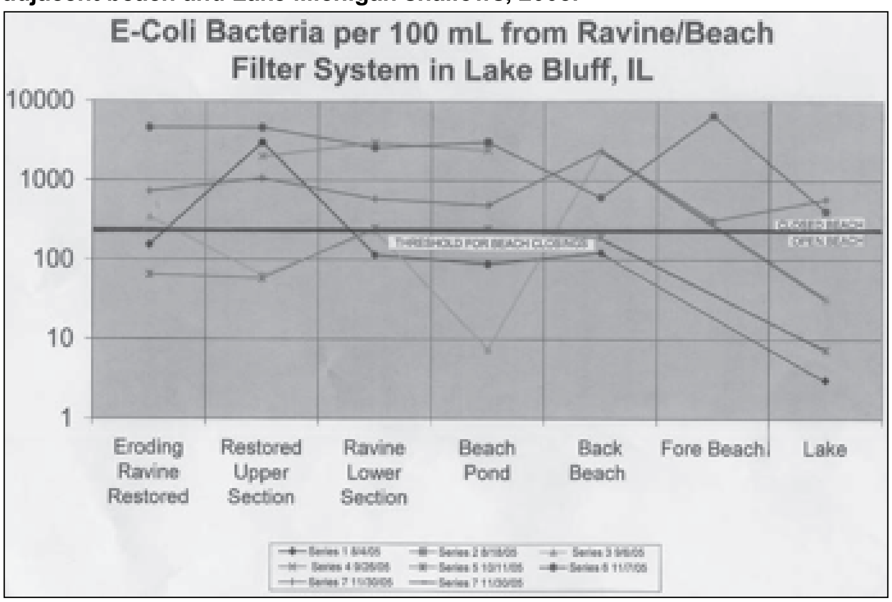


Figure 26. Table showing bacterial levels in Glencoe Ravine channel, adjacent beach and Lake Michigan shallows, 2005.

Figure 27. Table showing bacteria levels in Ravine Park Ravine channel, adjacent beach and Lake Michigan shallows, 2005.



lic park and beach located along the western shore of Lake Michigan north of Great Lakes Naval Training Center and south of Waukegan Harbor (Figure 31). While the tableland park is heavily frequented by North Chicago residents, the 1,640-foot-long beach and bluffs have historically been underused due to limited bluff access and a community-wide fear of long-shore currents and undertow at the beach. Prior to restoration work, the shoreline at Foss Park was one of the last actively eroding sections of high bluff coast in Illinois. Sediment starvation of the littoral system caused by the breakwaters at Waukegan Harbor has resulted in accelerated beach narrowing and bluff recession (Figure 32). To the south, the North Chicago water treatment plant protrudes into the lake, functions as a rocky headland, and affords a minimal amount of protection for the south section of beach and bluffs. At the north end of the beach, a 230-foot-wide, 70-foot-high segment of bluff was denuded and actively eroding because of excess runoff from the tableland and storm wave impact at the bluff toe. Comparison of historic air photos indicates an average rate of bluff recession of 1.6 to 2.5 feet per year. This represents approximately 1,500 tons of clay, soil and organic debris washed into Lake Michigan annually.

In 2002, the Foss Park Board commissioned a master plan for bluff and beach restoration for this site. Through contributed services, the south bluffs and dune/swale wetlands were restored in 2002 and 2003. Beginning in 2003, the eroding north bluff was restored and monitored through a grant funded by NOAA with contributions in time, materials, and labor by Herkey's Trucking, Edward E. Gillen Company, and Shabica & Associates. The project was administered by the Illinois Department of Natural Resources. The bluff was regraded to include a new pedestrian path, and seeded with native species (Figures 33, 34). To combat gullying and slumps caused by excessive runoff from the upper park, a swale and catch basin was installed at the top of the bluff. To minimize erosion of the new path, a stone-lined swale was constructed along its landward side. Additionally, a stone revetment/perched wetland swale was installed at the bottom of the eroding bluff to protect the system from storm wave attack and filter runoff from the tableland and bluff surface.BCI supplied and planted three native seed mixes designed for the three community types present at the project site: coastal-bluff low-profile prairie, beach filtration swale, and sandy-clay upper beach. The beach/swale mix included 44 species, the bluff mix 41 species, and the sandy beach mix 44 species. By October 2007, the bluff was fully vegetated and had stabilized bluff soils. Native plant species include grass-leaved goldenrod (*Solidago graminifolia*) and sawtooth sunflower (*Helianthus grosserratus*). Except for minor soil creep, active bluff erosion has been arrested. Periodic maintenance is necessary to assure a fully vegetated surface. The wetland swale at the toe of the bluff is functioning well and has full vegetal cover, including native sedges (*Carex stipata*) and rushes (*Juncus torreyi*). Unfortunately, the common reed (*Phragmites australis*) and cottonwood (*Populus deltoides)* have invaded the area (Figure 35) and require periodic removal. Little bluestem (*Andropogon scoparius*) is among the native prairie species (Figure 36) that are now growing on the bluff adjacent to the perched wetland (see Appendix for details).

With plantings of native coastal bluff, beach and wetland species, the installation functions as an organic filter system that includes the newly constructed dune/

Figure 28. Fully vegetated streambanks and check dam at mouth of Glencoe Ravine (2007 photo).

swale wetland at the south end of Foss Park (Figure 37). Semi-annual site visits have shown that the native species that were planted are now well established. It is noteworthy that Foss Park beach is one of the few in Illinois that has a healthy dune/swale wetland ecosystem. The projects are phases one and two of a coastal master plan that is intended to provide long-term, environmentally sound, safe access to Lake Michigan. Phase three, construction of a segmented series of pocket beaches is on-hold, pending funding.

COMPREHENSIVE RAVINE MAPPING

To date, no ravines on the Illinois shore of Lake Michigan have been fully stabilized. To address this problem, the Illinois Department of Natural Resources, in cooperation with the Lake Michigan Watershed Ecosystem Partnership (LMWEP) and Alliance for the Great Lakes, has initiated a ravine mapping program in Lake County, Illinois. Using information from this study, measurable indicators of ravine stability were established in order to assist local watershed groups in prioritizing ravine stabilization activities. This work combines detailed GIS analysis with on-the-ground assessments to quantify levels of instability throughout more than 45 ravines within the Upper Lake Michigan Watershed. A list of indicators or "data" representing many of the critical factors that lead to accelerated ravine erosion has been compiled and a scoring or ranking system applied to the results. From this, maps were generated using air photos that will be distributed to local communities, private landowners, and potential funding agencies. A detailed description of work and color-coded ravine maps can be viewed at www.greatlakes.org/lmwep/ssip.

Several map layers have been created using two-foot contours that represent characteristics such as the top of the bank, streambed centerline, and slope. Local maps provided the basic information including road locations and building outlines. The following is a list of indicators used as the foundation for GIS analysis. Each of these has been weighted to reflect relative importance. For example, channel slope and bank slope, important to ravine stability, were weighted three whereas the remaining GIS indicators like number of buildings within 50 feet, were weighted as two:

- Channel slope % of longest flow line;
- Average bank side slope;
- Average distance of buildings from top of ravine banks; homes within 50 feet of top of bank;
- Average distance of roads from top of ravine banks; roads within 100 feet of top of bank;
- Total number of buildings within 50 feet of top of bank;
- Total area (in acres) of buildings within 50 feet of ravine top bank; and
- Total area of roads (in acres) within 100 feet of ravine top bank.

Figure 31 (above). Foss Park, city of North Chicago, bluff and beach restoration project sponsored by NOAA and Illinois Department of Natural Resources.

Initial calculations comparing ravine channel slopes show a range of 0.2% (1:573) to 10% (1:10) slope with elevation changes between the top and bottom of ravines ranging from 10 to 100 feet. Steep slopes and narrow channels, combined with dense urban development and increased stormwater runoff highlight the potential for significant erosion within Lake Michigan ravines.

Figure 29 (opposite page, top). Glencoe Ravine mouth with newly established vegetation above lower check dam. Lake Michigan is in background.

Figure 30 (opposite page, bottom). Glencoe Ravine upper check dam. Vegetation is well developed but flanking (left side of structure) has scoured the streambanks. This needs to be restored as soon as possible. Note new sediment bar (foreground) and newly established vegetation, held by lower check dam.

A detailed field assessment of each ravine using a unique set of indicators was combined with the GIS analysis. Bed and bank stability indicators were collected in the field (see list of field indicators below) and combined with the GIS data to complete an overall ravine ranking that represents those ravines thought to be contributing the most sediment to Lake Michigan. The field indicators were weighted significantly higher than the indictors based on the GIS analysis. For example, all field indicators were weighted between five and 10. This was done to assure that the most significant data was reflected in the final ravine ranks. Field indicators include:

• Location, type and condition (working or failing) of erosion control structures;

• Residential/municipal stormwater discharge;

• Log jams;

• Channel stability: protected or eroding ravine bed, type and degree of instability;

• Bank stability: severity of eroding gully or scarp; and

• Knick points: abrupt changes in channel grade (drops).

The collection of field data was completed by two interns in 2008. Each indicator was identified over uniform ravine reaches with similar conditions using GPS. Ravine channel and bank stability were ranked based on a scale of one to five with one being the worst. This data was then processed using ArcMap GIS and a series of maps was generated.

The ravine maps representing the GIS indicators and reach-by-reach channel and bank conditions can be used to identify critical sections of ravine instability. The ravines were then ranked based on overall condition; 1 out of 47 being the worst. The most stable ravine was ranked as 47 in terms of erosion potential. Results indicate that the four ravines with

Figure 32 (top). Unrestored eroding bluff at north end of Foss Park Beach (Fall 2002 photo).

Figure 33 (middle). Bluff restoration at north end of Foss Park. Bluff to the right of new path was seeded and covered with erosion control cloth. Construction of perched wetland is proceeding at toe of bluff (Spring 2003 photo).

Figure 34 (bottom). Restored bluff and new perched wetland at Foss Park (lower left). Note sprouting seeds, erosion control cloth, and stone-lined swale to catch surface runoff to right of student (August 2004 photo).

the greatest potential for erosion and sediment transport into Lake Michigan include: Highland Park's Ravine 10 (ranked 1 out of 47), Highland Park's Ravine 7, Highland Park's Ravine 3, and Lake Forest's Witchhazel/Seminary Ravine. These ravines scored high due to a greater number and density of stormwater and residential outlets and greater total length of unstable channels and banks. Highland Park's Ravine 4, Glencoe's Ravine 7C and Lake Forest's Clark's Ravine have the highest overall percentage of unstable bed and banks, but due to their smaller size, are ranked lower in terms of overall erosion potential as they have a higher probability for comprehensive ravine restoration. The Ravine 10 Map (Figure 38) shows typical results from the data collection and analysis.

CONCLUSIONS

Plants: Prior to restoration, all three ravines and bluffs monitored in this study were overgrown with invasive trees and shrubs like buckthorn (*Rhamnis sp.*) and honeysuckle (*Lonicera sp.*) that compete with native species for resources, especially sunlight. Additional conditions impacting the viability of newly installed plants include moisture, scour during high flow conditions, and variations in the species germination success. The photographs and data show that the goal of stabilizing the ravines and beaches, enhancing the aesthetics, and improving the native vegetation community, was achieved. Problems encountered were aggressive invasive species like Garlic mustard (*Alliaria petiolata*) in all ravines, Common reed (*Phragmites australis*) in the Foss Park wetland and Lyme grass (*Leymus arenarius*) on the beaches. An-

Figure 35. Perched wetland at toe of bluff, Foss Park. Seeded and plugged native plants are thriving. Invasives, including the common reed (*Phragmites australis*) and Cottonwood (*Populus deltoides)* need to be removed (Fall 2007 photo).

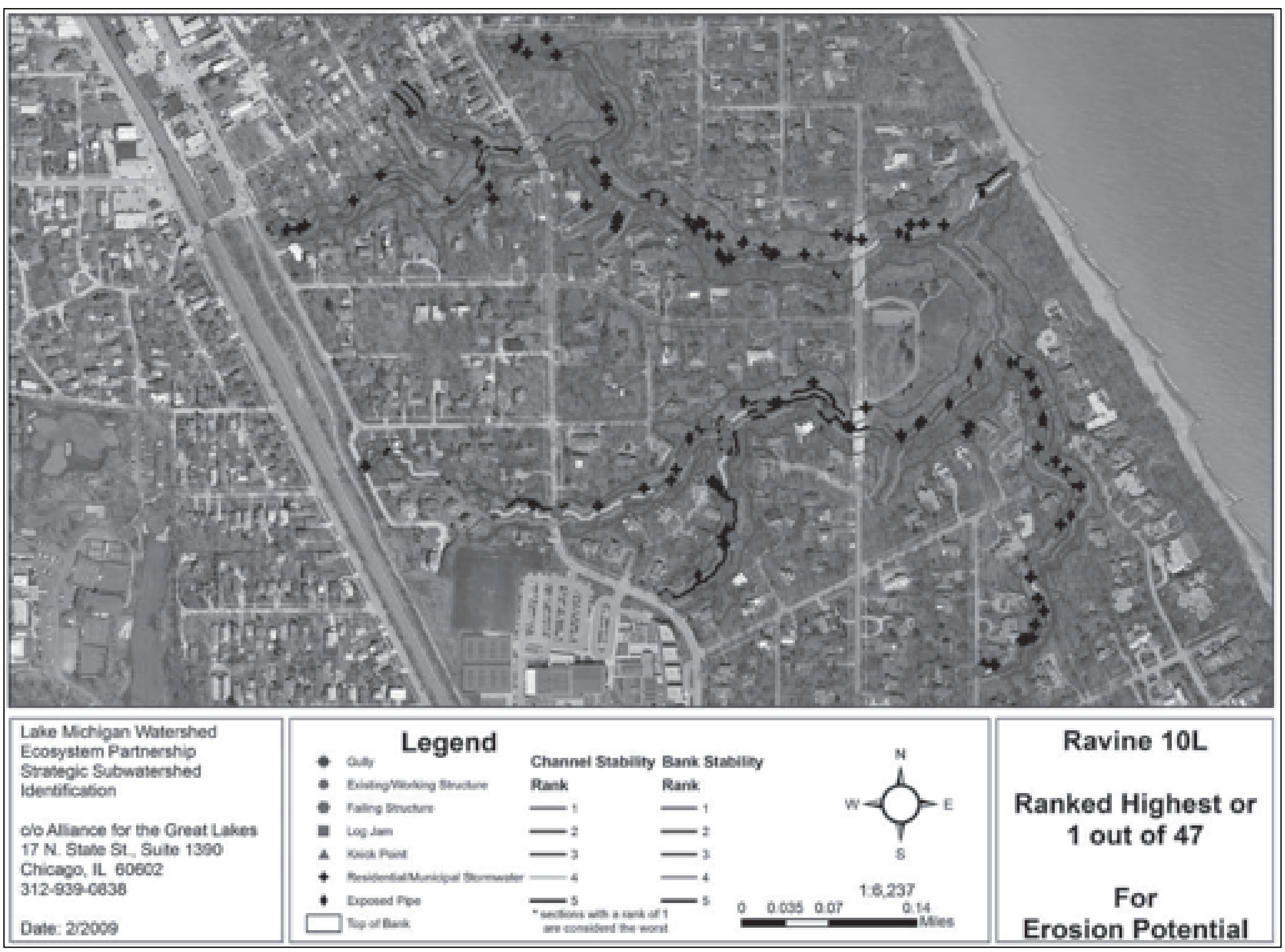
Figure 36. Little bluestem (*Andropogon scoparius*) thriving on poor-quality soil adjacent to perched wetland (Fall 2007 photo).

Figure 37. South end of study site at Foss Park. Restored dune/swale wetland at bottom of newly restored bluff (2003 photo).

Figure 38. Ravine 10, Highland Park. This is an example of a large ravine in a highly variable state and is ranked highest (worst) in terms of erosion potential. The newly stabilized study site (lower center of air photo) is in good condition ranking five (green) in terms of channel bed stability and four (blue) for ravine bank stability. Although colors are not shown, the extremes in ravine condition are indicated by varying shades of grey. To view the color-coded ravine maps go to www.greatlakes.org/lmwep/ssip.

other problem was the inability of plants to hold soil under high flow regimes (small sections of Foss Park bluff and flanks in Glencoe Ravine lower check dam). As the existing communities at all sites were considered degraded in regard to native plants, we were optimistic that planting native species would improve the "ecological quality" of the sites. However, regarding prevention of "sediment loss," invasive exotic grasses and forbs appear to work nearly as well as native species. See Appendix for a listing of plants (identified to species level) for each site.

Water quality: In addition to identifying and remediating point sources of sewage, a goal of ravine and beach restoration is to improve runoff water quality entering Lake Michigan through plant uptake of nutrients, aeration by riffles and waterfalls, detention of fine sediments and filtering runoff through sand beach wetlands. When identified, broken or leaking sewers were repaired by the responsible municipalities. Sampling of *E. coli* bacteria was chosen as one measure of water quality. Analyses showed elevated levels



of *E. coli* in the ravines and beach sand under all conditions. Although these high levels were unexpected, they may represent the "norm." It is probable that much of the *E. coli* is from a diverse animal community supported by the ravines that includes birds, rabbits, skunks, deer and foxes and not from human sewage. The *E. coli* levels measured in Lake Michigan were low except after heavy rains and high stream flow in the ravines. It is generally accepted by health science professionals that increased runoff from rainfall can bring additional bacteria into the system from animal feces (Mark Pfister, Lake County Health Department, personal communication 2006). There were no swim bans reported for Sunrise Park Beach (located approximately 200 feet north of the Lake Bluff ravine mouth) while the sampling for *E. coli* was in progress during August 2005 (Lake County Health Department 2007). In sharp contrast, beaches at Illinois Beach Park had 17 swim bans during the same time period (Lake County Health Department 2007). The wide beaches of Illinois Beach State Park are comparatively remote from sources of anthropogenic *E. coli* but are frequented by an abundance of sea gulls, and the roosting gulls are believed to be the primary source of the *E. coli* at these beaches. Today, scientists and regulators are investigating indicators other than *E. coli* for assuring that beaches are safe from human pathogens like *Cryptosporidium parvum* and *Giardia lamblia*. Wildlife-generated *E. coli* may be producing unnecessary false alarms for some urban beaches. Plans for further monitoring include measuring phosphates and nitrates at the heads and mouths of the ravines.

Sediments: Prior to restoration, all ravines and adjacent bluffs and beaches were adversely impacted by anthropogenic increases in runoff and diversion of sand. Erosion problems include mass wasting and stream channel and bluff toe incision. Results of historic air photo surveys and rod and transit surveys show large sediment loss from unrestored sections of ravines and Lake Michigan beaches. See Appendix for detailed survey data and analysis.

Monitoring of restored ravines shows that stream channel armor restoration with stone reduces sediment loss to Lake Michigan and provides a stable base for establishment of native plants. Recommendations for sustainable ravine management include:

• Measure existing stone sizes, conduct hydraulic study of ravine flow regimes, and survey ravine topography and geology to design system and determine minimal size and placement of materials.

• Apply for local, state, and federal permits for work.

• Remove invasive plants, especially trees, to maximize sunlight. There may be a dormant seed base of native plants that will sprout with additional sunlight. Regraded areas should be covered with erosion control cloth and planted with native species.

• Use a combination of quarried stone and special placement rounded "river stone" to protect streambanks and bed to provide matrix for plant growth (higher materials and installation costs, low maintenance); or use quarried "limestone" combined with gabions for steep-bank protection (lower installation cost, higher maintenance, and less natural appearance).

• Maximize use of riffles, waterfalls (check dams), and plunge pools to oxygenate ravine water and reduce ravine grade.

• Reduce excessive runoff into ravine with rain gardens, vegetated swales, and detention basins.

Air photo surveys of ravine mouth beaches stabilized with stone breakwaters and filled with new sand show no negative impacts on adjacent beaches. Planting of native beach species like American beach grass (*Ammophilia brevilingulata*) help stabilize the beach and improve the coastal ecosystem. Recommendations for sustainable beach management include:

• Conduct historical analysis of coastal geology and lake processes to design system and determine minimal size and placement of materials. Conduct a numerical model of coastal storm waves and storm setup. For large municipal systems, a physical hydraulic model may be necessary.

• Apply for local, state, and federal permits for work.

• Use a high-grade quarried stone like quartzite or granite to build a new pocket beach and provide a matrix for plants.

• Fill with clean coarse grade beach sand (20% overfill required in Illinois).

• Remove invasive plants such as Lyme grass (*Leymus arenarius*). Care should be taken not to confuse it with the similar looking but rare native grass (*Elymus lanceolatus*). Seeds from a nearby beach plant community including Sea Rocket (*Cakile edentula*) may then inhabit the new beach.

• Regraded lake bluff areas should be covered with erosion control cloth and planted with native species.

In conclusion, Lake Michigan coastal beaches and ravines are important but frequently overlooked components of the Great Lakes Basin ecosystem. Installation and formal monitoring of several projects over a three-year to 15-year period has expanded our understanding of these complex systems. Restoration of appropriately-sized natural streambed and streambank armor stones, combined with removal of invasives (especially trees) and restoration of the native plant community on a long section of ravine, will stabilize a once highly degraded system. While restoration of long sections of ravine is highly recommended, most sections of Illinois ravines are in private ownership where property lines typically lie along the ravine channel axis. A daunting task is to get neighbors to cooperate in restoring this important resource that has often been described as "out of sight, out of mind." Cost is also a factor where a typical ravine restoration project may cost $400 per linear foot of ravine. The ravine maps available online at www.greatlakes.org/lmwep/ssip will be useful in alerting citizens and municipalities to critical areas in ravines needing attention.

Ravine restoration is not complete if the transition zone (ecotone) to Lake Michigan is ignored. Construction of sand-nourished pocket beaches and wetlands at ravine mouths provides a filter for ravine water, storm wave protection as well as an ecological buffer for the ravine. While pocket beaches (beach-cells) are not inexpensive, typically costing $5,000 per linear foot, they are proving to be a sustainable long-term shore protection solution. According to the Illinois State Coastal Geologist: "Beach-cell systems may represent the future for beaches along much of the Illinois bluff coast…" (Chrzastowski 2005). The results are improvement in water quality, reduction of erosion and sedimentation into Lake Michigan, and improvement of the coastal ecosystem.

When restoration work is complete, periodic monitoring and maintenance is essential to assure project success. It is anticipated that with success of the ravine mapping project, mapping the Lake Michigan shoreline for stability and ecological viability will soon follow.

ACKNOWLEDGMENTS

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The Appendix referenced in this article is available online at http://www.shabica.com/index_files/Page1345.htm